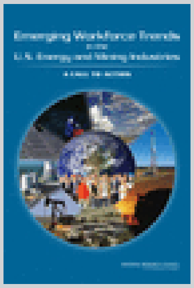


Emerging Workforce Trends in the U.S. Energy and Mining Industries: A Call to Action

ISBN
978-0-309-26744-1

390 pages
6 x 9
PAPERBACK (2013)

Committee on Emerging Workforce Trends in the U.S. Energy and Mining Industries; Committee on Earth Resources; Board on Earth Sciences and Resources; Division on Earth and Life Studies; Board on Higher Education and Workforce; Policy and Global Affairs; National Research Council

EMERGING WORKFORCE TRENDS IN THE U.S. ENERGY AND MINING INDUSTRIES: A CALL TO ACTION

PREPUBLICATION

Committee on Emerging Workforce Trends in the U.S. Energy and Mining Industries
Committee on Earth Resources
Board on Earth Sciences and Resources
Division on Earth and Life Studies
in Collaboration with
Board on Higher Education and Workforce
Policy and Global Affairs Division

NATIONAL RESEARCH COUNCIL
OF THE NATIONAL ACADEMIES

THE NATIONAL ACADEMIES PRESS
Washington, D.C.
www.nap.edu

Prepublication Version

THE NATIONAL ACADEMIES PRESS   500 Fifth Street, NW   Washington, DC 20001

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This study was supported by the Department of Energy under Contract No. DE-PI0000010/DE-DT-2115, Task Order No. 13. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the organizations or agencies that provided support for the project.

International Standard Book Number (ISBN-13) 978-0-309-26744-1
International Standard Book Number (ISBN-10) 0-309-26744-7

Library of Congress Control Number

Additional copies of this report are available for sale from the National Academies Press, 500 Fifth Street, NW, Keck 360, Washington, DC 20001; (800) 624-6242 or (202) 334-3313; http://www.nap.edu/.

Printed in the United States of America.

Prepublication Version

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. Upon the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, upon its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

www.national-academies.org

Prepublication Version

COMMITTEE ON EMERGING WORKFORCE TRENDS IN THE U.S. ENERGY AND MINING INDUSTRIES

ELAINE T. CULLEN (*Cochair),* Safety Solutions International, Chattaroy, Washington
CHARLES FAIRHURST (*Cochair*), Itasca Consulting Group, Minneapolis, Minnesota
KATHLEEN A. ALFANO, College of the Canyons, Santa Clarita, California
BURT S. BARNOW, George Washington University, Washington, D.C.
SALLY M. BENSON, Stanford University, Stanford, California
EMILY STOVER DEROCCO, E3, Washington, D.C.
LEIGH FREEMAN, Downing Teal Inc., Denver, Colorado
JOHN A. PAPPAS, Texas A&M University, College Station
ROY RADNER, New York University, New York
JOEL L. RENNER, Geothermal Consultant, Inver Grove Heights, Minnesota
STERLING J. RIDEOUT, JR, U.S. Department of the Interior, Washington, D.C.
KENNETH C. ROGERS, U.S. Nuclear Regulatory Commission (Retired), Rockville, Maryland
REGINAL SPILLER, Azimuth Investments, LLC, Houston, Texas
JERRY VENTRE, Photovoltaic Systems Engineering Consultant, Oviedo, Florida

National Research Council Staff

CY BUTNER, Study Director
ELIZABETH A. EIDE, Director of the Board on Earth Sciences and Resources
GAIL GREENFIELD, Senior Program Officer
NICHOLAS D. ROGERS, Financial and Research Associate
COURTNEY R. GIBBS, Program Associate
JASON R. ORTEGO, Research Associate (until June 2012)
CHANDA T. IJAMES, Senior Program Assistant

COMMITTEE ON EARTH RESOURCES

CLAYTON R. NICHOLS (*Chair)*, Department of Energy, Idaho Operations Office (Retired), Ocean Park, Washington
JAMES A. BRIERLEY, Brierley Consultancy LLC, Highlands Ranch, Colorado
THURE CERLING, University of Utah, Salt Lake City
ELAINE T. CULLEN, Safety Solutions International, Chattaroy, Washington
DONALD JUCKETT, American Association of Petroleum Geologists (Retired), Springfield, Virginia
ANN S. MAEST, Stratus Consulting, Inc, Boulder, Colorado
LELAND L. MINK, U.S. Department of Energy Geothermal Program (Retired), Worley, Idaho
MARY M. POULTON, University of Arizona, Tucson
ARTHUR W. RAY, City of Rockville, Maryland
RICHARD J. SWEIGARD, University of Kentucky, Lexington

National Research Council Staff

ELIZABETH A. EIDE, Director (from April 2012)
NICHOLAS D. ROGERS, Financial and Research Associate
ERIC EDKIN, Senior Program Assistant

BOARD ON EARTH SCIENCES AND RESOURCES

CORALE L. BRIERLEY (*Chair)*, Brierley Consultancy LLC, Denver, Colorado
WILLIAM L. GRAF, University of South Carolina, Columbia
MURRAY W. HITZMAN, Colorado School of Mines, Golden
EDWARD KAVAZANJIAN, JR, Arizona State University, Tempe
DAVID R. MAIDMENT, University of Texas, Austin
ROBERT MCMASTER, University of Minnesota, Minneapolis
M. MEGHAN MILLER, UNAVCO, Inc., Boulder, Colorado
ISABEL P. MONTAÑEZ, University of California, Davis
CLAUDIA INÉS MORA, Los Alamos National Laboratory, Los Alamos, New Mexico
BRIJ M. MOUDGIL, University of Florida, Gainesville
CLAYTON R. NICHOLS, Idaho Operations Office (Retired), Ocean Park, Washington
HENRY N. POLLACK, University of Michigan, Ann Arbor
DAVID T. SANDWELL, University of California, San Diego
PETER M. SHEARER, University of California, San Diego
REGINAL SPILLER, Azimuth Investments, LLC, Houston, Texas

National Research Council Staff

ELIZABETH A. EIDE, Director
ANNE M. LINN, Senior Program Officer
SAMMANTHA L. MAGSINO, Senior Program Officer
MARK D. LANGE, Program Officer
NICHOLAS D. ROGERS, Financial and Research Associate
COURTNEY R. GIBBS, Program Associate
ERIC J. EDKIN, Senior Program Assistant
CHANDA T. IJAMES, Senior Program Assistant

BOARD ON HIGHER EDUCATION AND WORKFORCE

WILLIAM E. KIRWAN (*Chair*), University System of Maryland, Adelphi
F. KING ALEXANDER, California State University, Long Beach
SUSAN K. AVERY, Woods Hole Oceanographic Institution, Woods Hole, Massachusetts
CARLOS CASTILLO-CHAVEZ, Arizona State University, Tempe
RITA COLWELL, University of Maryland, College Park, and the Johns Hopkins University Bloomberg School of Public Health, Baltimore
PETER EWELL, National Center for Higher Education Management Systems, Boulder, Colorado
SYLVIA HURTADO, University of California, Los Angeles
WILLIAM KELLEY, University of Pennsylvania School of Medicine, Wayne
EARL LEWIS, Emory University, Atlanta, Georgia
PAULA STEPHAN, Georgia State University, Atlanta

National Research Council Staff

PETER H. HENDERSON, Director, Board on Higher Education and Workforce
GAIL GREENFIELD, Senior Program Officer
SABRINA E. HALL, Program Associate

Acknowledgments

In conducting this study, the committee relied not only on its own expertise, but it also drew upon input from a range of recognized professionals with extensive expertise in the energy, mining, education, and related areas covered in this study. Some of these individuals made presentations to the committee, some participated in discussions with committee members and staff, and some provided valuable reference information and data in various forms. Together, all of these inputs provided a rich resource base for the committee's consideration. The committee wishes to extend its gratitude to all of the individuals who provided assistance for this study. The committee further wishes to acknowledge the following individuals in particular for their valuable assistance.

The committee wishes to thank the following individuals for their presentations during open sessions at the committee meetings: Steven Seachman (National Energy Technology Laboratory); Allyson Anderson (Professional Staff, U.S. Senate Energy and Natural Resources Committee); Kathy Benedetto (Legislative Staff, Subcommittee on Energy and Mineral Resources, House Committee on Natural Resources); Christopher Keane (American Geosciences Institute); John Tombari (Schlumberger Carbon Services); Karl Gawell and Dan Jennejohn (Geothermal Energy Association); Mary Poulton (University of Arizona); John Craynon and Michael Karmis (Virginia Polytechnic Institute and State University); David Curtiss (American Association of Petroleum Geologists); Andrew Swift (Texas Wind Energy Institute, Texas Tech University); Elizabeth McAndrew-Benavides and Carol Berrigan (Nuclear Energy Institute); Samantha Jacoby (formerly with the Solar Energy Industries Association); Ellen Kabat-Lensch (Advanced Technology Environmental and Energy Center, Bettendorf, Iowa); Doug Ratcliff and Jon Olson (University of Texas at Austin); John Galiotos (Houston Community College, Northeast College, Energy Institute); Al Escher (Schlumberger Business Consulting); Ron Ness (North Dakota Petroleum Council, Inc.); Susan Howes (Chevron and Society of Petroleum Engineers Talent Council); Marshall Schott (University of Houston, Greater Houston Partnership's Energy Collaborative Workforce Committee); Brian McPherson (University of Utah); Anthony Carnevale (Georgetown University Center on Education and the Workforce); David Holt (Consumer Energy Alliance); Dennis McDonaugh (Alamo Colleges, St. Philip's College); Dixie Sommers (Bureau of Labor Statistics); Martin Scaglione (ACT); Suzanne Tegen, Barry Friedman, and Steven Hauser (National Renewable Energy Laboratory); Peter McKenny (Gonzaga University); Dennis Ray (University of Wisconsin–Madison); Clifford Brandon (Automated Systems Alliance Inc.); and Stephen Enders (Colorado School of Mines). These presenters were also helpful in providing additional information and assistance to the committee.

The committee also extends its thanks to the following representatives from federal government agencies for their participation in an open discussion meeting with the committee: Mary Cummings (National Nuclear Security Administration), Jeff Duncan (Mine Safety and Health Administration), Thomas Galassi (Occupational Safety and Health Administration), John Howard (National Institute for Occupational Safety and Health), Robert LaBelle (Bureau of Safety and Environmental Enforcement), Brenda Pierce (U.S. Geological Survey), and Tim Spisak and Steven Wells (Bureau of Land Management). In addition, the committee thanks the following Department of Energy staff members for discussing workforce issues with selected members of the study committee and staff: Guido DeHoratiis, Natenna Dobson, Shannon Gipson, Sharon Weaver, and Dawn Tolley (Office of Fossil Energy); Penny Boyce (Office of the Deputy Assistant Secretary for Human Capital and Corporate Services); Serena McIlwain (Office of the Chief Human Capital Officer); Kathy Fear (Human Resources Division of the Office of Institutional Operations at the National Energy Technology Laboratory); and Michelle Fox, Linda Silverman, Christina Nichols, Jonathan Bartlett, and Joanna Maher (Office of Energy Efficiency and Renewable Energy). The committee further thanks the following for discussing career pathways and education with selected members of the study committee and staff: Pierce Hammond and Libby Livings-Eassa (Office of Vocational and Adult Education of the Department of Education).

In addition, the following representatives from a range of professional societies and industry associations also provided valuable assistance and information to the committee, for which the committee is grateful: Dave Kanagy and John Hayden (Society for Mining, Metallurgy and Exploration); Hal Quinn, Bruce Watzman, and Leslie Coleman (National Mining Association); Joy Wilson (National Stone, Sand and Gravel Association); Mark Ellis and Darrell Smith (Industrial Minerals Association—North America); Patrick Leahy (American Geosciences Institute); Leila Gonzales (formerly with the American Geosciences Institute); Kevin McCray (National Ground Water Association); and Ann Randazzo (Center for Energy Workforce Development). The committee also thanks Marilyn Suiter and Celeste Carter (National Science Foundation) for their assistance.

The committee wishes to offer special thanks to the following individuals for their valued assistance: Raymond Durante (Raymond Durante Associates) for providing a variety of information to the committee, and Donald Juckett for his sage advice and guidance throughout the study and for his service as a liaison with the Committee on Earth Resources.

This report has been reviewed in draft form by persons chosen for their diverse perspectives and technical expertise in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of the independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards of objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We thank the following individuals for their participation in the review of this report:

R. Lyndon Arscott [NAE] International Association of Oil & Gas Producers (Retired), Danville, California
Alicia Carriquiry, Iowa State University, Ames
Michael Corradini [NAE], University of Wisconsin-Madison
James Dooley, Pacific Northwest National Laboratory, College Park, Maryland
Charles Goodman, Southern Company (retired), Birmingham, Alabama
Stephen A. Holditch [NAE], Texas A&M University, College Station
Ellen Kabat-Lensch, Eastern Iowa Community College District, Davenport
Marc LeVier K. Marc LeVier & Associates Highlands Ranch, Colorado
Andrea Luecke, The Solar Foundation, Washington, D.C.
Syd. S. Peng [NAE], West Virginia University, Morgantown
Susan Petty, Altarock Energy, Inc. Seattle, Washington
Mary Poulton, University of Arizona, Tucson
Raja V. Ramani [NAE], Pennsylvania State University
Andrew Swift, Texas Wind Energy Institute Texas Tech University, Lubbock

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Roderick J. Little, University of Michigan, Ann Arbor, and Lawrence T. Papay, PQR, LLC, La Jolla, California. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Contents

Summary **1**

1 Introduction **13**
What Is Included in the Report and What Is Not, 16
Data Considerations, 16
Organization of the Report, 18
Report Recommendations, 19

2 Mature Sectors **20**
Introduction, 20
Oil and Gas, 21
Nuclear Energy, 44
Mining, 62

3 Emerging Sectors **87**
Introduction, 87
Solar Energy, 88
Wind Energy, 108
Geothermal Energy, 126
Carbon Capture, Use, and Storage, 146
Shared Recommendations, 157

4 The Electric Grid **159**
Today's Electric Grid, 159
The Smart Grid, 161
Workforce and Training Required to Implement Grid Extensions and Improvements and for the Smart Grid, 164
Conclusions, 167

5 Federal Energy and Extractive Industry Workforce Issues **169**
The Workforce and Its Issues, 169
Possible Solutions, 177

6 Safety and Health in Extractive Industries **179**
A Look at Demographics, 179
A Safety Dilemma, 183
Workforce Challenges, 190
Conclusions and Recommendations, 193

7 Educating and Training the Energy and Mining Workforce 195
Introduction: On Our Present Course, Demand Will Soon Outstrip Supply, 195
Building the Pipeline: Academic and Workforce Preparation Begins in K-12, 197
Bridge from Secondary to Postsecondary and First 2 Years of Higher Education, 201
Moving the Model into Energy, 207
Special Considerations for Energy- and Mining-Related Bachelor's- and Master's-Level Engineering and Science Education, 209
Issues and Challenges Relating to Success, 214
Conclusions and Recommendations, 215

8 Overview of the Energy and Mining Workforce Using Federal Data Sources: Key Findings and Recommendations.. 219
Key Findings, 219
Recommendations to Meet Future Labor Requirements, 220

9 Overarching Conclusions 222
Overarching Findings and Recommendations, 225

References.. 229

Appendixes

A. Overview of Federal Data Sources Most Relevant to the Energy and Mining Workforce................. 251
B. Overview of Energy and Mining Workforce Using Federal Data Sources.. 260
C. Data on the Energy and Mining Workforce from Federal Sources.. 299
D. Acronyms and Abbreviation 369
E. Committee and Staff Biographies... 374

Summary

Energy and mineral resources are essential for the nation's fundamental functions, its economy, and its security. Energy in the United States comes from a variety of sources, including fossil fuels, nuclear energy, and renewable energies, all with established commercial industry bases. Mineral resources include fuels (oil, natural gas, coal, and uranium), and nonfuel minerals. Nonfuel minerals are essential for the existence and operation of products and services used by people every day and are provided by various sectors of the mining industry. The United States is the largest electric power producer, with about 1,100 GW of generating capacity, serving the world's largest economy. The overall value added to the U.S. gross domestic product (GDP) in 2011 by major industries that consumed processed nonfuel mineral materials was $2.2 trillion. A skilled workforce is essential to supply the energy and mineral needs of the nation. This report examines the energy and mining workforce trends and issues, and proposes approaches to address crucial, emerging needs.

Numerous reports have discussed the changing demographics of the U.S. workforce and the potential impacts of the widespread retirement of the generation born between 1946 and 1964 (the "baby boomers") on many workforce sectors. The industries that support the production of energy and mineral resources, including the institutions that train their workers, and conduct research for, or regulate these industries, are impacted by these changes. These industries also are responding to increased demand for energy and products derived from minerals as the domestic and global populations increase.

Recognizing the importance of understanding the state of the U.S. energy and mining workforce to ensure a trained and skilled workforce of sufficient size for the future, the Department of Energy's (DOE's) National Energy Technology Laboratory contracted with the National Research Council (NRC) to perform a study of the emerging workforce trends in the U.S. energy and mining industries. Accordingly, the NRC convened a committee of experts to perform the study and to prepare this report on its findings. The study's statement of task is presented in Box S.1.

All of the energy industries in the statement of task contribute to satisfying the nation's energy needs. The related area of geologic carbon sequestration, involving the subsurface storage of carbon dioxide (CO_2), is part of the larger area of carbon capture, use, and storage (CCUS). Within CCUS, technologies are being developed to minimize CO_2 emissions into the atmosphere and to provide CO_2 to enhance oil production from mature fields. The committee addressed the potential workforce for CCUS to cover both sequestration and CO_2-enhanced oil recovery (CO_2-EOR).

BOX S.1
Statement of Task

An ad hoc committee will conduct a study of the availability of skilled workers to meet the energy and mineral security requirements of the United States.

This study will include an analysis of:

(1) The need for and availability of workers for the oil, natural gas, coal, geologic carbon sequestration, nuclear, geothermal, solar, wind, and nonfuel minerals industries;
(2) The availability of skilled labor at both entry level and more senior levels; and
(3) Recommendations for actions needed to meet future labor requirements.

Specifically, this study will, to the extent possible given available data:

(1) Provide historic and current trends in the size, growth, and demographics of the workforce in these industries, disaggregating for each industry and sector (business, government, and academia) and identifying the main worker groups by sector and occupation.
(2) Examine key labor market characteristics of the workforce in each industry, including sectoral workplace practices and any labor market impediments, constraints, and failures.
(3) Discuss future demand for and supply of workers in these industries, sectors, and occupations.
(4) Describe current and projected education and training programs for these groups at community and technical colleges and universities or through other on-the-job or job-specific training and retraining initiatives.
(5) Discuss the potential for skilled foreign labor meeting projected sectoral labor requirements.
(6) Assess potential job health and safety impacts and national security of a long-term (more than 3 years) workforce shortage or surplus.
(7) Describe and evaluate data sources available, federal data collection and coordination, and possible research initiatives for future decision making on workforce issues.

A view into the future of the workforce is important for avoiding possible disruptions in the supply of energy and mineral resources and for making well-informed decisions and plans for a workforce that can continue to meet national needs.

STUDY APPROACH

The committee considered the information and data available from a variety of sources because no single entity collects, analyzes, and reports data on all aspects of the energy and mining workforce.

Data from federal sources were used where possible, because they are heavily vetted and collected using standard protocols. Federal sources were used to provide a snapshot of the nature and composition of the energy and mining workforce. Although helpful for a broad overview, especially of the mature industries (oil and gas, nuclear energy, and mining), the federal data have some limitations in terms of the level of detail of codes used to classify workers in various industry sectors and a lack of information on self-employed workers. In characterizing the workforce, information from the U.S. Bureau of Labor Statistics (BLS) was mainly used. Other federal data sources that were used are the Department of Education's National Center for Education Statistics, the Department of Labor's Mine Safety and Health Administration (MSHA), and FedScope, which was used to provide workforce information on the primary federal agencies responsible for management and oversight of energy and mining).[1] Data from the U.S. Energy Information Administration (EIA) were used to describe current and projected future industry markets and trends, which provide possible insights into industry employment trends, and EIA projections for oil and gas extraction and coal mining were also used.[2]

Where data on market size, trends, and projections and on employment were available from sources other than the federal government, they also were used to provide a more complete view of each industry and its workforce. Such sources included industry, industry associations, professional societies, and academic sources. Given the limitations of the federal data, these additional data were helpful in supplementing the committee's understanding of the industries and their workforces, especially in the case of the emerging industries, for which federal data are absent.

The available data sets were collected by different entities for different purposes using a variety of methods, and these entities do not coordinate their data collection and analysis efforts, making direct data comparisons difficult and imprecise, and combining data sets generally impossible. Moreover, the data do not provide a complete view of the industries or their workforces.

The report primarily addresses the generation or extractive portion of the energy and mining industries, CCUS, the electric grid (including the Smart Grid), the federal workforce responsible for research and regulation, workforce safety and health, and education and training opportunities for workers at all levels, including the pool of qualified educators.

THE NUMBERS

The available workforce estimates for the energy and mining industries are summarized below. When they exist, workforce projections are mostly short term and carry significant uncertainty. Projection time frames also vary considerably among the different sources. Detailed discussions of the data and their sources are given in the report and Appendixes A and B.

For examining energy and mining employment, BLS data have limitations as described above. They are helpful for an overview of the mature industries, but it is currently infeasible to examine the workforces of the emerging industries (solar, wind, geothermal, and CCUS) using BLS data. Available data are summarized by industry as follows.

Oil and Gas: BLS data indicate that the workforce in oil and gas extraction, well drilling, and support activities for oil and gas operations is about 494,200 (2010), and the oil and gas extraction workforce is expected to grow from 158,900 in 2010 to 182,100 in 2020.[3] EIA projects increases in oil production through 2030 and in gas production through 2035, but for employment in the oil and gas extraction sector to decline from 2020 through 2035.

Nuclear Energy: BLS estimates employment in the nuclear electric power generation industry to be about 56,800 (2010; 93 percent in the private sector), and no future projections are

[1] Federal data sources are described in Appendix A. Appendix B addresses Task 1 of the statement of task, which requests trends in the size, growth, and demographics of the energy and mining workforce, disaggregating each industry of interest by sector and occupation. The future demand for and supply of workers in these industries, sectors, and occupations are also discussed. Data tables also are contained in Appendix C.
[2] BLS data are used for EIA projections.
[3] This excludes self-employed workers.

provided by BLS. The U.S. nuclear power industry is in a transformational state, and the future of nuclear power plant construction is difficult to predict. The most optimistic scenario (nuclear power continuing to supply 20 percent of U.S. electricity) has the potential for 287,200-359,000 man-years of labor for building new nuclear units, and 8,000-17,500 jobs to operate them, with additional jobs for maintenance and outages. Although difficult to estimate, jobs will exist in other industry sectors not directly affected by plant construction.

Mining (Nonfuel and Coal): BLS estimates that employment for nonfuel mining is about 128,000 (2010; about 122,600 in mining/quarrying, 5,400 in support activities for mining, with all but 268 in the private sector), and private-sector employment is projected to rise to 125,600 for mining/quarrying by 2020.[4] MSHA estimates that nonfuel mining employment is about 225,600 (2010; about 160,100 for mining operators and 65,500 for contractors).

BLS estimates that employment for coal mining is about 81,100 and 8,100 for support activities for coal mining (2010; totalling roughly 89,200), with all in the private sector. BLS projects coal mining employment to decrease to 77,500 by 2020. MSHA estimates that operator employment is about 89,200 and contractor employment is about 46,300 (2010; totalling about 135,500).[5] EIA projects coal mining employment to increase through 2035.

Solar Energy: The Solar Foundation estimates that there are about 119,000 solar workers (2012). A National Renewable Energy Laboratory study indicates that, if the solar development defined in its SunShot scenario[6] is achieved, 290,000 new solar jobs could result by 2030 and 390,000 by 2050. EIA projects strong solar market growth through 2035.

Wind Energy: The American Wind Energy Association estimates that the wind energy industry employs 75,000 workers (2011). EIA projects strong growth in wind generation through 2035.

Geothermal Energy: The Geothermal Energy Association estimates that the geothermal industry supports about 5,200 direct jobs and the total direct, indirect, and induced impact of geothermal energy represents about 13,100 jobs (2010). The EIA projects healthy growth for geothermal power generation and the number of residential geothermal heat pumps through 2035.

CCUS: CO_2 capture and sequestration is unlikely to become a significant industry absent government policies, incentives, and regulations for large reductions in CO_2 emissions. Continued growth in projects using CO_2-EOR can be expected. Employment data for a prospective CCUS industry are not available. Speculative estimates show that, if large-scale implementation of CO_2-EOR occurs and the amount of CCUS quadruples by 2030, a workforce of 14,000-36,000 would be needed. More accelerated estimates suggest that 35,000-90,000, or even 100,000 workers might be needed. A reasonable assumption is that the CCUS workforce in 2030 will be a small fraction of today's existing oil and gas workforce.

---

[4] The BLS data undercount contractor employment.
[5] The BLS figures undercount coal mining employment, likely due to the undercounting of contractor employment.
[6] The SunShot scenario assumes that the SunShot Initiative's targets will be reached by 2020. The targets are for installed system prices of $1/W for utility-scale photovoltaic (PV) systems, $1.25/W for commercial rooftop PV systems, $1.50/W for residential rooftop PV systems, and $3.60/W for concentrating solar power systems with a capacity of up to 14 hours of thermal energy storage.

THE BIG PICTURE

Despite the data shortcomings, the available data and information provide a clear indication of the nature of the energy and mining workforce and its related, important trends, issues, and concerns.

The present and future are bright for energy and mining jobs. Demand for workers at all levels will remain strong for the foreseeable future and these jobs will continue to pay well. However, there are factors adversely affecting the current workforce, and their negative impact will continue to grow unless addressed.

Demographic Issues

A major factor impacting all of the energy and mining industries is that about a third of the U.S. workforce comprises baby boomers and they are poised to retire in great numbers by the end of this decade. Moreover, there are too few younger workers in the pipeline[7] to replace them. A related issue is the need to capture the knowledge of experienced employees before they leave.

Education and Training

Another major crosscutting factor is that a strong foundation in science, technology, engineering, and math (STEM) skills is needed for many energy and mining jobs, and the need is growing at all levels as STEM principles are increasingly applied in the workplace. The current pipeline of STEM-capable students and workers is inadequate to meet workforce needs.

STEM preparation begins in K-12. The poor preparation of high school students is well known. High dropout rates and a lack of alternative pathways to high school graduation[8] are also problems. Improvement in curricula and teacher preparation is a key need, and this report highlights examples of programs addressing the need. K-12 issues are discussed in numerous other reports, and so this report focuses primarily on postsecondary education.

Many energy and mining jobs require some education beyond high school, but the majority do not require a 4-year degree. This need is growing because, as the workplace becomes increasingly reliant on technology, new workers require different skills than their predecessors. Strategies to meet this need will go beyond current educational approaches.

Industry–education partnerships, particularly at community colleges or in the first 2 years of higher education, have emerged as critical to the nation's energy and mining future. They are designed to create competency-based educational pathways to careers in industry. Successful models exist in manufacturing—closely aligned with the energy industry—and in several energy sectors (nuclear power, electrical transmission, and, most recently, renewable energy). There is great potential for extending this model into all of the energy and mining industries, with these industries partnering with education and government.

---

[7] The pipeline is defined as K-12 and postsecondary educational institutions and programs, including community colleges, universities, vocational technical institutes, specialty training facilities and programs, and apprenticeship programs that train and prepare people to join the energy and mining workforce.

[8] Such alternatives would include career and technical education pathways that integrate academic and project-based learning.

In this model, basic skills are building blocks for industry careers. These skills can be learned in secondary or community college programs, resulting in high school and/or college credit and degrees, and industry-granted skill certifications. Skill certifications map to career and educational pathways.

Community colleges are proving to be the best vehicle for delivering the technician-level, skills-based education that the energy and mining industries need in a STEM technical workforce. They provide postsecondary education from 1-year certificates through associate's degrees, and are often the first 2 years of higher education leading to degrees in 4-year institutions.

Specialized programs at the bachelor's and master's levels are also needed, especially for mining, petroleum engineering, and geosciences. They reside in traditional bachelor's engineering and science programs at specialized universities and in new programs, such as professional science master's programs.

Scientists and engineers from universities are also essential. Until recently, university geoscience departments and faculty, along with undergraduate enrollment, had been decreasing. In the past few years, these trends have reversed, and petroleum engineering has had similar trends. (These disciplines are needed in the oil and gas, geothermal, and CCUS industries.) There also has been a long decline in mining and mineral engineering programs and faculty, with the U.S. graduating a nonsustaining number of mining engineers.

A common, serious problem for these disciplines is a faculty shortage, which impacts the oil and gas, mining, and geothermal workforces, and possibly eventually the CCUS workforce, if this workforce grows significantly and a geoscience faculty shortage persists. Unless this is corrected, the nation risks losing its capacity to provide new science and engineering professionals for the workforce. Increased industry and federal government funding is needed for academic research to attract and train students and strengthen faculty.

Potential Solutions

There is a pressing need to attract young people (including ethnic minorities and women), starting at an early age, into STEM programs and into technical programs that lead to energy and mining careers. With big changes already underway in the oil and gas industry, the need is particularly acute for this industry, but it is also crucial for the other energy and mining industries. An opportunity exists for industry and government to recruit these groups. Investments are required in organizations, institutions, and faculty that have educational outreach programs focused on young students, ethnic minorities, and women. Examples of successful programs are highlighted in the report for possible emulation in multiple energy and mining sectors.

Additional Considerations

Oil and Gas: The oil and gas workforce is in transition. It is concentrated at the younger and older ends of the age spectrum, creating a gap in experience and maturity between retiring and younger workers, making it difficult to replace retiring leadership.

Nuclear Energy: The nuclear industry is in a transformational phase, and precise prediction is difficult. However, with coming retirements, the current pipeline of future workers is inadequate to meet expected needs.

Mining (Nonfuel and Coal): A personnel crisis for professionals and workers is pending, and it already exists for faculty.

Solar Energy: There is a shortage of trained workers for the solar industry. An interactive solar career map is available online to allow users to explore opportunities for entering a specific solar occupation and to identify possible routes for career changes.[9]

Wind Energy: Coming retirements, continued long-term growth in the wind industry, and competition from the manufacturing, construction, and other energy sectors will exacerbate the existing shortage of workers.

Geothermal Energy: It is difficult for the geothermal industry to compete with the mining and petroleum industries for geoscience and engineering professionals, and growing demand in these other industries will exacerbate this problem.

CCUS: The geologic sequestration workforce straddles the environmental consulting and the oil and gas industries. With some retraining, a workforce exists for this industry. For the foreseeable future, absent a strong climate change policy, there is likely to be a sufficiently large workforce. However, unless increased student recruitment is sustained, the lack of a strong geosciences workforce could limit CCUS implementation.

The Electric Grid: The electric utility industry faces a near-term shortage of skilled workers, particularly power engineers. One study found fewer than five very strong power engineering programs in U.S. universities. Companies also are having difficulty finding qualified workers to fill skilled craft jobs. Enhancing the electric grid into a Smart Grid would offer benefits, including a more reliable system and increased integration of wind and solar systems. An estimated 81,600 jobs could be created during Smart Grid deployment and 27,200 jobs following deployment.

Federal Energy and Extractive Industry Workforce: Federal agencies play a key role in the energy and extractive industries, but those interviewed by the committee are having difficulty attracting and retaining qualified workers. The reasons expressed include the government's inability to match industry salaries and benefits, and the fact that many agency field offices are geographically located in areas that are not attractive to many potential candidates. Federal managers find it increasingly difficult to post vacancies and fill them with qualified candidates. They view the internal human resources systems as cumbersome and intolerant of innovation. Agencies are using various approaches to mitigate workforce difficulties, but the recruitment and retention of knowledgeable employees remain major concerns.

Safety and Health in Extractive Industries: Safety and health training for all new employees is critical and more effective if trainers are industry knowledgeable. It also is important for experienced workers to mentor younger workers and for companies to capture the knowledge of experienced workers before they leave and to use that knowledge to train new generations. To maintain safety in an increasingly diverse workplace, it is important that supervisors and managers be trained in how to lead and communicate with a diverse workforce.

Educating and Training in Earth Resources Engineering: The establishment of several interdisciplinary graduate Centers of Excellence in Earth Resources Engineering at leading research universities could help alleviate science and engineering challenges faced by the

[9] Available at www1.eere.energy.gov/solar/careermap (accessed January 18, 2013).

extractive industries (petroleum, mining, and geological engineering), provide more holistic earth resources curricula, and develop the professional expertise that industry needs.

Immigration Policy: Current workforce-related immigration programs are misaligned with the need to increase the STEM professionals and STEM technical workforce. Although reformed policies could be helpful, it is most important to pursue strategies to produce our own talent.

OVERARCHING FINDINGS AND RECOMMENDATIONS

In considering the breadth of information covered in this study, the committee chose to formulate the following set of overarching findings and recommendations to capture the key, fundamental themes contained in the full array of its findings and recommendations. The committee's full findings and recommendations, along with the information and data to support them, are provided within the report. The overarching recommendations have equal importance and should be initiated as soon as possible. Indicated with each recommendation is the time frame expected for it to become fully operational after initiation. Short term is defined as 2 years or less, medium term as 2-5 years, and long term as more than 5 years. All are expected to continue for the long term.

Pathways

Traditional routes to degrees in higher education do not adequately align curriculum to energy and mining industry requirements, they are increasingly unaffordable and inaccessible and therefore do not provide enough qualified STEM-educated workers and professionals to fulfil the nation's energy and mining workforce needs.

The goal in addressing the shortfalls of the current education pipeline is to create an education system that can respond to changes in the economy more quickly and produce a more flexible, STEM-competent workforce, resulting in students equipped with multiple skills and levels of skills, preparing them to adjust more quickly to industry requirements and job availability by moving and advancing on career lattices.

Finding 1: Community colleges are providing important new pathways for supplying the energy and mining workforce by providing direct alignment among their programs of study, the credentials they bestow, and industry education and skill requirements.

Finding 2: With a direct alignment to industry education and skill requirements, the success of education programs can be measured by successful attainment of employment and advancement opportunities in the energy and mining industries.

Recommendation 1: The Department of Education, in collaboration with the Department of Labor, state departments of education, and national industry organizations, should convene (perhaps in workshops or as a working group) critical industry, government, and educational leaders to create and support new approaches that provide multiple pathways in higher education that take full advantage of the attributes of our higher education system. Recognizing the differences in regional workforce requirements, these workshops and/or meetings should be convened in different parts of the country. These models would benefit greatly from including, for example:

- Community colleges integrating industry-recognized credentials, their learning standards, and content into associate degree programs, providing more “on” and “off” ramps to postsecondary education, resulting in stackable interim credentials with real value in the labor market, and leading to direct employment or continuing postsecondary educational opportunities; and
- Partnerships between 4-year colleges and universities and community colleges to create new pathways for STEM curriculum, with the first 2 years of STEM-related programs of study being offered at the community college and the second 2 years being offered at the university, thereby expanding the capacity of the critical university degree programs. (Short Term)

Business–Education–Government Partnership

No one sector—government, industry, or education—can provide the needed energy and mining workforce on its own. University research also can contribute to workforce development by enhancing the education pipeline.

Finding 3: Ensuring that the United States has the educated and skilled workforce necessary for the success of the energy and mining industries requires a strong partnership among business, education at all levels, and the government.

Finding 4: Technical research leads not only to innovation—the lifeblood of industry’s business success—but also to better education and educators.

Recommendation 2: To address common goals and to provide a mechanism for industry’s engagement with the education process and the graduates it produces, federal agencies (e.g., the National Science Foundation, DOE, Department of Defense, National Institute for Occupational Safety and Health, and National Institutes of Health) should consider providing increased research funding to universities, with matching funding from industry, with specific requirements to incorporate two outcomes from the research: (1) advancing technology or business processes to drive innovation and enrich graduate and undergraduate education; and (2) developing university faculty who work on the cutting edge of research to enhance the quality of higher education. The engagement of both faculty and graduate students in this research will extend the pool of STEM-qualified faculty for all educational levels. (Short Term)

Energy and Mining Information for the Public

Importantly, building the best educational pathways in the world and the most qualified STEM faculty for our educational institutions does not mean that more students will pursue energy and mining programs of study. “Build it and they may not come.” The public perception of the mature extractive industries in the United States is often that they are environmentally damaging and their jobs are undesirable (due to concerns over pollution, noise, environmental degradation, and health issues, for example). This negative image dissuades some from pursuing careers in these industries. Also, although renewable energy is generally seen as positive, some negative perceptions (questionable technology viability, long-term existence, and cost-effectiveness, for example) exist that might dissuade people from joining those workforces. Information about all of these industries can educate the public about their importance to the nation and the career opportunities they offer. The government has a natural role to play in providing and disseminating such information as a complement to nongovernment sources. Information about these industries may also motivate students to pursue STEM courses and prepare for careers in energy and mining. For example, about 7,000 students drop out of high school every school day in the United States, and about 1.3 million students do not graduate each year. Also, in 2011, only 25 percent of graduating high school seniors met or surpassed the four ACT College Readiness Benchmarks in the areas of science, math, reading, and English.

Finding 5: Students mostly do not stay in STEM courses in K-12 that would prepare them for STEM postsecondary education or employment.

Recommendation 3: National industry organizations, in partnership with educational institutions, should embark on a national campaign to create and provide accurate and timely information on the industries and their careers, educational and career navigation resources, and experiential learning opportunities to explore jobs and career paths in energy and mining. They should work with the Department of Labor and other government institutions to ensure that timely government information is included. (Short Term)

Recommendation 4: In like fashion, national industry organizations and educational institutions should also embark on an informational campaign to educate students, parents, educators, and public policy makers about the importance of the energy and mining industries to our economic and national security, the relevance of STEM education to jobs and careers in these industries, and the opportunities available in these industries—again including timely government information. (Short Term)

Data

The nation cannot redesign its education programs and business–education partnerships to better provide a qualified energy and mining workforce without accurate data on occupations, jobs, and skill requirements.

Finding 6: Although the federal (and other) databases provide an abundance of information on the energy and mining workforce, such as employment estimates and demographic information, the data currently available for addressing the energy and mining workforce are not sufficiently consistent, comprehensive and up-to-date for these rapidly evolving, technology-infused industries and they do not exist at a sufficient degree of granularity.

Finding 7: To collect and analyze the data needed for effective energy and mining workforce decision making and policy making, it is critical to foster the collaboration of government data-gathering agencies with industries that gather data.

Recommendation 5: The Department of Labor, through its Bureau of Labor Statistics, should determine and pursue a more effective way to partner with industry, through its national industry associations, to more quickly and accurately reflect the fast-paced change of job and occupation titles and characteristics, as well as the levels of education and training required in 21st century jobs.[10] (Medium Term)

Recommendation 6: The Bureau of Labor Statistics should work with industry and the Departments of Education and Labor to better define the STEM technical workforce needed to support STEM professions in our economy so that appropriate and useful data can be identified, collected, and analyzed. (Medium Term)

The Federal Workforce

Federal employees have a critical role in, and impact on, the success of the U.S. energy and mining industries. They are involved in all aspects of the energy and extractive industries, from initial access (through the permitting process), through production and the regulation of those activities, to closure and restoration during the reclamation process. Federal employees link industry's ability to produce energy and minerals with civil society's concerns about these industries. However, the National Nuclear Security Administration reports that a majority of mission-critical employees are currently eligible or will be eligible for retirement in the next 4 years. MSHA projections show that 46 percent of their coal-sector workforce will be eligible to retire within 5 years, and they expect to lose 40 percent of their metal/nonmetal workforce in the same period.

Finding 8: Federal agencies involved in the energy and extractive industries are facing high retirement rates and there is an acute need to replace the departing federal workforce.

Finding 9: Because of the relatively restrictive personnel processes that federal agencies must follow and the relatively higher compensation offered by industry, it is difficult for federal agencies to hire and retain the employees they need.

Recommendation 7: All involved federal agencies should review and revise recruitment, training, and employment arrangements for federal employees directly involved in minerals and energy policy, permitting, and production oversight to ensure the agencies' ability to attract and retain qualified federal workers. Industries involved in energy production and resource extraction should develop collaborative efforts to partner with government at all levels to develop solutions to the problem of recruiting and retaining quality public-sector employees. (Medium Term)

[10] Chapter 8 contains a set of specific recommendations that are based on a detailed overview of the energy and mining workforce, using federal data sources, presented in Appendix B.

THE IMPORTANCE OF THIS REPORT

Why are the study results important?

The United States has built and maintained a high standard of living and its role as a world leader, based largely on mastery of technology and innovation and firmly on access to energy and mineral resources. This access is needed for continued success. An educated and skilled workforce to drive these industries is essential, yet immediate corrective action is needed to ensure that this workforce will be available in sufficient numbers. As this report describes, the nation is facing large-scale retirement of experienced workers in industry, academia, and government. Also, these essential organizations currently are having difficulty finding enough qualified workers at all levels. Securing and replacing the needed expertise is at risk because of the low numbers of adequately prepared, prospective employees currently in the pipeline. As this report describes, the nation's current educational system is not able to provide the needed STEM-trained workers in adequate numbers. Some innovative solutions are being pursued, but more effort is needed. If the nation fails to act now to prepare its workers, it places its continued access to essential energy and mineral resources at risk.

1

Introduction

Three key components of a thriving economy are the availability of natural resources (mineral commodities) as building blocks to develop and to produce goods and services; steady, reliable sources of energy; and the ability to use these raw materials to drive commerce—specifically, a capable workforce and an economic system.

The United States has access to both natural resources and energy. However, a look into the future reveals that there are challenges related to these vital components that must be overcome if the United States is to maintain its economy and standard of living.

Energy in the United States comes from a range of sources, including oil, natural gas, coal, and nuclear, solar, wind, and geothermal sources. Each of these industries is an important piece of the nation's energy "quilt." Carbon dioxide (CO_2) is also of interest when considering energy conversion processes since it is a by-product of coal- or gas-fired power plants and petroleum refineries. It also is associated with global warming and climate change. The process of geologic carbon sequestration is the subsurface storage of CO_2 and it falls within the area of carbon capture and storage, or more recently renamed carbon capture, use, and storage (CCUS). CCUS activities affect energy production and utilization because these activities are intended to minimize the emission of CO_2 into the atmosphere, and to provide CO_2 to enhance the production of oil from mature oil fields through the process of CO_2-enhanced oil recovery.

A trained and skilled workforce of sufficient size is necessary to provide the energy and mineral resources that the nation needs. Considering the importance of energy and mineral resources to our national prosperity and security, it is important for the nation and its leaders and planners to know the current state of the energy and mining workforce. In addition, insight into the future of the energy and mining workforce is also necessary for avoiding possible disruptions in the supply of energy and mineral resources and for making well-informed decisions and plans for how the future of these industries and their workforces should develop in order to continue to meet national needs.

Because of the national importance of the energy and mining workforce, the Department of Energy's National Energy Technology Laboratory contracted with the National Research Council (NRC) to perform a study of the emerging workforce trends in the U.S. energy and mining industries. Accordingly, the NRC convened a committee of experts to perform the study and to prepare this report on its findings. The statement of task for the study is shown in Box 1.1.

BOX 1.1
Statement of Task

An ad hoc committee will conduct a study of the availability of skilled workers to meet the energy and mineral security requirements of the United States.

This study will include an analysis of:

(1) The need for and availability of workers for the oil, natural gas, coal, geologic carbon sequestration, nuclear, geothermal, solar, wind, and nonfuel minerals industries;
(2) The availability of skilled labor at both entry level and more senior levels; and
(3) Recommendations for actions needed to meet future labor requirements.

Specifically, this study will, to the extent possible given available data:

(1) Provide historic and current trends in the size, growth, and demographics of the workforce in these industries, disaggregating for each industry and sector (business, government, and academia) and identifying the main worker groups by sector and occupation.
(2) Examine key labor market characteristics of the workforce in each industry, including sectoral workplace practices and any labor market impediments, constraints, and failures.
(3) Discuss future demand for and supply of workers in these industries, sectors, and occupations.
(4) Describe current and projected education and training programs for these groups at community and technical colleges and universities or through other on-the-job or job-specific training and retraining initiatives.
(5) Discuss the potential for skilled foreign labor meeting projected sectoral labor requirements.
(6) Assess potential job health and safety impacts and national security of a long-term (more than 3 years) workforce shortage or surplus.
(7) Describe and evaluate data sources available, federal data collection and coordination, and possible research initiatives for future decision making on workforce issues.

This report focuses on the current and future availability of a workforce that has the skills necessary to recover raw materials and to generate the energy needed in the decades to come in the face of increasing global competition. Included in this report are discussions on the mining of metals, nonmetals, aggregates, and coal; oil and gas extraction; nuclear, solar, wind, and geothermal energy production; and the related industries associated with CCUS and the electric power grid that will make it possible to use the energy we create.

The report considers a multifaceted workforce that includes entry-level workers, technical and professional employees, managers and leaders, and professors and researchers as well as the "pipeline"[1] that prepares them for the workforce. The study committee recognizes that creation of a skilled workforce begins at an elementary school level, that the nation depends on these workers to be capable in science, technology, engineering, and mathematics (STEM) disciplines, and that this prerequisite creates a parallel requirement for an educational system that can effectively teach these subjects. The report therefore includes discussions on K-12 STEM competencies, the role of community colleges in strengthening those competencies, and the state of higher education in relation to the nation's ability to graduate the engineers and scientific professionals needed for the workforce. The report also includes a discussion of the federal workforce needed to provide oversight of resource management, regulatory support for safety

[1] For this report, the pipeline is defined as K-12 and postsecondary educational institutions and programs, including community colleges, universities, vocational technical institutes, specialty training facilities and programs, and apprenticeship programs that train and prepare people to join the energy and mining workforce.

and health, as well as environmental protection, training, and research. The topic of safety and health is of critical importance in any consideration of the workforce, and to address this concern the report contains a discussion of workforce safety and health issues.

As shown in Figure 1.1, the Energy Information Administration (EIA) is projecting a steady increase in the demand for energy through 2035. The increase is expected to be both domestic and international. Although the makeup of the energy "quilt" may change over time, it is extremely unlikely that the energy sector itself will weaken or disappear altogether. Similarly, the minerals necessary to build the energy infrastructure and to produce the goods it makes possible also play a vital role in the nation's future. It is important that these sectors work together in order to support the future we envision, and their success depends on a skilled workforce.

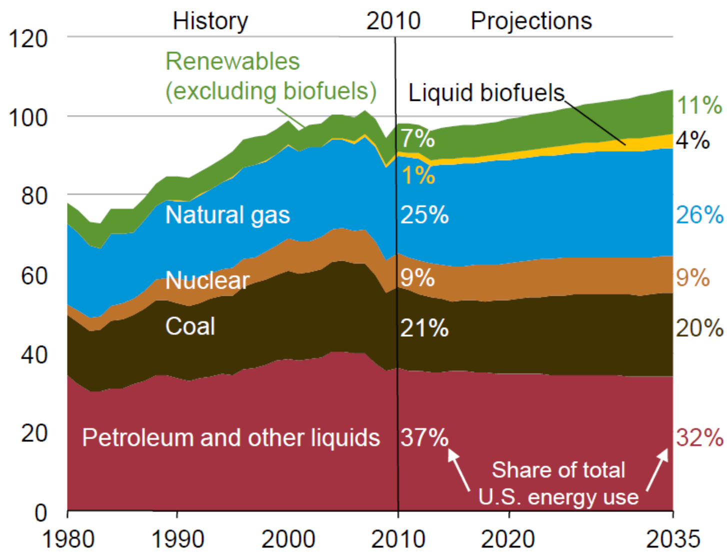


FIGURE 1.1 Primary energy use by fuel, 1980-2035 (quadrillion Btu). SOURCE: EIA (2012a, Fig. 73, p. 76).

The energy and extractive sectors will continue to grow to support the increasing population, and they will be looking for the qualified employees that are necessary to do the work. The jobs in these sectors are very high paying, compared with jobs in other industries. As this report discusses, the very future of the United States depends on a workforce that is competent in STEM. Growing energy and mining sectors combined with a current workforce that is aging and preparing to retire are creating unprecedented opportunities for young people interested in these fields. The demographics of the United States are changing, with increases in populations from other countries, and growing numbers of women and minority students entering the workforce and earning college degrees. It is key for the nation to look for new workers with both traditional and nontraditional backgrounds in order to provide future employees at all levels. The future is very bright if we choose to prepare for it.

WHAT IS INCLUDED IN THE REPORT AND WHAT IS NOT

The scope of this study is quite broad, covering the workforce for the U.S. oil, natural gas, coal, geologic carbon sequestration, nuclear, geothermal, solar, wind, and nonfuel minerals industries. Therefore, not every portion of the energy and mining workforce could be considered in detail within this study. The focus of the study was placed primarily on the production or extractive portion of the energy and mining industries because these are the fundamental sources of the supply of energy and minerals. The infrastructure that extends beyond these basic footprints to the users of the energy and mineral resources is not considered in detail with respect to workforce needs and issues.

The one specific exception to this approach is the electric grid, including the Smart Grid (an improved electric grid with greatly enhanced performance as discussed in Chapter 4). The reasons for this exception are: (1) the lack of an expanded and enhanced grid infrastructure poses a limitation on the expansion of the renewable energy sectors (wind and solar, in particular); and (2) so much is being said about the promise of the Smart Grid that a brief overview of the grid helps to identify its central features, along with potential enhancements and associated impacts on the energy picture and workforce.

There are other industry components beyond the basic production and extraction footprints that are touched on but not pursued in substantial detail with respect to workforce needs and issues. Appendix B gives an overview of the U.S. energy and mining workforce (overall and for each of the mature sectors), based on data from federal government sources. This discussion is largely based on the North American Industry Classification System (NAICS)—the standard industrial classification system used by government statistical agencies—and it includes all of the NAICS industry codes that apply to the energy and mining industries. Some of these NAICS codes apply to the workforce beyond the basic production and extraction footprints, and the discussion gives a variety of information about such industry segments. This, in turn, provides the reader with a sense of the size (current and projected) and other characteristics of these industry segments, but no further exploration of them is pursued with respect to workforce issues. Examples of industry components that are not explored in detail include oil and gas pipelines, rail distribution, trucking distribution, power lines/electricity distribution systems (past a general overview of the grid, including the Smart Grid), power plant construction (except nuclear plants and geothermal facilities), petroleum refineries, wholesale and retail trade, equipment leasing, and equipment and machinery repair. Also, although other energy sources, such as hydroelectric sources and biofuels, also contribute to the nation's supply of energy, they are not included in the study's Statement of Task, and therefore, are not covered in this report.

DATA CONSIDERATIONS

In conducting this study, the committee considered the information and data available from a range of sources, including federal, industry, industry association, professional society, and academic. The committee found that different entities collect and analyze data for their own particular purposes; consequently, they collect different data, they collect data in different ways, and they do not coordinate their data collection and analysis efforts. This makes direct comparisons of data from different sources difficult and imprecise, and combining data sets generally impossible. In addition, no single entity collects, analyzes, and reports data on all aspects of the energy and mining workforce. As a result, the data that are available are not sufficiently consistent and comprehensive or refined to an adequate level of detail to provide a complete and precise description of the workforce. When they exist, workforce projections are frequently near-term and carry significant uncertainty. However, the committee found that, despite their substantial shortcomings, the available data and information do provide a clear indication of the general nature of the energy and mining workforce and the important trends, issues, and concerns related to it.

Data from federal sources were used where possible because they are heavily vetted and well accepted. These data sources were used to provide a snapshot of the nature and composition of the U.S. energy and mining workforce. In characterizing the workforce, U.S. Bureau of Labor Statistics (BLS) information mainly was used because the BLS is the primary federal agency responsible for collecting and disseminating information about the U.S. workforce. As an independent agency, the BLS is the single best source of objective information about the U.S. energy and mining workforce. However, information from the BLS (and other federal agencies) utilizes standardized coding schemes (such as standardized industry and occupation classifications) that limit the way in which the energy and mining workforce can be examined. The other federal data sources that were used to characterize the workforce are the Department of Education's National Center for Education Statistics and the Department of Labor's Mine Safety and Health Administration. FedScope also was used to provide workforce information on the primary federal agencies responsible for management and oversight of energy and mining.

As noted above, the use of BLS data for examining the energy and mining workforce has limitations. The primary limitations are associated with the NAICS. Because the mature industries of oil, natural gas, nuclear energy, and mining (coal and nonfuel minerals) have been in operation for some time, NAICS codes exist that relate to these industries. Unfortunately, the NAICS codes of relevance to the mature industries do not all uniquely map to each one of the mature industries. However, with the exception of nuclear energy, NAICS categories match fairly well with the mature industries with only a modest amount of overlap. Nuclear electric power generation is the only nuclear energy activity that is associated with a unique NAICS code.

Whereas there are NAICS codes that are helpful in understanding the more mature industries, this is not the case for the emerging industries (solar, wind, geothermal, and CCUS), making it currently infeasible to examine or project the workforce in each of these areas using BLS data. This limitation may be mitigated in time as the NAICS codes are updated.

The use of BLS data for determining employment is complicated and it does not provide a clean and complete view. The BLS's Quarterly Census of Employment and Wages offers the advantage of a high level of industry detail (employment information is available at the 6-digit-level NAICS code), facilitating the disaggregation of employment into the industries of interest. A drawback is its exclusion of self-employed workers, which results in an employment undercount. The BLS's Current Population Survey includes self-employed workers, although with less industry detail. This survey of households captures information by industry based on the 2007 Census industry classification system, which is derived from the 2007 NAICS taxonomy, but there is not a one-to-one mapping between these codes. However, a crosswalk can be used to map the two classification systems.

The EIA is the government body that collects, analyzes, and disseminates energy information. Data from the EIA were used to describe current and projected future industry markets and trends, which in turn provide possible insights into the related industry employment trends. The EIA also projects employment for the oil and gas extraction and coal mining sectors, based on BLS data.

Where data on market size, trends, and projections, and on employment were available from sources other than the federal government, they also were used to provide a more complete view of each industry and its workforce. These sources included industry, industry associations, professional societies, and academic sources. Given the limitations of the federal data, these additional data were helpful in supplementing the committee's understanding of the industries and their workforces, especially in the case of the emerging industries.

There are drawbacks associated with the use of data from these other sources, particularly industry, industry associations, and professional societies. These sources typically act as advocates for their respective communities. Therefore, their data may be valid, but the data also may be nuanced by the ways in which they were collected, compiled, analyzed, and presented, which results in some uncertainty about the data and the limits of their application. Moreover, these data were collected to meet specific needs and they do not provide a complete view of the energy and mining industries or their workforces.

ORGANIZATION OF THE REPORT

Following the Summary and Chapter 1 Introduction, Chapter 2 presents a discussion of the "mature" sectors included in this study—oil and gas, nuclear energy, and mining (including coal and nonfuel minerals)—and their workforce characteristics and issues. These industries are considered mature because they have been in existence for a long time and they are well established and well understood. Although mature, however, these industries continue to change.

Chapter 3 follows with a discussion of the "emerging" sectors—solar, wind, and geothermal energy, and CCUS—and their workforce characteristics and issues. These sectors are considered emerging because they are not as mature or as long established as those discussed in Chapter 2, and their pieces of the future U.S. energy quilt are still evolving.

The energy and mining sectors are grouped into these two categories because the similarities of their characteristics and the workforce data that are available (and not available) make this a natural grouping, and because it facilitates the discussion of these varied industries.

Chapter 4 presents a discussion of the electric grid (including the Smart Grid, an emerging part of the energy infrastructure). As noted above, the grid is discussed in some detail (albeit from an overview level) because the lack of an expanded and enhanced grid limits expansion of the renewable energy sectors (wind and solar, in particular).

Because the federal government has such a significant role in the domestic production and distribution of energy and raw materials, if the government cannot find qualified workers, the energy and extractive industries will be dramatically impacted as a result. A discussion of federal workforce issues is provided in Chapter 5. Of similar crosscutting importance is the area of workforce safety and health in the extractive industries, and this is the subject of Chapter 6.

Workforce education and training related to each of the energy and mining sectors are discussed in their respective sector sections of the report. The broader issues of education and training affecting the range of energy and mining industries are discussed in Chapter 7. This discussion includes a description of the significant challenges that currently exist and that are anticipated for the future workforce, as well as promising approaches for addressing them. Chapter 8 contains a set of key findings and recommendations that are based on a detailed overview in Appendix B of the U.S. energy and mining workforce, which is derived from federal data sources. Chapter 9 provides the overarching conclusions of the study.

Accurate and refined data are essential for a clear picture of the size, characteristics, and trends of the energy and mining workforce, and are an important consideration in this report. Data are available from a range of sources, and multiple sources are used in the discussions throughout the report. However, as noted above, the data from the various sources were originally collected by those sources in different ways and for different purposes, and they are therefore quite disparate, making refined comparisons and linkages difficult.

Appendix A describes the federal data sources that are most relevant to an examination of the energy and mining workforce. Using these vetted and broadly accepted federal data, Appendix B provides an overview of the U.S. energy and mining workforce, addressing trends in workforce size, growth, and demographics, disaggregating each industry by sector and occupation. Appendix C contains detailed tables of the workforce data obtained from federal sources. The federal government data, although not available for all sectors and not all refined to the level of greatest detail, provide a unified and vetted view of the workforce. Data from other appropriate and knowledgeable sources also are used throughout the report to help fill gaps and broaden the constrained workforce view afforded with the federal data. The key workforce issues and trends are clearly identifiable despite the disparate and incomplete nature of the workforce data that are currently available.

Appendix D provides a list of acronyms and abbreviations used in the report. Appendix E provides biographical information about the study committee and staff.

REPORT RECOMMENDATIONS

To capture the key fundamental themes contained in the full array of their findings and recommendations, the committee formulated a set of overarching findings and recommendations, which is contained in the report's Summary. The full set of findings and recommendations, as well as the information and data to support them, are provided throughout the report.

Several recommendations that are shared across the mature and renewable industries described in Chapters 2 and 3 are given in the final section of those chaapters. Also, important industry-specific recommendations for each of the industries are given in their respective sections of the report. In addition, through its discussion and set of recommendations, Chapter 7 lays out an approach to education and training that applies to the range of energy and mining industries covered in this report (except that the final recommendation does not apply to nuclear, solar, or wind energy). Chapter 8 presents a set of key findings and recommendations that are based on a detailed overview in Appendix B of the U.S. energy and mining workforce, which is derived from federal data sources.

2

Mature Sectors

INTRODUCTION

The sectors of oil and gas, nuclear energy, and mining (including nonfuel and coal mining) have been in existence for a long time and are well established. Therefore, although these industries continue to change, they are well understood and considered to be mature.

These mature (but changing) sectors are the subject of this chapter. The discussion of each sector begins with an introduction, with the exception of the mining sector which begins with a discussion of the significance of minerals. Following then is a detailed discussion of each industry, often with an industry overview and profile, market trends and projections, occupational categories, career pathways, employer needs and challenges, workforce education and training, possible solutions, potential impact of innovation, conclusions, and recommendations.

This chapter also highlights examples of very effective educational programs that are addressing workforce issues. These programs primarily target minority sectors of the young population—a pool that traditionally has not been tapped, but which is needed for the future workforce. These approaches could have application across the energy and mining sectors, and they serve as examples for industry, academia, and government to consider and emulate.

Recommendations of importance for each of the mature industries in this chapter, along with the information and data to support them, are provided within their respective chapter sections. In addition to these industry-specific recommendations, a set of Shared Recommendations that, as their name implies, apply across the industries in the chapter are presented at the end of the chapter.

Since no one source of complete workforce data exists, the committee relied on data from a number of sources. As the most objective and officially vetted and accepted data available, the committee used data from the federal government wherever possible. Bureau of Labor Statistics (BLS) data were used for all of the mature industries. In addition, data from the Mining Safety and Health Administration (MSHA) and National Institute for Occupational Safety and Health (NIOSH) were used for the mining workforce, and data from the Energy Information Administration (EIA) were used for the oil and gas extraction and coal mining workforces. However, the government data do not provide a complete picture of the workforce within the industries of interest in this study. Therefore, in each industry, the committee also drew upon other sources of information in order to gain a more complete picture of the associated workforce and its issues.

As noted in Chapter 1 and discussed in detail in Appendix B, this report primarily uses workforce data from the BLS. However, there are limitations to using BLS data (primarily associated with the North American Industry Classification System (NAICS), the standard industrial classification system used by the BLS and other federal statistical agencies). Because the mature industries have existed for some time, NAICS codes exist that relate to these industries. Unfortunately, with the exception of nuclear electric power generation, the NAICS codes of relevance are not all uniquely mapped to each one of the mature industries. However, NAICS categories match fairly well with the mature industries with only a modest amount of overlap.

Workforce information, data, and projections from sources other than the federal government are discussed as appropriate in each of the mature industry sections. There are variations among data from different sources, and these differences are noted in the discussions.

Some general points should be mentioned. Workforce estimates and near-term projections related to the oil and gas workforce from several studies are given. Nuclear Energy Institute (NEI) workforce estimates for the nuclear power industry, as well as NEI long-range workforce estimates (based on a potential industry scenario), are provided. Also, workforce projections for coal mining to 2030 from a study by the Virginia Center for Coal and Energy Research are given. The projection timeframes vary among the different data sources.

Industry market trends and projections also provide insights into possible workforce trends. The EIA is the source of energy statistics from the U.S. government, so EIA data are used to describe market trends and projections to 2035 for oil, gas, and coal production, and for nuclear power generation. Another source of trend and near-term projected trend information for oil and gas production is noted.

The data included in this report were collected by different entities for different purposes using a variety of methods and workforce definitions, making direct data comparisons difficult and imprecise. Additional information about these data can be obtained from their associated referenced sources.

OIL AND GAS

Introduction

A big crew change is underway in the oil and gas industry. A “big crew change” refers to a rapid shift in industry demographics, triggered by mass retirements of baby boomers, resulting in a shortage of experienced technical talent.

Industry Overview and Profile

The oil and gas industry satisfies more than 60 percent of the total U.S. energy demand and more than 99 percent of the fuel used in U.S. vehicles (PriceWaterhouseCoopers, 2009). In 2010, domestic oil and gas production totaled more than $244 billion (EIA, 2011c), and the industry has seen a renaissance of new drilling and production. Driven largely by technology associated with newly found shale reservoirs, deep-water discoveries, and heavy-oil development, the decline of the past several decades has been arrested for the foreseeable future.

The nation depends on foreign sources for 49 percent of its 19.2- million-bbl/day consumption of liquid fuels. On the other hand, 89 percent of the 24 trillion cubic feet of natural gas consumed in the United States is produced within the continental United States (EIA, 2012a)

Production Regions of the United States

Hydrocarbons are produced from 22 states. Well over 80 percent of hydrocarbon production is from onshore operations. Large additional resources have been estimated by the

U.S. Geological Survey (USGS) to exist in the undrilled outer continental shelf regions of the eastern United States, offshore California, and eastern Gulf of Mexico, where a drilling moratorium currently exists.

Industry Size, Employment, and Structure

Based on 2007 data, the total operational oil and gas workforce has been estimated to be 7,818,437 workers (2,123,291 direct and 5,695,146 indirect and induced),[1] according to one source (PriceWaterhouseCoopers, 2009). This number encompasses all types of employment, from oil and gas well drilling to petroleum and petroleum products merchant wholesalers to gasoline stations—a far broader footprint than is the focus of this study.

The BLS also reports oil and gas workforce data. (A discussion is provided in Appendix B.) Table 2.1 shows BLS employment data for 2010 for the NAICS industry codes that are unique to oil and gas. The exploration and production (E&P) technical workforce (known as "upstream") is estimated to be 494,201 workers. The "midstream" technical sectors of pipeline construction and transportation total around 250,608, and the "downstream" technical workforce is 72,689 workers in refining. Altogether for these NAICS industry codes, the total employment is 817, 498, with the vast majority in the private sector (an additional 7,699 workers, not shown, are in the local government sector)—see Table B.12.

The data in Table 2.1 are from the BLS Quarterly Census of Employment and Wages (BLS, 2011d) and include employees of oil- and gas- producing companies as well as service companies that work on a contract or fee basis. However, these data exclude self-employed workers and unpaid family workers, leading to an undercount. This factor contributes to a portion of the difference between the BLS total and the PriceWaterhouseCoopers (2009) total (which covers a much broader view of the overall oil and gas industry). Table 2.1 also shows average hourly earnings, indicating that jobs in these sectors pay well.

However, a BLS estimate for a 2010 employment level that includes self-employed, wage and salary, and unpaid family workers is available for the oil and gas extraction sector only, through the BLS Employment Projections Program. Therefore, this more complete level of 2010 employment for this NAICS code is given in Table B.14 (158,900, compared to 158,423 from Table 2.1, which is based on the BLS Quarterly Census of Employment and Wages). Unfortunately, estimates of self-employed and unpaid family workers are not available for the sectors of drilling oil and gas wells and support activities for oil and gas operations.

---

[1] Indirect impact is jobs, labor income, and value added within other industries that offer goods and services to the oil and gas industry. Induced impact is jobs, labor income, and value added coming from household spending of income earned directly or indirectly from the oil and gas industry's spending.

TABLE 2.1 2010 Upstream Technical Oil and Gas Employment (yellow), Midstream Employment (green), and Downstream Employment (blue).

NAICS Code	NAICS Title	Total Employment	Private Sector Employment	Private Sector Average Hourly Earnings
211	Oil and Gas Extraction	158,423	158,423	$35.94
213111	Drilling Oil and Gas Wells	74,491	74,491	n/a
213112	Support Activities for Oil and Gas Operations	201,685	201,685	$24.43
2212	Natural Gas Distribution	115,138	108,605	$31.49
23712	Oil and Gas Pipeline and Related Structures Construction	92,319	92,039	$24.51
32411	Petroleum Refineries	72,689	72,689	$36.66
333132	Oil and Gas Field Machinery and Equipment Manufacturing	59,602	59,602	n/a
486	Pipeline Transportation	43,151	42,265	$33.61
	Total Upstream Employment	494,201		
	Total Midstream Employment	250,608		
	Total Downstream Employment	72,689		
	Total	817,498		

NOTE: Earnings information includes overtime. SOURCES: BLS (2011d [employment]; 2012a [average hourly earnings]).

Table B.13 provides a BLS historical view of the average annual U.S. oil and gas employment by NAICS industry code for 2005-2010. Over this period, employment in these oil- and gas-specific NAICS codes grew by almost 140,000, with an annual growth rate of 3.8 percent. The growth was concentrated in 2005-2008, with an annual growth rate of 9.2 percent. The largest growth was in support activities for oil and gas operations, with an annual growth rate of 6.7 percent for 2005-2010. Employment over this same period grew in all of the oil and gas NAICS codes except for natural gas distribution, in which employment remained basically the same. Tables C.11 and C.12 in Appendix C show average annual oil and gas employment for 2005-2010 for the private and local government sectors, respectively.

Table C.13 provides key demographic information for the oil and gas workforce by Census industry for which information is available. The data show that relatively few women are employed in oil and gas compared with the overall U.S. workforce, and a sizable percentage of the workforce is Hispanic/Latino. A key point to note is that the oil and gas workforce is relatively old compared with the overall U.S. workforce. This important issue is discussed more fully below. (Table C.14 maps U.S. oil and gas NAICS industries to Census industries.)

Industry Occupations

Table C.15 of Appendix C provides 2010 employment estimates for the 20 largest private- sector occupations in the oil and gas extraction NAICS industry code. These occupations account for more than 50 percent of this industry. (Similar data for natural gas distribution and pipeline transportation are given in Tables C.16 and C.17.)

Salaries for skilled oil and gas workers are relatively high. BLS data indicate that the U.S. employed about 1.48 million engineers in 2010. Petroleum engineers numbered 30,880 (2 percent of the overall engineering population), and received the highest salaries, with an annual mean of $138,980 (BLS, 2011b, Code 17-2171).

The average annual pay for petroleum geoscientists is given in Table 2.2. As indicated, salaries have been increasing over time. The increase has been driven mostly by the demand for energy and mining commodities, along with the associated price increases over the same period. Table 2.2 also shows how experience is prized and rewarded.

TABLE 2.2 Historical average salaries for petroleum geoscientists.

Historical Averages Salary

YEARS EXPER	2004	2005	2006	2007	2008	2009	2010	2011	2012
0-2	$ 65,600	$ 67,800	$ 74,400	$ 82,200	$ 82,800	$ 83,600	$ 87,600	$ 93,000	$ 98,700
3-5	67,700	75,600	81,300	89,600	107,800	108,000	105,600	102,300	109,400
6-9	75,700	78,800	95,400	98,500	121,100	118,400	121,700	127,800	137,300
10-14	91,900	107,500	114,400	111,500	119,800	121,900	123,500	139,100	153,400
15-19	102,500	116,000	119,600	141,000	151,600	139,400	150,800	151,000	193,600
20-24	118,100	112,800	139,000	155,000	167,400	176,800	180,300	191,000	199,200
25+	125,100	128,300	134,100	149,900	162,800	171,700	186,800	206,300	199,600

SOURCE: Nation (2012). Used with permission from the AAPG.

Oil and Natural Gas Market Trends

Over the past 50 years, U.S. oil consumption has almost doubled, from 10 million bbl/day in 1960 to more than 19.2 million bbl/day in 2010 (2 percent per year). Currently, the United States is the largest consumer of oil in the world, but countries such as China and India are on growth trajectories that show rapid increases in consumption (EIA, 2012c). In 2003, China became the fastest growing consumer of oil, surpassing Japan, with consumption in 2011 estimated to be about 10 million bbl/day. This new demand has created an economic global shift in the price of oil beginning around 2005.

For 2010 through 2011, the U.S. gross domestic product (GDP) grew 4.6 percent (BEA, 2012), while the GDP in China and India increased dramatically by 11.6 percent and 10.7 percent, respectively (IMF, 2012). Large populations such as China and India with growing GDPs are expected to keep worldwide oil demand and prices high for the foreseeable future.

The U.S. Oil and Gas Exploration and Production Revival

The U.S. oil and gas industry is experiencing a revival as a result of strong prices and new technological advances. Except for the 2008 economic downturn, oil prices have remained above $30/bbl, averaging well above $70/bbl, and they are increasing (EIA, 2012h). Natural gas prices have been above $3.00 per thousand cubic feet and have averaged above $5.00 per thousand cubic feet since 2003 (EIA, 2012e). However, with the advent of new shale gas drilling and excess supplies, natural gas prices have softened.

The strong demand for oil and gas at higher sustained prices has created new opportunity, with boom effects being experienced in the onshore regions of the country that have not been seen since the 1970s. The resulting explosion has created demand for workers and equipment. Demand for onshore equipment has tripled since 2000. In the offshore areas, where the number of deep-water projects has been increasing rapidly, the number of floating production and storage and offloading vessels (ships that are used in the development of deep-water oil fields worldwide) is on a 57-vessel backlog (IMA, 2011). The trend in U.S. onshore and offshore rig counts (EIA, 2011c) is an indicator of activity. The number of onshore rigs has grown rapidly in response to drilling in the shale plays across the country. The total U.S. rig count is 2,008 units according to Baker Hughes (2012), with more than 98 percent of the rigs drilling onshore.

Oil and Gas Market Trends and Projections

The Oil Production Boom

U.S. oil production peaked in 1970 at about 9.5 million bbl/day, when total imports were 1.4 million bbl/day. Total U.S. oil demand in 1970 was 10.9 million (EIA, 2011c). Prior to the embargo of 1973, U.S. oil production supplied about 87 percent of U.S. demand. Since then, U.S. and Canadian oil production has steadily declined. In 2008, U.S. production dropped to an all-time low of 5 million bbl/day, while demand was about 20 million bbl/day. Domestic production was about 25 percent of U.S. demand. According to Fowler (2011), BENTEK Energy anticipates a production turnaround, and U.S. oil production in areas including the West Texas Permian Basin, South Texas Eagle Ford Shale, and North Dakota Bakken Shale having an increase of slightly more than 2 million bbl/day from 2010 to 2016.

Due mainly to improved technology associated with horizontal drilling in oil shale and unconventional reservoirs such as the Bakken formation, as well as improved oil-sands production in Alberta, Canada, oil production in the United States is expected to hit levels not seen since 1990, and production in Canada also is expected to be at an all-time high. Figure 2.1 shows the historical and expected future trends in U.S. and Canadian oil production.

Projections from the EIA also indicate increases in domestic oil production through 2030 and domestic gas production through 2035 (see Table 2.3). The EIA projections for oil production are not as optimistic as the BENTEK Energy projections.

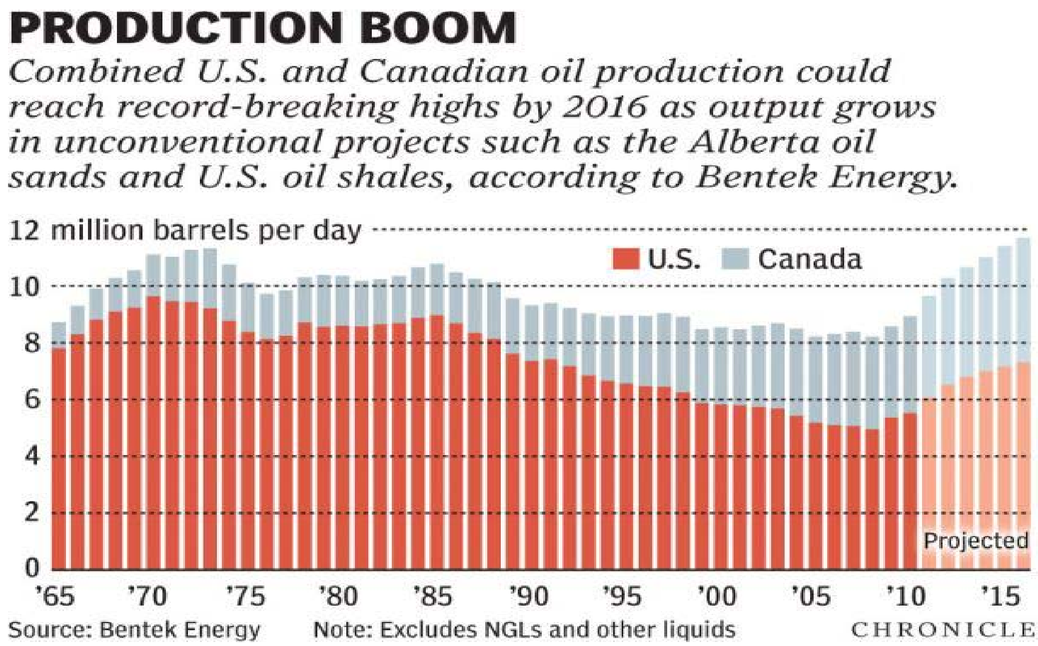


FIGURE 2.1 Historical and future U.S. and Canadian oil production.
NOTES: Excludes natural gas liquids and other liquids. The decline in oil production that has been the norm for the last 40 years is expected to reverse as a result of production increases from the shale reservoirs and heavy-oil production. SOURCE: BENTEK Energy.

TABLE 2.3 Domestic Oil and Gas Production (EIA Reference case)

	2009	2010	2015	2020	2025	2030	2035	Annual Growth 2010-2035 (%)
Crude oil and lease condensate (million bbl/day)	5.36	5.47	6.15	6.70	6.40	6.37	5.99	0.4
Natural gas plant liquids (million bbl/day)	1.91	2.07	2.56	2.91	3.01	3.05	3.01	1.5
Dry natural gas[a] (trillion ft^3/year)	20.58	21.58	23.65	25.09	26.28	26.94	27.93	1.0

[a]Marketed production (wet) minus extraction losses. SOURCES: EIA (2012a, Table A11, pp. 153-154; Table A13, pp. 157-158).

The Bakken and Eagle Ford Shales

With expected production increases, due mainly to unconventional projects, the demand for a qualified workforce is very strong. Two examples are the Bakken Shale and Eagle Ford Shale formations.

The North Dakota Petroleum Council reported to the committee that it had conducted its own workforce study in 2010 and determined that 7,000-10,000 workers would be needed per year to develop the Bakken Shale formation in North Dakota alone. The Bakken Shale is located in northwestern North Dakota and northeastern Montana. The local Job Service North Dakota Web site[2] listed more than 1,600 oil and gas jobs available at the time of writing and the North Dakota unemployment rate was under 3.2 percent when the U.S. national average was over 9 percent. Similar demand for workers extends into Montana and Canada (Ness, 2011).

A similar story is being played out in the Eagle Ford Shale of South Texas, where large multinational companies have been acquiring acreage for the high liquid and gas yields expected from this reservoir. Depending on the depth of this formation (which in turn determines the maturation of the hydrocarbons found in it), the reservoir can produce either black oil, condensate, and/or gas. Wells that are entirely drilled as horizontal with multistage fracturings ("fracs") have reported flows of more than 1,000 bbl/day, with the potential of accumulating 600,000 bbl over their lifetime.

Other oil shale development projects similar to the Eagle Ford Shale (Fayettville, Niobrara, and Woodford Shale, and others) will take tens of years to develop, requiring a workforce that includes truck drivers, welders, and field workers as much as it does a petroleum geologist or engineer. Developing a pipeline of workers through education will be a key to ensuring that these workers are available in the future.

The Boom in Natural Gas

The shale gas plays[3] that recently have come to the forefront have largely developed as a result of horizontal drilling and new fracturing ("fracking") techniques. These technologies have unlocked more than 1,000 trillion cubic feet of potential new gas reserves. With the United States consuming approximately 24 trillion cubic feet per year, these gas volumes represent a long-term energy solution, provided the industry can overcome environmental and socioeconomic concerns about the extraction technology.

The expected domestic production of huge amounts of natural gas will have a major impact on electricity generation, where currently 45 percent is generated by coal, 20.3 percent by nuclear energy, and 23.4 percent by natural gas. Producers are finding that natural gas in the $4-5 per million cubic feet range can be profitable and they are selling long-term contracts to the power generation industry. In some cases, companies such as Natural Fuels and Seneca Resources are becoming vertically integrated to take advantage of the synergy between upstream and downstream activities. With combined-cycle efficiencies that can reach 60 percent, coupled with a smaller CO_2 footprint, natural gas will be used over the life of an expected 100+ years of reserves. The relatively low cost of gas will affect future power generation by all sources. The largest resources are in formations such as the Marcellus, Haynesville, Eagle Ford, and Utica shales.[4] With production quickly ramping up, these reservoirs are expected to represent 49 percent of the total U.S. gas production by the year 2035 (EIA, 2012a). EIA projections for domestic gas production are shown in Table 2.3, above. Figure 2.2 offers an historical view of production by formation type and projections to 2035.

---

[2] http://www.jobsnd.com/.

[3] A play is a set of oil and or gas accumulations in the same region that share similar geological and temporal properties.

[4] A map of the potential U.S. shale gas basins is available at http://www.eia.gov/oil_gas/rpd/shale_gas.pdf.

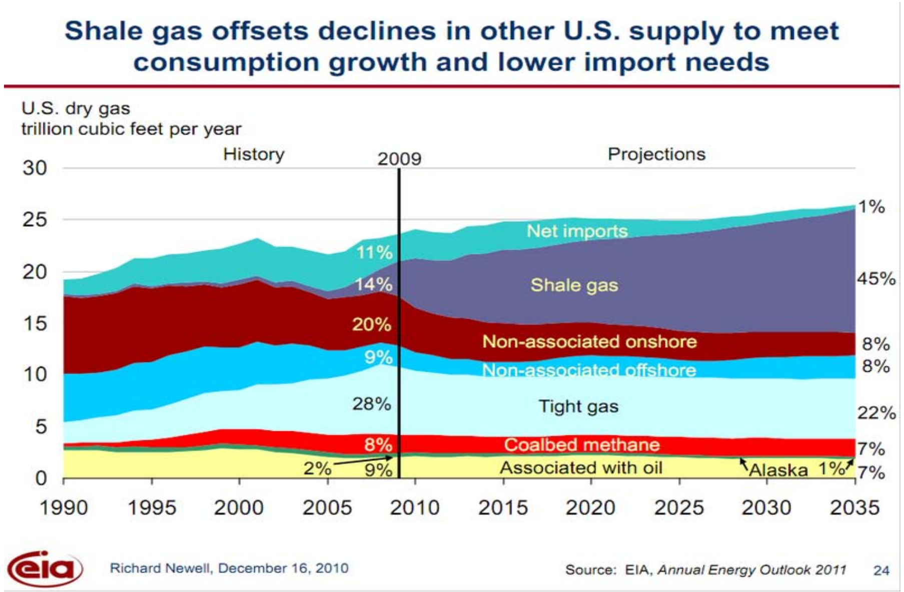


FIGURE 2.2 EIA historical and future production trends for gas by reservoir type. SOURCE: Newell (2010).

Employer Needs and Challenges

Oil and gas employment projections are limited. BLS projections for 2020 for the private sector are available for only a subset of oil and gas NAICS codes. The available projections are shown in Table B.14 in Appendix B, and they indicate that employment in the oil and gas extraction industry is expected to grow by 23,200 (an annual growth rate of 1.4 percent), from 158,900 in 2010 to 182,100 in 2020. EIA projections indicate that total employment in oil and gas extraction was 452,891 in 2010 and it is expected to rise to 459,032 in 2020, and then decline to 404,866 in 2030 and 383,205 in 2035 (EIA, 2011a; EIA projections are based on BLS data.) Table 2.3, above, projects oil production to rise through 2020 and then decline through 2035, and natural gas production to rise through 2035. The EIA employment projection for oil and gas extraction reflects the projection for oil production.

The Bakken and Eagle Ford shales noted above are only two of perhaps 10-20 other basins that will have productive shales. The shale projects will take decades to develop, requiring a diverse workforce of professionals and nonprofessionals. However, the industry is facing two challenges. The first is increasing international competition for workforce talent that is being drawn from the United States to high-paying jobs in a well-integrated international market. The second, larger challenge is the prospect of large numbers of worker retirements in the near term.

The Aging Workforce

The boom in oil and natural gas exploration and production has created a demand for workers and equipment that comes when a large portion of the existing workforce, professional and nonprofessional, is less than 5 years from retirement. Many of these workers are actually now at retirement age, but still remain employed because of an undersupply of experienced workers.

U.S. Census data indicate that about 76 million baby boomers are poised to retire in great numbers by the end of the decade (see Figure 2.3). Baby boomers represent about a third of the nation's workforce, and there are too few younger workers to replace them. Expected labor shortages in important industries will require a major reconsideration of recruitment, retention, work schedules, and retirement (Reeves, 2005).

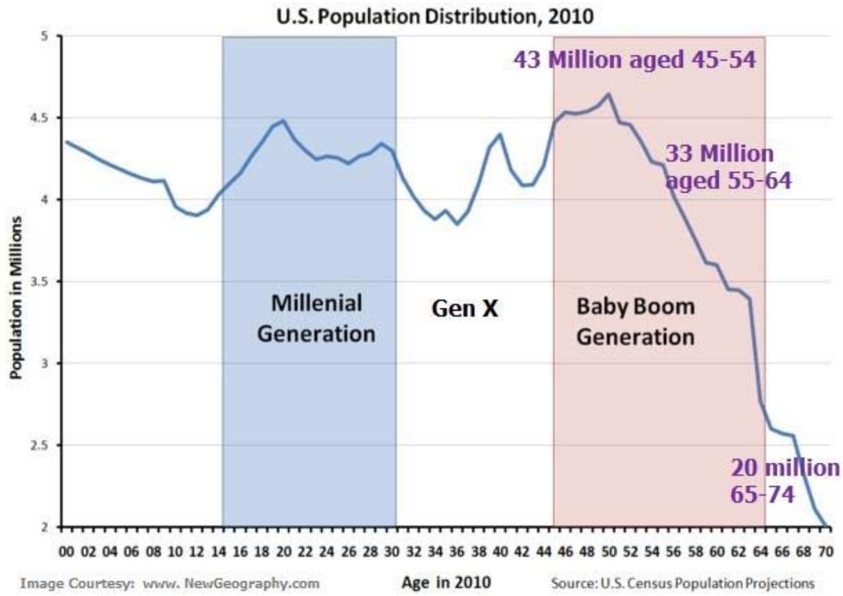


FIGURE 2.3 U.S. population distribution in 2010. SOURCE: Schill (2008). Reprinted with permission from Mark Schill, NewGeography.com.

The oil and gas workforce reflects a similar age distribution and retirement issue (see Figure 2.5, below). According to the EIA, energy and commodity prices are expected to stay high well into the century (EIA, 2012d). Accordingly, demand for skilled and professional oil and gas workers at all levels is expected to continue to climb; however, the future source of the workers to replace the retiring population is still in question.

Soon-to-retire boomers also are a large portion of the experienced technical and skilled workforce. A discussion with the U.S. Department of Energy (DOE) Fossil Energy Headquarters management team indicated that all of their technical staff is eligible for retirement. Other agencies within the federal government also are experiencing a similar situation, with a large gap between the younger workforce and older management. (The federal workforce is discussed in Chapter 5.)

Reeves (2005) indicates that the number of U.S. workers aged 35 to 44—or those typically moving into upper management—declined by 19 percent in 2007, the number of workers aged 45 to 54 increased 21 percent, and the number of workers aged 55 to 64 increased 52 percent. The age demographics are not limited to the United States. Similar demographics exist for Germany, the United Kingdom, Italy, Japan, and China (Reeves, 2005).

The Workforce Concern in the Earth and Engineering Sciences

The discussion now focuses on the earth and engineering sciences, specifically, future workers with careers in geology, geophysics, petroleum and natural gas engineering, drilling, and related fields associated with the oil and gas industry. According to the National Petroleum Council's 2007 Global Oil and Gas Study (Raymond et al., 2007), the majority of the U.S. oil and gas workforce is eligible to retire in this decade and there are not enough prospective employees in the pipeline. Virtually every major technical society across the energy spectrum has conducted workforce studies, and they have expressed concerns about the aging petroleum workforce and the lack of qualified personnel. Figure 2.4 shows the dramatic effect of the U.S. E&P workforce that will be lost and the number of incoming graduates to replace them. As shown, the U.S. petroleum engineering workforce in place in 2000 will decline because of retirement and attrition, and the number of incoming graduates will be insufficient to fill the gap.

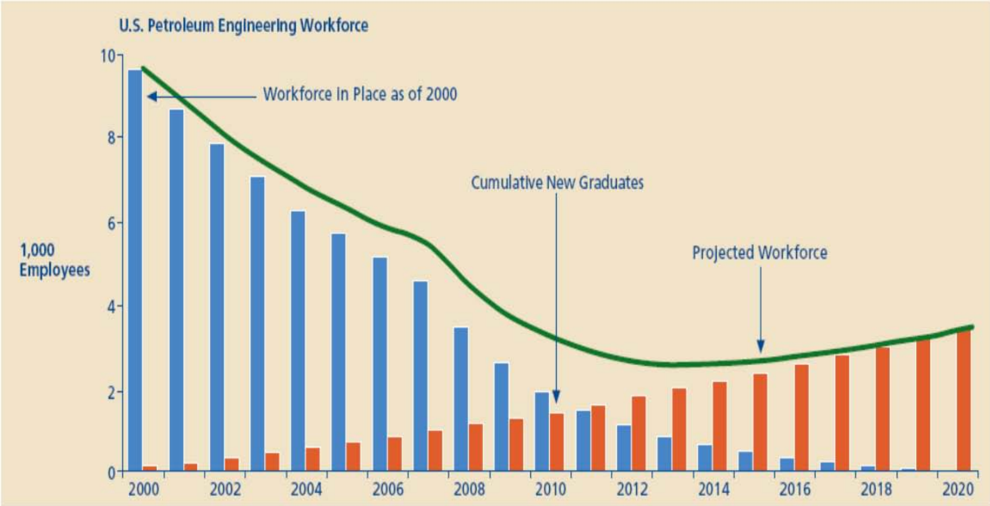


FIGURE 2.4 U.S. petroleum engineering workforce. NOTE: Blue columns are the workforce in place as of 2000, red columns are cumulative new graduates, and the green curve is the projected workforce. SOURCE: Sampath and Robinson (2005, Exhibit 2, p. 3).

The 2010-2011 annual American Association of Petroleum Geologist Salary Survey (Nation, 2011) indicates that groups in high demand are workers with 10-14 and 25-plus years of experience. Almost 44 percent of the survey respondents had more than 25 years of experience, indicating the magnitude of workforce aging. Another concern is that smaller and mid-size companies are reluctant to add entry-level staff because they cannot spare the mature geologists the time needed to mentor new geologists. This trend does not help prepare new, trained workers.

A similar aging trend for the petroleum engineering sector has been documented by the Society of Petroleum Engineers membership survey. It revealed that more than 30 percent of the members were 50 years of age or older.[5]

A global workforce study in 2008 indicated that nearly a third of the global petrotechnical workforce (about 40,000 workers) was 50 years of age or older and expected to retire in the following 5 years (SBC, 2008). These older workers are typically the most experienced, highly trained, and senior members of the workforce.

A more recent analysis by Rousset et al. (2011) indicates similar trends. This article describes the transition that is now in progress for the global petrotechnical workforce. It notes that 25 percent of petrotechnical employees of E&P companies are older than 50 years of age

[5] SPE membership demographics are available online at http://www.spe.org/about/demographics.php.

and most will retire in the next 5 years. They came into the industry at the height of the oil and gas growth cycle, and the subsequent long period of weak recruitment produced a gap in mid-career professionals. The growth period of 2003-2008 has increased graduate recruitments, resulting in the bimodal workforce distribution (Rousset et al., 2011).

The bimodality of the age distribution is of concern because it indicates that a significant gap in age and, hence, experience, training, and maturity exists between the older workers who are poised to retire and the younger workers who would remain. This gap portends that there may be difficulty in finding managers with the needed experience, training, and maturity to replace the retirees in positions of leadership.

The so-called “big crew change” in the petrotechnical workforce is under way. A loss of 22,000 experienced workers and an addition of 17,000 younger petrotechnical workers are expected between 2009 and 2014. It is important for companies to be addressing the transition now to avoid the loss of knowledge and experience. Moreover, the other challenge of the transition will be to recruit and develop the younger workers to help the industry address its future needs. Figure 2.5 illustrates the transition (Rousset et al., 2011).

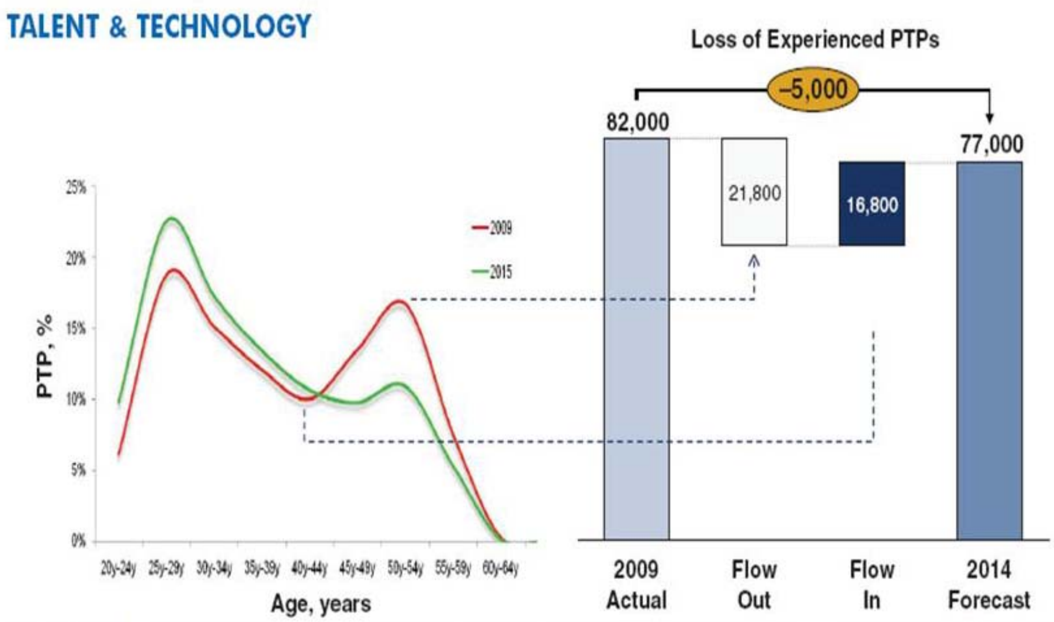


FIGURE 2.5 The large turnover of retiring industry personnel to a younger workforce is under way. The graph displays the percentage of petrotechnical professionals (PTPs) by age category on a global basis. The number of experienced petrotechnicals (those age 35 and older) is expected to drop by 5,000 between 2009 and 2014. Experienced petrotechnicals refers to those age 35 and older. SOURCE: Rousset et al. (2011, Fig. 1).

Education and Training

The Geoscience Trend

Until recently, the number of geoscience departments and faculty, and the undergraduate enrollments have been declining in the United States (see Figure 2.6). The state of geoscience departments has a direct impact on the size and training of the future geoscience workforce. A master's degree is the professional degree in geoscience occupations, meaning that there is a lag of about 5 years between undergraduate enrollment and entry into the workforce for students receiving a geoscience master's degree. Geoscience bachelor's degrees afford limited job opportunities. Nonacademic job opportunities exist for geoscience doctorates, but more than 80 percent seek academic careers. A lag of 10-15 years exists in the geoscience academic workforce, depending on the time spent by doctoral graduates in postdoctoral positions before taking a faculty position (Gonzales and Keane, 2011).

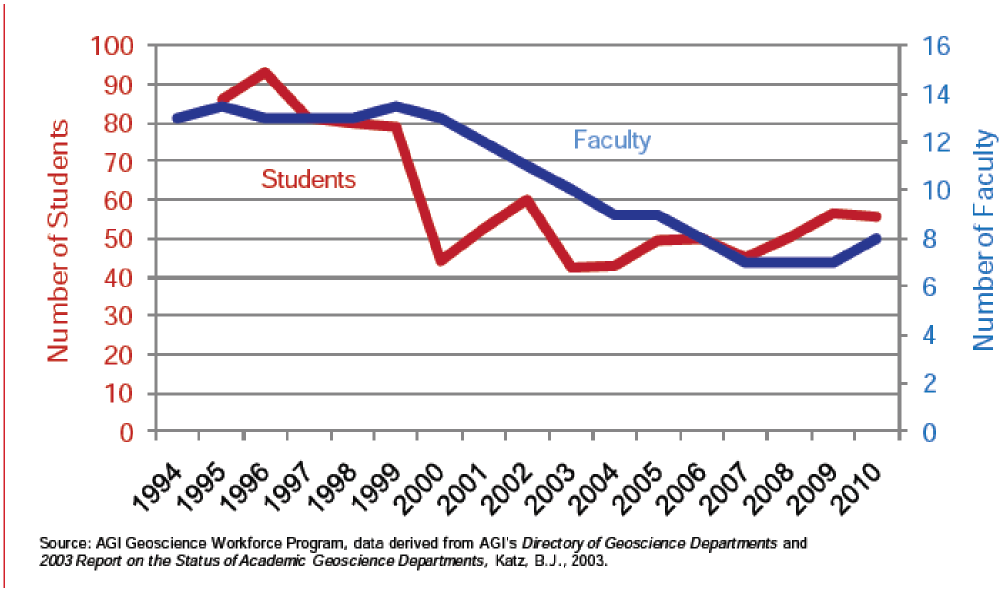


FIGURE 2.6 Median size of geoscience departments based on number of faculty and number of students. SOURCE: Gonzales and Keane (2011, Fig 3.3, p. 50). Reprinted with permission from American Geological Institute.

The American Geological Institute (AGI) regularly conducts a census of geoscience departments across the country. According to their report on 2004 results, after 1994, the trend was for the number of students enrolled in geosciences departments and associated facility to decrease. Also, the number of academic departments in the United States decreased dramatically after the 10-year oil market bust of the mid-1980s —70 geoscience departments had closed or merged since 1999. Most of the affected programs were at community colleges. Many were folded into physics programs and the geology courses were phased out, and many bachelor's programs shifted from geology to environmental programs (Keane, 2005).

The most recent (2011) AGI workforce report is somewhat more optimistic. For the 2009-2010 academic year, the number of geoscience undergraduates enrolled in U.S. institutions was 23,983 majors (the most in a decade). Graduate geoscience enrollment increased significantly to 9,054. The increases probably are due to several factors—continued high prices for commodities, better recruitment of students, and, for graduate students, the impression of a negative job market. (For petroleum geoscientists, for example, Table 2.2 indicates how salaries have been increasing due to high commodity demand and prices, a motivating factor for increased enrollment.) Despite the fact that employment opportunities in the geosciences remain good, the impression of a negative job market drives undergraduates into graduate programs. There also was a significant increase in the number of geoscience degrees conferred (3,037 bachelor's degrees, 1,078 master's degrees, and, 668 doctorates), probably linked to earlier growth in undergraduate enrollment and the bad economy. The bad economy motivates graduate students to complete their studies at a higher rate, rather than to find jobs before they receive their degree (Gonzales and Keane, 2011).

The Petroleum Engineering Trend

The history of petroleum engineering graduates over time has been a story of boom and bust. Dr. Lloyd Heinze of Texas Tech University has been tracking enrollments of petroleum engineering students for more than 20 years and provides the following information in Figures 2.7, 2.8, and 2.9 (Olson, 2011).

As shown in Figure 2.7, the United States saw its highest petroleum engineering enrollment in 1983 (approximately 12,000 students), only to see a 10-year hiatus during the years of low oil prices. After the oil crash of 1986, enrollment dropped below 3,000 students and remained low until 2006. With the advent of higher oil prices, enrollment climbed at almost every major institution. Enrollment has steadily increased since 2005. Figure 2.8 shows the undergraduate enrollment from the 19 largest programs in the nation for 1993-2011. The top six schools (Texas A&M University, University of Texas, Colorado School of Mines, University of Oklahoma, Louisiana State University, and Texas Tech University) account for well over 50 percent of the total petroleum engineering students. As shown in Figure 2.9, the U.S. graduated about 1,000 undergraduate petroleum engineers in 2011. According to the BLS, there currently are about 30,880 petroleum engineers employed in the U.S., up 10,000 from 2008 (Olson, 2011). With universities graduating many fewer than this number over the same period, it is possible that the difference has been covered by individuals returning to work after the 10-year oil crash and by foreign nationals that have been given U.S. work visas.

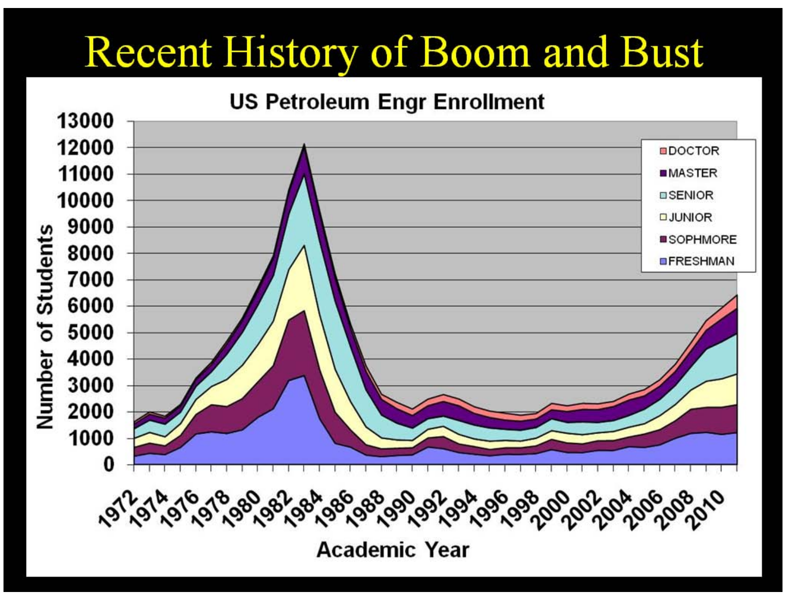


FIGURE 2.7 U.S. petroleum engineering enrollment for 1972-2010. SOURCES: Heinze (2004), Holditch (2009), Olson (2011). Used with permission from Lloyd Heinze and the U.S. Petroleum Engineering Heads.

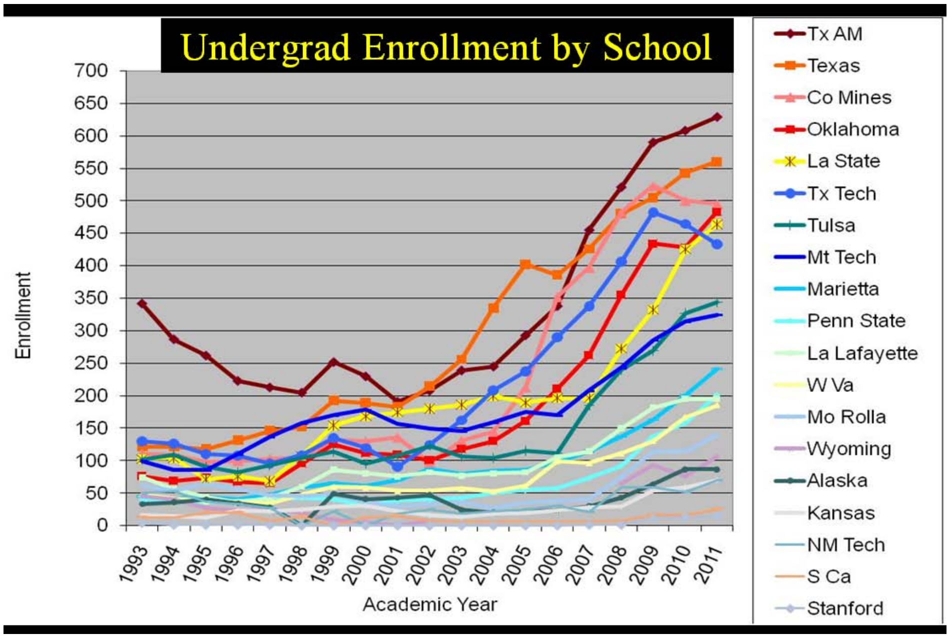


FIGURE 2.8 Petroleum undergraduate enrollment by university. SOURCES: Heinze (, 2004),; Olson (2011). Used with permission from Lloyd Heinze and the U.S. Petroleum Engineering Heads.

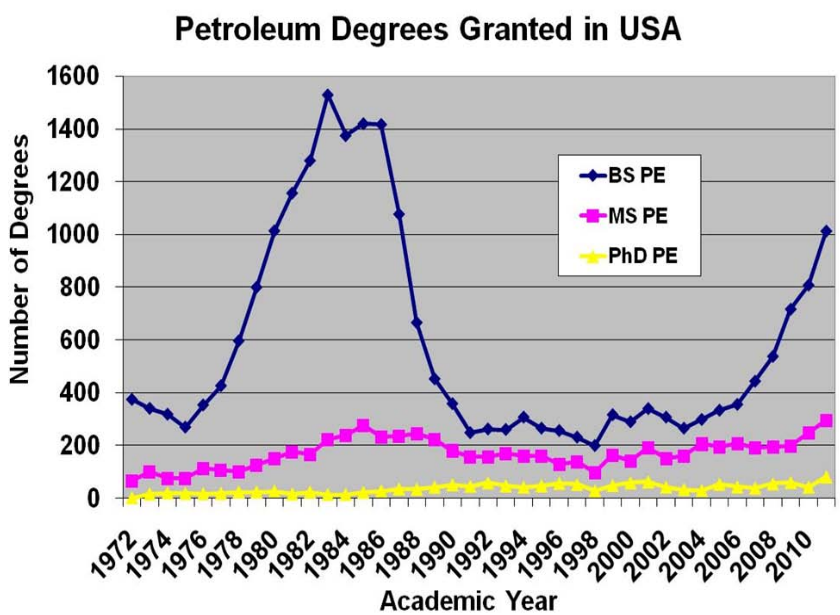


FIGURE 2.9 Petroleum degrees granted in the United States. SOURCES: Heinze (2004), Olson (2011). Used with permission from Lloyd Heinze and the U.S. Petroleum Engineering Heads.

In considering the overall petroleum engineering population and the number of individuals currently in the pipeline in universities and other institutions, it becomes obvious that, as large numbers of the petroleum population retire, it will be very difficult to replace them under the status quo situation. This problem becomes even more acute as the country experiences the anticipated oil and gas boom.

The Need for Technicians

Geological and engineering technicians are also needed. Once considered to be in an apprentice position, these technicians provide expertise in computer applications and data analysis that supports the daily activity of a company or institution. As the demand for engineers and geoscientists increases, so does the demand for these mid-level positions. Many suggest that technician positions are today in even greater demand. Technical colleges offering 2-year degrees focused on providing certified training for these jobs have been very successful. Competition for these workers can be fierce because they often crosscut a variety of energy and technology disciplines. Virtually all find employment after completing their training.

Faculty and STEM Teacher Shortages

An important problem common to geoscience and petroleum engineering education is a faculty shortage in institutions of higher learning. Also, as noted above, increased funding from industry and the federal government for academic research is needed to attract students, and, hence, faculty.

Likewise, STEM education at the middle- and high-school levels is also key to workforce development and it faces a shortage of qualified and motivated STEM teachers. Two programs that serve as good examples of approaches to addressing this issue are AggieTEACH[6] and UTeach,[7] which work to provide university-educated and motivated STEM teachers.

AggieTEACH at Texas A&M University prepares mathematics and science teachers for undergraduate and secondary-level (grades 8-12) education. Students receive classroom teacher education with skilled teachers, and they can obtain a bachelor’s degree and a Texas mathematics or science teaching certification. The UTeach program is discussed in Chapter 7.

The Role of the Community Colleges

One of the best investments in STEM education is community colleges, which are cost-effective and, in some cases, allow students to receive certifications in STEM-related fields. They also can provide a pathway to 4-year institutions. One successful example of such a partnership is the Blinn Community College and Texas A&M University Transfer Enrollment at A&M (TEAM) program,[8] which is a collaborative, coenrollment partnership between these institutions. Through this program, hundreds more students have been admitted each year into the Texas A&M freshman class than would have been possible without the program. Students enter Texas A&M University on a part-time basis and then may earn full admission.

Counseling is a valuable tool for students planning to enter a community college. Counseling can inform them about employment trends and opportunities in an industry, and about the best classes to take. Although the future looks bright for the oil and gas industry, with a history of past ups and downs, counseling can help students make well informed decisions.

In summary, oil and gas production in the United States is expected to dramatically increase at the same time that a large portion of the E&P workforce is expected to retire. At

---

[6] http://aggieteach.tamu.edu.
[7] http://www.nationalmathandscience.org/programs/uteach-program; http://uteach.utexas.edu/.
[8] http://blinnteam.tamu.edu/.

present, it is not clear that the United States has the capacity in its universities and community colleges to meet the demand for trained workers.

Finding Solutions

As experienced workers retire, they not only leave a void in the professional workforce, but also a gap in the number of mentors for younger workers. Experienced workers are critical for the continuation of historical and corporate memory. In the earth resource industries, analogs are used as a source of new geological and engineering concepts. Mentors are the source of support for new ideas coming from the younger workers. Mentors also are a critical addition to the training material and programs for new hires. The loss of mentors in an industry facing significant workforce retirement will negatively affect productivity. Without experienced supervision and guidance, past mistakes will be repeated and past learning forgotten until new knowledge is acquired. As talent and experience are lost, not only is capacity lost, but also the capability to perform the tasks at hand.

Knowledge capture and management are very important to any company, and many have worked to find ways of effectively capturing the knowledge of experienced workers. As one example, Schlumberger has developed the InTouch[9] system that provides mentors and experts online for any employee to access. An employee may pose a technical question to, or seek advice from, an InTouch engineer. A database provides answers if a question has been asked before, but if a question is new, a domain expert offers answers and the answers are added to the database.

As noted above, there is an experience gap in the oil and gas workforce—between 15 and 30 years of experience. With a knowledge database such as the one described above, and with the experienced professionals who are poised to retire, the energy industry could benefit from refining the ways in which engineers and geoscientists are trained after they have worked for 5 or 10 years. New training methods (perhaps using simulators) to accelerate experience-based learning could offer promise. Simulators are used for training in many areas, including drilling. The development of simulators to train engineers and geoscientists in order to endow them with the equivalent of many more years of experience than represented by their time on the job alone could greatly smooth the big crew change. Potentially, research into ways of training young professionals could yield other, more effective approaches.

The Search for Talent

During its meetings, the committee heard about a number of ways that oil and gas producers are planning to cope with shortages of workforce talent. Many of the larger integrated companies recognize the problem and have sought workers from the international markets. Education of the future workforce has been a high priority for supplying replacements; however, the workers being trained are often of foreign origins. Presentations by many educational institutions indicated a surge in U.S. enrollments by foreign students in the geosciences and engineering fields, where they can compose as much as half of the overall graduate populations in the major educational institutions. This trend is not expected to change anytime soon.

The committee's experience is that, to meet the demand now; however, companies also are filling U.S.-based positions with foreign nationals via the H-1B visa work program.

[9] http://www.slb.com/news/inside_news/2010/2010_0312_make_award.aspx.

However, hiring foreign workers through this process has its own set of problems. It is not only expensive and time-consuming for companies to apply, but they also are constrained by mandated ceilings imposed by the government. H-1B visas are typically for professional jobs that require a minimum of a bachelor's degree in a specific academic field.

The committee is also aware that another approach used by some companies to meet their demand for workers is through the acquisition of other companies' assets and the retention of all of their employees. Often as much time and effort goes into evaluating the age and expertise of the talent of the company being acquired as goes into evaluating the assets themselves.

A practice used by many companies is to address the problem by retaining their aging workers through incentive programs that keep experienced, active employees well beyond the typical retirement age. Small and mid-size companies frequently have many geoscientists and engineers that are in their 70s and 80s.

These approaches are only temporary stopgaps. Inevitably, to adequately address the coming workforce shortage, the United States will need to train its new workforce now.

The New Workforce

One of the primary ways to address the workforce talent needs will be to attract a younger generation of workers. As the U.S. demographics continue to change, the population will have an increasing percentage of people, who typically have not been attracted to the earth and engineering sciences. Ethnic minorities and women are expected to make up a large portion of the population. In addition, as companies look for more global resources, they will continue to identify and attract non-U.S. talent to satisfy their workforce needs. There is an opportunity for government and industry to recruit these groups, and investments in organizations, institutions, and faculty that have educational programs focused on young students, ethnic minorities, and women are required. Successful technical programs such as GeoFORCE, which focuses on Hispanic Americans, and collaborative efforts by the Cooperative Development Energy Program, which focuses on African Americans, are just two examples of how the organic growth methods have been successful. These and other example programs are described below. They have been driven primarily by industry with some government support, but they have long lead times for worker development that begins as early as grade 7 and requires 10-12 years of education and training, in what is referred to as the "energy pipeline."

In 2007, the National Petroleum Council released a study report on the future of oil and gas to 2030 (Raymond et al., 2007). The oil and gas workforce was a component of the study. Also released were certain topic papers from the study. Topic Paper #23 (Andersen et al., 2007) specifically addressed workforce issues, and its conclusions are still valid today.

The study concluded that attracting as many young people as possible to technical and engineering careers was necessary, and much remains to be done, especially in recruiting women. Industry, state and federal governments, and academia could work together to create programs to attract high school seniors to study technical disciplines. Increasing funding from industry and the federal government for academic research is also necessary for attracting students and maintaining U.S. leadership in technology development. Additional professionals also are needed to invent and use the technologies that will enable oil and gas operations in challenging environments, and to manage the resulting resources (Andersen et al., 2007).

The study had further conclusions. The industry's public image makes it difficult to attract graduates of other scientific and engineering disciplines. One company's hiring of a mid-career worker from another company is expensive and it may help the hiring company, but it hurts the other company. Workforce data are lacking. Except for petroleum engineers and geologists, engineering, procurement, and construction contractors are frequently competing with their oil and gas company clients for many entry- and mid-level workers. In 2005, a period of craft labor scarcity began in the United States, in which aggregate demand exceeds supply for many skilled crafts, and the trend will continue (Andersen et al., 2007).

Solutions—Programs to Emulate

The committee learned of a number of ongoing efforts by a variety of educational institutions that have established excellent pathways to address the workforce issues. These successful programs are due recognition, and great benefits could be realized by emulating them. These programs are: the Petroleum Engineering Technology Program at Houston Community College–Northeast Energy Institute, the Cooperative Development Energy Program at Fort Valley State University, GeoFORCE Texas at the University of Texas, Penn State AfricaArray; and the Greater Houston Partnership Energy Collaborative. They are described in Boxes 2.1-2.5.

BOX 2.1
Program 1: The Petroleum Engineering Technology Program at Houston Community College–-Northeast Energy Institute

The Petroleum Engineering Technology Program (HCC, 2012) is designed to prepare people to work as petroleum engineering technicians in the oil and gas and related industries. Students complete an intense core curriculum that includes two field experience courses developed in partnership with industry organizations, including BP, Shell, Chevron/Texaco, ExxonMobil, Conoco, and Halliburton.

Program graduates take positions in the following areas: data entry and evaluation, reservoir process design,; well operations, plant engineering, oil and natural gas exploration and production, environmental control, geological surveys, engineering sales, research and development,; and manufacturing. Industries that are common employers for these graduates include: power, petrochemical processing, gas processing, refineries, oil and gas mining, manufacturing, drilling and exploration services, government organizations, and other relevant industries and servicing companies. (Over its history, the Energy Institute’s student population has been quite diverse, with students from Houston’s many ethnic communities.)

Features of the program include the following:

- Society of Petroleum Engineers student chapter on campus;
- Training on a live rig (PetroDrill);
- On-campus interviews (Conoco, BP, Chevron);
- Dual credits with high schools (Milby High School Petroleum Academy);
- Funding to increase the female population in the oil and gas industry (Perkins);
- Student scholarships (BP, CHEVRON, SPE, Halliburton);
- Over 90 percent placement of graduates; and
- Well-known program faculty.

BOX 2.2
Program 2: The Cooperative Development Energy Program at Fort Valley State University

The Cooperative Development Energy Program (CDEP) created at Fort Valley State University (FVSU, part of the University System of Georgia) is highly successful in finding and attracting minority students to the earth and engineering sciences (FVSU, 2012). The CDEP began in 1983 and it recruits students from all 50 states. The CDEP has partnered with more than 60 companies and U.S. government agencies, including the Department of Energy, the Environmental Protection Agency, and the U.S. Geological Survey. Collaborating universities include: Penn State University; University of Oklahoma; University of Nevada, Las Vegas; University of Texas; and University of Arkansas. The CDEP has graduated more minority earth and engineering scientists than any program of its kind in the country, having graduated 71 engineers, 25 geoscientists, and 4 health physicists since 1997. The program identifies high-potential students in the 7th grade and places them in an educational pipeline of mentorship and summer internships. The students' 3-year experience at FVSU culminates in their moving to a major institution. Known as the 3+2 development program, it permits students to attend FVSU for the first 3 years and major in biology, mathematics, or chemistry and then to transfer to one of the partnering universities for the 4th and 5th years to earn a second degree in engineering, geology, geophysics, or health physics. The CDEP is the predecessor of the highly acclaimed GeoFORCE program at the University of Texas

BOX 2.3
Program 3: GeoFORCE Program

GeoFORCE Texas (UT, 2011), which began in 2005, is a highly acclaimed earth and engineering science program, patterned from the Forth Valley program. Designed by the University of Texas with an Hispanic student focus, the program has been very successful in identifying students in Texas. GeoFORCE Texas is an industry–education partnership that has successfully implemented a cohort model targeted at disadvantaged youth in Texas. The comprehensive program stresses academic achievement, retention, and transfer, while learning about geosciences. Measures of those who complete the program demonstrate the benefits of this effort compared with those of their peers in their high schools. Program benefits include highly increased high school graduations and almost double the college readiness, college matriculation, and high college persistence, compared with peers (Figure 2.10). The program has relationships with various high schools across Texas, where STEM programs are being instituted for students at a young age. The high school graduation rate for GeoFORCE Texas is 100 percent and its college matriculation rate is over 95 percent. It currently has 268 students enrolled in more than 50 colleges and universities across Texas and the United States.

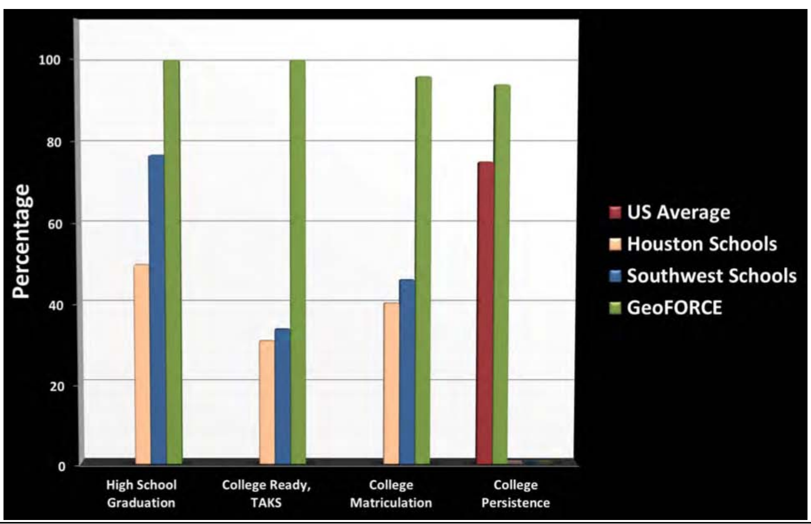


FIGURE 2.10 Comparison of achievements of GeoFORCE students with other educational indicators. SOURCE: Ratcliff and Snow (2011).

The program was expanded in the fall of 2011 to Alaska through the cooperation of the University of Texas and the University of Alaska Fairbanks. The Texas program was adjusted to account for differences in culture and environment, and then replicated in Alaska as GeoFORCE Alaska (UAF, 2012). The first cohort was 40 rising 9th graders during the summer of 2012. The program will achieve its capacity of 160 students in grades 9 through 12 by the summer of 2015. Corporate contributors to the GeoFORCE Alaska program will qualify for the Alaska Higher Education Tax Credit.

BOX 2.4
Program 4: Penn State AfricaArray

AfricaArray is a multifaceted initiative focused on developing a pool of diverse and talented undergraduate and graduate students for the geoscience workforce in the United States and Africa through linked research and training programs (Pennsylvania State University, 2012). In the U.S. program, the Department of Geosciences at Penn State University is collaborating with minority-serving institutions (California State University at Northridge and Bakersfield, Colorado State University at Pueblo, Fort Valley State University, North Carolina A&T State University, and University of Texas at El Paso) to create a pipeline of underrepresented minority students for the domestic workforce. The program's goal is to graduate up to 25 students with bachelor's degrees in STEM fields per year by 2014, preparing them to compete for and matriculate into geoscience graduate programs and industry positions in the United States. Figure 2.11 shows U.S. students working with international students on a geophysical project in South Africa.

Figure 2.11 U.S. students working with other international students on a geophysical project in South Africa. SOURCE: Pennsylvania State University (2012).

In Africa, AfricaArray is building a scientific workforce for the natural resource sector through degree and technical training programs at African universities and affiliated government institutions. These programs engage students and technicians in hands-on training, quality research, and international collaboration. The U.S. and African programs are connected in several ways. Geoscience courses at U.S. and African universities are taken together by U.S. and African students. Students and faculty collaborate on running an environmental observing network that includes 46 stations in 18 African countries that record weather, GPS, and seismic data. Those data then are used by many students and faculty working collaboratively on research projects. In the United States since 2005, AfricaArray has supported more than 50 undergraduate students from minority-servicing institutions, as well as many graduate students that have completed or are working toward M.S. (10 students) and Ph.D. (6 students) degrees. The program is supported by a public–private partnership that includes government agencies, academic institutions, and corporations (A. Nyblade, personal communication, 2012; Pennsylvania State University, 2012).

BOX 2.5
Program 5: The Greater Houston Partnership Energy Collaborative

The focus of the Greater Houston Partnership's Energy Collaborative (Houston's Energy Future, 2011; Schott, 2011) is to attract a workforce for the many greater-Houston-area energy companies. The collaborative focus is on students in K-16 to provide the talent pool with appropriate skills to fill key energy sector employment opportunities. STEM education is promoted, as well as the development of minority students. The Energy Collaborative creates alliances among its members, who represent industry, academia, and the public sector, in order to address target industry clusters, including workforce development. The Energy Collaborative Workforce Committee works to identify and support initiatives that promote awareness of the importance of STEM education, striving to strengthen the relationship between industry and academia and address the shortage of new technical workers in the energy industry. The Committee's core values are: it is industry led; it is inclusive and collaborative; it supports best practices that are replicable and scalable; it capitalizes on networking opportunities; and it focuses on enhancing the K-16 talent pipeline. The Greater Houston Partnership Energy Collaborative is a comprehensive workforce strategy. The educational challenge is illustrated in Figure 2.12.

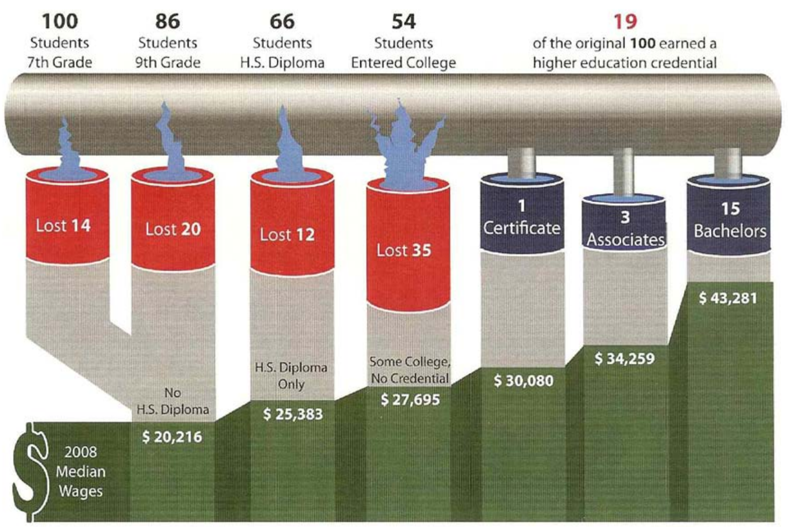


Figure 2.12 The Gulf Coast P-16 education pipeline and 2008 median wages. SOURCE: Schott (2011). Used with permission from the All Kinds Alliance with data from the Texas Higher Education Coordinating Board.

Innovation

Innovations in horizontal drilling and hydraulic fracturing technologies are making access to large shale reservoirs of oil and gas possible, holding great promise for future domestic supplies and a robust and growing oil and gas workforce, provided the industry can overcome environmental and socioeconomic concerns related to the extraction technologies. Successful resolution of these concerns, advancements in technologies to be used in challenging environments, such as the arctic and in ultra-deep water, and continued advancements in technologies that would increase the efficiency of oil and gas extraction and production would provide a direct stimulus to workforce growth at all levels.

A Potential Government–Industry Collaboration

As described in Chapter 5, the federal government plays a key role in the energy and mining sectors, but it has challenges in retaining and recruiting needed employees. There is a collaborative approach that could be of potential benefit to the government and the oil and gas industry. With health, safety, and environment and an understanding of new operational regulations playing an increasing role in energy, a public service program to permit workers to rotate in and out of critical government agencies could be a short-term remedy for attaining needed employees and a way of facilitating cross training. Such a program also could promote the safety culture concept that has government moving from checklist systems to more integrated, risked-based safety management systems, where cultural shifts in safety play a key role in making the workplace safer. Many excellent programs are already under way at energy companies (like ExxonMobil, Shell, and StatOil) that are implementing new federal and state safety and environmental rules. As envisioned, the program would focus on employees with 5-7 years of industry experience, who would do a 2- to 3-year (or more) rotation in government and then return to industry. Also, consideration could be given to older industry and government workers, who wish to be a part of the institutional memory transfer process.

A similar kind of program could be implemented with state governments. Several excellent examples already exist, in which industry personnel rotate in and out of critical positions that are sponsored by a state. Examples include the Bureau of Economic Geology at the University of Texas at Austin,[10] State geological surveys (where there is a relationship with a state university), and institutions such as the University of Utah's Energy and Geoscience Institute.[11]

Conclusions and Recommendations

Conclusions

2.1 The exploration and production technical workforce in the oil and natural gas industry is estimated to be about 494,200 workers.

2.2 Demand for domestic workers in the oil and gas industry will remain strong for the foreseeable future. This demand is being driven primarily by recent technological advances in drilling and completion in unconventional shale reservoirs, advancements in oil sands development, and strong commodity prices.

2.3 Opportunities for employment across the oil and gas industry for skilled technical and professional workers are bright and will continue beyond 2030.

2.4 Demand for, and production of, oil and gas on a worldwide basis are expected to continue to increase. High commodity prices and domestic production increases are predicted (at least through 2030 for oil and 2035 for gas). The United States will increasingly compete for workforce talent that is being drawn to high-paying jobs in a well-integrated international market.

2.5 Similar to U.S. national trends, baby boomers that currently make up a third of the existing oil and gas workforce will retire within the decade. There are concerns within the business, academic, and technical communities about the ability to adequately replace the retiring workforce.

2.6 There is an urgent need to attract young workers into the energy workforce.

[10] http://www.beg.utexas.edu/.
[11] http://egi.utah.edu/./

2.7 There is an urgent need for enhancing the education "pipeline" by attracting nontraditional students and training, retaining, and rewarding more faculty to ensure that the demand for U.S. workers will be met.

2.8 Increasing funding from industry and the federal government for academic research in the geosciences and petroleum engineering is necessary for attracting students and faculty, and for advancing innovation.

Recommendations

The following recommendations should be initiated as quickly as possible and some will take longer than others to become fully operational. The recommendations are ordered and labeled in terms of when they would be expected to be operational. All of the recommended actions are expected to continue for the long term.

2.1 The committee recommends that government and industry develop a closer working relationship through collaborative programs that focuses on cross training employees in the technical and regulatory aspects of health, safety, and environment. (Short Term)

2.2 In pursuing Shared Recommendation 4, it would be important to consider, encourage, and emulate successful programs, such as the University of Texas GeoFORCE, the Petroleum Engineering Technology Program at Houston Community College's Energy Institute, Fort Valley State's CEDP, Penn State University's AfricaArray, and the Greater Houston Partnership Energy Collaborative. (Medium Term)

2.3 In pursuing Shared Recommendation 5, these same example programs should be examined and considered for models and lessons that might successfully be applied in this context. (Medium Term)

In addition to these recommendations, the Shared Recommendations for Chapter 2 (at the end of the chapter) also apply for the oil and gas industry.

NUCLEAR ENERGY

Introduction

The nuclear power industry is an important component of the energy portfolio of the United States. It currently provides 20 percent of the electricity used in the United States and it is expected to remain a major and integral part of the national energy system for the foreseeable future. The industry is composed of four interrelated sectors—nuclear power plants, nuclear fuel facilities, nuclear waste facilities, and nuclear decommissioning activities (MIT, 2010). Each of these has its own initiation or construction phase, operating phase, and termination phase, with special workforce training, skills certifications, and licensing requirements. The U.S. nuclear power industry and its workforce are discussed in this section of the report.

Figure 2.13 shows a nuclear power plant with new construction under way. Figure 2.14 illustrates the U.S. nuclear fuel cycle, from the mining of uranium ore through processing to make usable fuel for the nuclear power plant through subsequent storage of spent fuel.

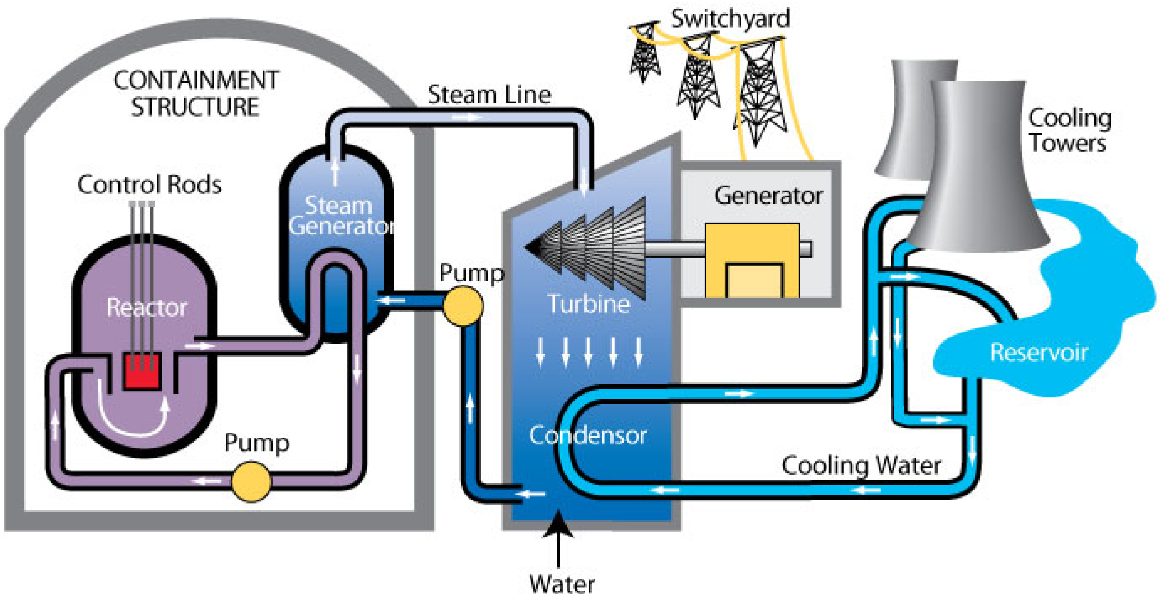
FIGURE 2.13 New construction at an existing two-unit nuclear power plant. SOURCE: © Southern Company, http://www.southerncompany.com/nuclearenergy/photos.aspx.[1]

[1] http://www.southerncompany.com/nuclearenergy/photos.aspx

FIGURE 2.14 U.S. nuclear fuel cycle. SOURCE: IAEA (2012a).

There are only two types of large nuclear power plant designs currently in use in the United States—pressurized water reactors and boiling water reactors. Figure 2.15 illustrates and describes the design and operation of a pressurized water reactor system, and Figure 2.16 illustrates and describes a boiling water reactor system.

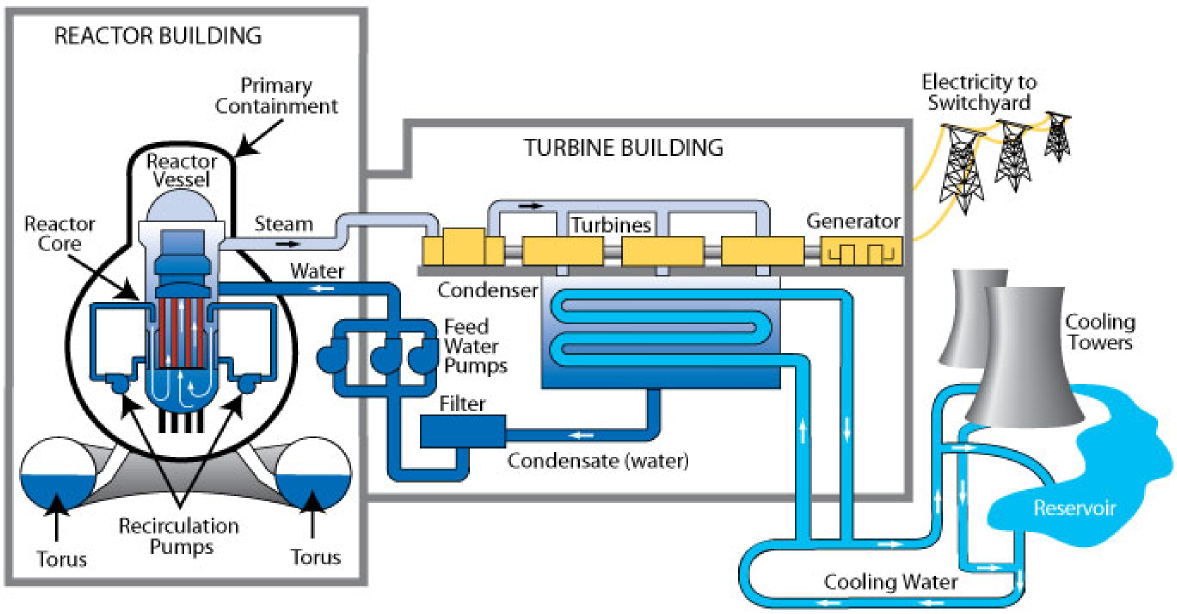
In a typical commercial pressurized light-water reactor the reactor core generates heat, pressurized-water in the primary coolant loop carries the heat to the steam generator, inside the steam generator heat from the primary coolant loop vaporizes the water in a secondary loop producing steam, the steam line directs the steam to the main turbine causing it to turn the turbine generator, which produces electricity. The unused steam is exhausted to the condenser where it is condensed into water. The resulting water is pumped out of the condenser with a series of pumps, reheated, and pumped back to the steam generator. The reactors core contains fuel assemblies which are cooled by water, which is force-circulated by electrically powered pumps. Emergency cooling water is supplied by other pumps, which can be powered by onsite diesel generators. Other safety systems, such as the containment cooling system, also need power.



Sources: Tennessee Valley Authority

FIGURE 2.15 A pressurized water reactor system. SOURCE: EIA (2012g).

In a typical commercial boiling water reactor the reactor core creates heat, a steam-water mixture is produced when very pure water (reactor coolant) moves upward through the core absorbing heat, the steam-water mixture leaves the top of the core and enters the two stages of moisture separation where water droplets are removed before the steam is allowed to enter the steam line, the steam line directs the steam to the main turbine causing it to turn the turbine generator, which produces electricity. The unused steam is exhausted to the condenser where it is condensed into water. The resulting water is pumped out of the condenser with a series of pumps, reheated, and pumped back to the reactor vessel. The reactor's core contains fuel assemblies which are cooled by water, which is force-circulated by electrically powered pumps. Emergency cooling water is supplied by other pumps which can be powered by onsite diesel generators. Other safety systems, such as the containment cooling system, also need electric power.



Sources: Tennessee Valley Authority

FIGURE 2.16 A boiling water reactor system. SOURCE: EIA (2012f).

Industry Overview and Profile

Value to the U.S. Economy

Nuclear power plants provide a large part of the electricity generated in the United States. In 2009, nuclear power plants provided 799 billion kilowatt-hours (kWh) of electrical energy—20 percent of the total electrical energy generated domestically (EIA, 2011c). U.S. nuclear power capacity in 2009 was 101.0 gigawatts (GW). In 2010, the status of all U.S. nuclear units was 104 operable units (with electricity net generation of 807.0 billion kWh—still 20 percent of the U.S. total) and 28 permanently shutdown units (EIA, 2011c).

Structure

The nuclear power industry has four sectors: nuclear power plants, nuclear fuel facilities, nuclear waste facilities, and nuclear decommissioning activities. Each sector has its own workforce requirements and opportunities, as discussed below.

Size and Employment

The Nuclear Energy Institute (NEI) estimates that there are 120,000 workers employed in the total U.S. commercial nuclear industry. This workforce includes direct employees of nuclear power plants, as well as contractors (Berrigan, 2010). Figure 2.17 shows the nuclear industry employment distribution by age and the total employment over time, indicating that the total employment for 2009 (excluding contractors) was 57,200.

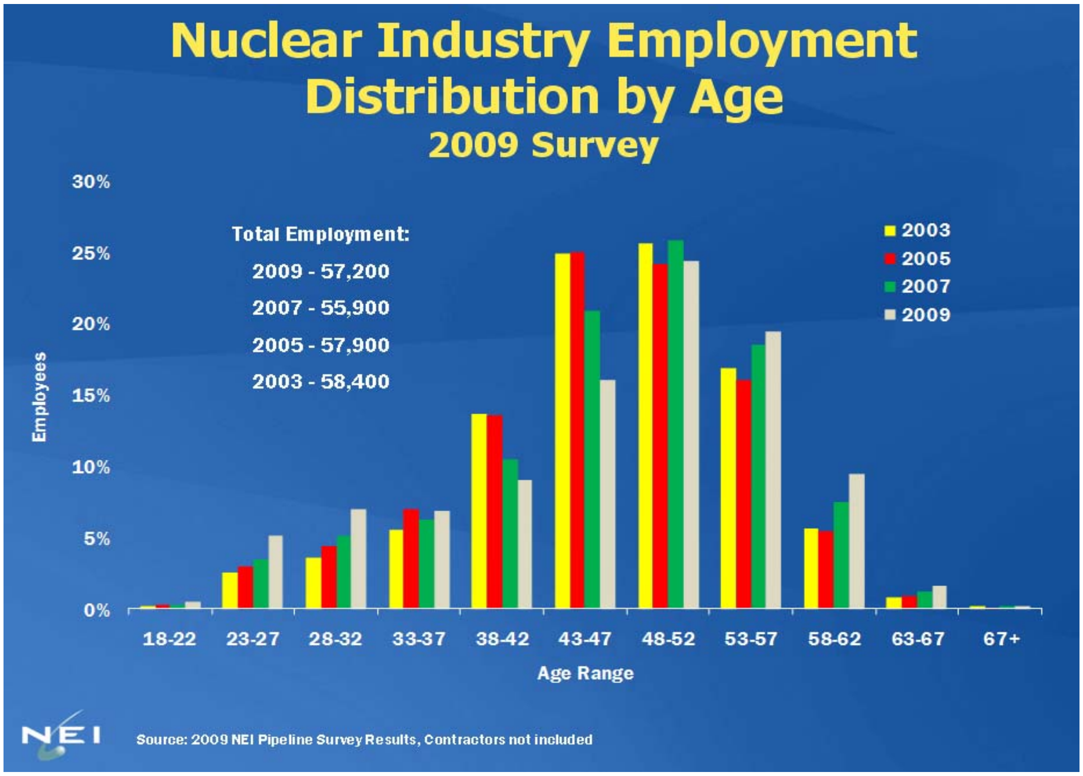


FIGURE 2.17 Nuclear industry employment distributions by age for 2003, 2005, 2007, and 2009. SOURCE: Berrigan and McAndrews-Benavides (2011).

Appendix B contains a detailed description of data for the nuclear energy workforce from federal data sources (BLS). Nuclear electric power generation is the only nuclear-energy-related activity that is associated with a unique NAICS code. Table B.15 in Appendix B gives the 2010 average annual employment by sector (private and federal, state, and local governments) for this industry, and Table B.16 gives the average annual employment for 2005-2010. According to the BLS data (BLS, 2011d), employment in the nuclear electric power generation industry across all sectors is 56,778, with about 93 percent in the private sector—the remaining workforce is in the federal government (2.4 percent) and local government (5 percent). Employment increased for 2005-2009, but fell below 2005 levels in 2010 because of declines in local government employment (see Tables B.18, B.19, and B.20 in Appendix B). If government employees are not included, the nuclear industry employment (excluding contractors) data from the NEI and the BLS are in good agreement.

BLS employment projections, demographic information, and employment information by occupation are not available for the nuclear electric power generation industry.

Nuclear Power Market Trends

From 1957 through 1990, the number of nuclear generating units and their electricity generation capacity grew rapidly, reaching a peak of 112 units in 1990, representing about 20 percent of the electricity generated in the United States (see Figure 2.18). Subsequently, the number of units declined and leveled off in the late 1990s to the current level of 104. Nuclear power's share of the U.S. total has hovered around 20 percent over this latter period, as indicated in Figure 2.19, which shows the nuclear share of total electricity net generation for 1957-2010, reflecting the trend in generating units in Figure 2.18.

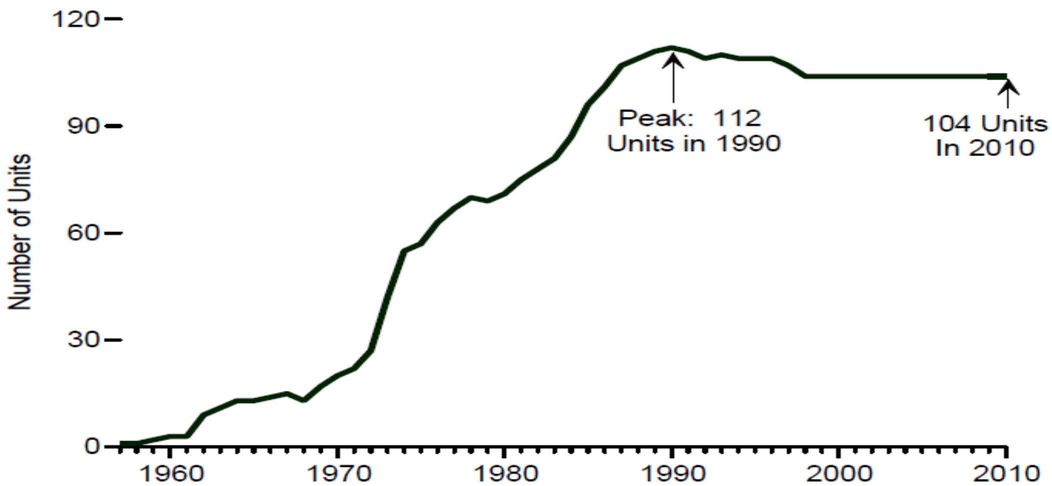


FIGURE 2.18 Operable nuclear generating units, 1957-2010. NOTE: Units holding full-power operating licenses, or equivalent permission to operate, at the end of the year. SOURCE: EIA (2011c, Fig. 9.1, p. 282).

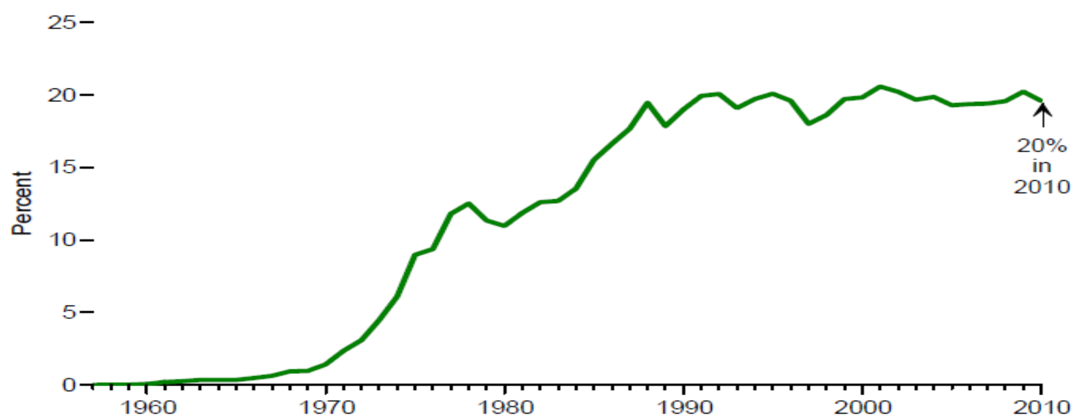


FIGURE 2.19 Nuclear share of total electricity net generation, 1957-2010. SOURCE: EIA (2011c, Fig. 9.2, p. 284).

The U.S. nuclear power sector is in a transformational state and significant new developments are taking place, which bring significant uncertainty to efforts to predict the future of nuclear power plant construction. For more than 30 years, no new nuclear power plants have been constructed. However, the U.S. Nuclear Regulatory Commission (USNRC) recently approved licenses permitting the construction of two new nuclear reactors at the Vogtle nuclear power plant complex in Georgia, the first license approvals since 1978; —one reactor is expected to go into operation in 2016 and the second in 2017 (Hargreaves, 2012). The USNRC subsequently also approved a license to build and operate two new nuclear reactors at the Virgil C. Summer plant in South Carolina (Downey, 2012). Nuclear power plants are all subject to federal safety regulations and, to varying degrees, state utility commission economic regulation.

The U.S. nuclear power industry has learned many lessons over the years and now has achieved very high performance reliability, and until recently, fairly high public acceptance that now may be waning due to the recent nuclear power plant accident at the Fukushima site in Japan (Cooper and Sussman, 2011; Pappas, 2012). Operating plants are producing good financial returns for their owners. Because they release negligible greenhouse gases during normal operation, electric utilities have again become interested in building new nuclear power plants, and in maintaining nuclear power as an important contributor among their energy sources.

Impediments to the construction of a large number of new plants in the United States are the high capital requirements of a large plant, and the current lack of a means of removing and permanently disposing of or storing spent nuclear fuel from the plants. However, there are a number of activities under way to safely store spent fuel off of plant sites that can meet an interim (decades) storage requirement (Nesbit, 2012). Still unknown is the full impact of the disaster in Japan, arising from the unanticipated, combined destructive forces of a huge earthquake and tsunami on four nuclear power plants at the Fukushima site, giving rise to a severe nuclear power plant accident. The worldwide response has been mixed. Several countries, including Japan, Germany, Switzerland, and Italy, have declared their intentions to phase out or to not build any new nuclear plants. The U.S. response has been more measured, with an emphasis on lessons learned, but not an outright rejection of nuclear power. Economic considerations continue to be the greatest obstacle to new nuclear plant commitments, provided that the USNRC develops an acceptable response to the District of Columbia Court of Appeals ruling that found the USNRC's Waste Confidence Decision and Temporary Storage Rule to be unacceptable (NRDC, 2012). This might take several years.

The future for construction of new large (1,000-megawatt (MW) electric) nuclear power plants in the United States has become much less favorable because of the rapid fall in natural gas prices since 2009, along with the increasing glut of produced gas arising from newly developed domestic gas-bearing shale formations and oil well drilling spurred by high oil prices. Also, the historically high costs of large nuclear power plants have not improved in the few new plants that have been under construction in Finland and France (Davis, 2011).

Therefore, the anticipation of a new near-term nuclear power renaissance has dimmed somewhat. However, a rising interest in small, modular nuclear reactors has been developing (Kelly, 2011). Furthermore, most existing U.S. nuclear plants have obtained or are in the process of obtaining license amendments to operate for an additional 20 years beyond their current license of 40 years, and some may operate for even longer times.

Whatever the future holds for new nuclear power plants, there will be many job opportunities in other sectors of the nuclear power industry that may not be directly affected by the progress of new nuclear power plant construction.

Market Projections

The EIA (Reference case) has projected the nuclear power net summer capacity and total electricity generation through 2035 (see Table 2.4). In the Reference case, nuclear power capacity is projected to expand by 15.8 GW (8.5 GW for new units and 7.3 GW for power uprates at operating plants) from 2010 to 2035. This expansion includes the recently approved Vogtle and Summer reactors. Generation from nuclear plants is projected to increase by 10 percent over this period; however, the nuclear share of total generation is expected to decline from 20 percent in 2010 to 18 percent in 2035, with increased shares for natural gas and renewable sources. The Reference case projects that 6.1 GW of capacity will be retired by 2035, with most coming after 2030. As Table 2.4 shows, capacity decreases somewhat after peaking in 2025, due mainly to plant retirements (EIA, 2012a).

TABLE 2.4 Nuclear Power Electricity Generating Capacity and Generation (EIA Reference Case).

	2009	2010	2015	2020	2025	2030	2035	Annual Growth 2010-2035 (%)
Net summer capacity[a] (GW)								
Electric power only[b]								
Nuclear power[c]	101.1	101.2	103.6	111.2	114.7	114.3	110.9	0.4
Cumulative								
Nuclear	0.0	0.0	1.1	6.8	6.8	6.8	6.8	–
Cumulative unplanned additions[d]								
Nuclear power	0.0	0.0	0.0	0.0	0.0	0.1	1.8	–
Cumulative retirements[e]								
Nuclear power	0.0	0.0	0.0	0.6	0.6	1.1	6.1	–
Total electricity generation (billion kWh)								
Nuclear power	799	807	830	887	917	914	887	0.4

[a] Net summer capacity is the steady hourly output that generating equipment is expected to supply to system load (exclusive of auxiliary power), as demonstrated by tests during summer peak demand.
[b] Includes plants that only produce electricity. Includes capacity increases (uprates) at existing units.
[c] Nuclear capacity includes 7.3 GW of uprates through 2035.
[d] Cumulative additions after December 31, 2010.
[e] Cumulative retirements after December 31, 2010.
SOURCE: EIA (2012a, Table A8, pp. 148-149 and Table A9, pp. 150-151).

As described below, the NEI projects the demands posed by assuming that the current nuclear share of the U.S. electricity supply will continue. This scenario is more aggressive than the EIA's Reference case assumptions, requiring construction of 20-25 new nuclear units by 2030 (Berrigan, 2010).

Employment Status and Opportunities in the Nuclear Power Industry

Operating Nuclear Power Plants

On average, nuclear plants directly employ 400 to 700 people, and a stand-alone single unit may directly employ as many as 1,000 people. In addition to these employees, there are many vendors and contractors called upon to support operations, which may add up to an additional 1,000 workers or more with various skills and competencies. The NEI estimates that there are 120,000 workers employed in the total U.S. commercial nuclear industry. NEI surveys indicate that 38 percent of nuclear utility employees (or 21,600 employees) will be eligible to retire within the 5-year period of 2009-2014, and over the same 5-year period, there may be a need to replace an additional 10 percent (or 6,000 workers) for other reasons (Berrigan, 2010). The important issue of nuclear workforce aging is described in detail below.

New Nuclear Power Plants

A rejuvenation of nuclear energy would produce an increasing demand for skilled labor at all levels. An analysis by the National Commission on Energy Policy indicates that development of a nuclear power plant requires 14,360 person-years per GW (1,000 MW) installed (NCEP, 2009). Such jobs include skilled crafts (e.g., welders, pipefitters, masons, sheet metal workers, carpenters, ironworkers, electricians, and heavy equipment operators), along with project managers, engineers, and construction supervisors (Berrigan, 2009).

If the current nuclear energy share of 20 percent of the U.S. electricity supply continues, construction of between 20 and 25 new nuclear units by 2030 would be necessary, requiring 287,200-359,000 person-years of labor. These plants also would need 8,000-17,500 permanent full-time workers to operate them, along with additional supplemental labor to handle maintenance and outages (Berrigan, 2010).

Smaller (one-tenth the capacity) alternative modular designs for nuclear power plants (far less costly than the standard 1,000-MW baseload designs) are now attracting considerable attention, and some designs offer not only much lower capital costs but also less frequent requirements for spent-fuel removal.

Construction cost estimates for new large plants, however, are very high and uncertain. Cost estimates for small modular reactors (SMRs), while considerably lower, are even more uncertain. One study found that assuming a 100-MW SMR costing $500 million to manufacture and install would create nearly 7,000 jobs and in operation would provide 375 jobs. However, first production would not occur until 2015 and would peak in 2030. Thirty to nearly 40 SMRs per year might be produced. Already three large utilities have signed an agreement to acquire the necessary approvals for commercial use of one particular design in the United States (EPI, 2010; World Nuclear Association, 2012b)

Apart from the recently approved licenses, 10 applications are under consideration by the USNRC for a total of 16 large power reactors (USNRC, 2011a). The likelihood that all of these will actually be built in the foreseeable future is generally considered to be small. Only a single, 2-unit site has construction occurring.

Decommissioning

More than 40 percent of existing U.S. nuclear power plant licenses will expire by 2015 (USNRC, 2012). While many power plants will renew their 40-year operating licenses for an additional 20 years, a small number will be closed and decommissioned at the end of their licensed period.

Under the present system, every nuclear power plant licensed by the USNRC is authorized to collect a fee from the electricity customers to cover the cost of decommissioning. The USNRC estimates that decommissioning can cost $350-400 million per plant, but there have been cases well in excess of that amount. As a result, many plants do not have sufficient funds set aside and are delaying final closure, opting for “SAFESTOR” (a system to monitor and maintain the shutdown plant in a safe manner). Some states have funding, but not the workforce. To date, there have been 21 commercial reactor plants decommissioned or placed in SAFESTOR, and all but 7 still have spent fuel on site (USNRC, 2011b). There are 13 large plants in the decommissioning process as of April 2011; 10 of those will be in SAFESTOR, in line for future decommissioning. These then could provide $4 billion to $8 billion dollars in future work, requiring specially trained blue collar and administrative personnel. Moreover, in most cases, the spent fuel is still stored on site, and special facilities must be constructed to monitor and maintain these facilities safely. Note that this is a long-term, continuing, and growing business and the current workforce is aging and must be replaced, adding to the overall need for a workforce with varying levels of nuclear training.

Enrichment Facilities

Several new large facilities for the enrichment of uranium for fresh nuclear fuel are under construction or under serious consideration. These facilities are intended to meet domestic nuclear power plant requirements and to supply possible markets among the more than 430 nuclear power plants in operation worldwide with uranium and enriched uranium fuel (World Nuclear Association, 2012a).

This will have a positive impact on the mining industry, but most natural uranium is mined outside of the United States. Advanced facilities needed to enrich the uranium to fuel grade are in various stages of being built in the United States. They represent significant capital investments and huge workforce requirements. Although the workers may not necessarily be nuclear specialists, they will be high-end technical workers, requiring additional training. These projects will be done with private funding, some DOE loan guarantees, and in some cases, overseas money. Examples of new facilities that are under contract or in various stages of development are the following.

URENCO USA (formerly the National Enrichment Facility) is a $1.5 billion centrifuge enrichment facility that began operation in June 2010 in New Mexico, and construction continues. Phase 1 capacity will be reached in 2012, and at eventual full capacity, the facility is expected to produce enough enriched uranium for fuel to provide about 10 percent of the nation’s electricity needs (URENCO, 2012; World Nuclear Association, 2012c).

The French nuclear giant AREVA has announced the construction of an advanced enrichment plant to be built in Idaho. The Eagle Rock Uranium Enrichment Plant also will use centrifuge technology, and it has received a DOE loan guarantee of $2 billion. However, AREVA has announced a suspension of work on the project until 2013 or 2014 (Mufson, 2012; World Nuclear Association, 2012c).

General Electric Energy has teamed with Hitachi of Japan (GE-Hitachi, GEH) in a program to develop an entirely different enrichment concept, using laser-beam technology to enrich uranium to fuel quality. This project will proceed in phases, building sections at a time and testing each one to obtain the optimum performance. The Global Nuclear Fuel's (GNF's) Wilmington, North Carolina fuel fabrication facility has now completed the first phase of testing with technology validation continuing. GNF is a partnership of GE, Hitachi, and Toshiba (World Nuclear Association, 2012c).

The United States Enrichment Company (USEC) in Piketon, Ohio, is to provide enriched uranium for fabrication into fuel elements in U.S. reactors. In addition to building and support facilities, this plant will utilize 11,520 special high-technology 43-foot-tall centrifuges and a wide range of specialty support equipment. This large manufacturing and construction effort will require highly trained workers and special installation equipment. New financial problems have developed and the project has been put on hold; its future is now uncertain (Mufson, 2012; World Nuclear Association, 2012c).

These projects represent private or non-U.S. funding, roughly estimated to be on the order of $10 billion to $12 billion for construction and manufacturing alone. Much of the investment money will be provided by foreign sources to create American jobs. These projects represent a potentially substantial job market for skilled workers, and they are located in areas where unemployment is high. In addition to the jobs created in building each facility, new transportation, supply, security, and civil support jobs will be needed.

Storage and Disposal of Low-level Radioactive Waste

The means of disposing of spent commercial nuclear fuel under congressional statutes was to be at a site in Nevada, operated by DOE, but that is now seriously in doubt, and other possible alternatives are to be explored (BRC, 2012).

Storage and disposal of radioactive waste has focused mostly on high-level waste in the form of spent fuel. Such activity is to be carried out by the DOE but is funded by the nuclear utilities that collect from their ratepayers a percentage of nuclear generation rate costs and set the money aside to pay for waste disposal. There is a vast amount of low-level waste produced in the United States by operating commercial power plants, research facilities, hospitals, universities, and many industrial companies, which must be disposed of in some manner. Today the methods of choice are burial in landfills or storage in vaults. In many instances, valuable materials and equipment that become only slightly radioactive are summarily disposed of at considerable expense. There are a number of commercial disposal sites (notably in Texas and Utah) that receive low-level waste that have proven to be profitable ventures. Rather than setting aside land for low-level waste dumps and not recycling material and equipment that could be salvaged for future use, a new industry and new technology could offer the potential for finding ways to safely and effectively decontaminate materials that may have been exposed to radioactivity.

It is difficult to estimate how many new jobs will emerge, but based on the number of companies entering the field of waste handling, the number could be sizable. Also, much research is being done to develop new ways of transporting and storing wastes. Design and fabrication of shipping casks, remote handling tools, robotics and crawlers, shielding materials, and chemical decontamination systems is a growing business. These activities will require technicians and engineers with credentials similar to those in other nuclear power activities, but with additional training in radiation protection and chemical technology at the community-college level.

Supply Chain

Berrigan (2010) provides a comprehensive overview of the nuclear supply chain and the opportunities that it represents for U.S. companies. The following discussion draws from this source.

Construction of new nuclear power plants domestically and internationally has been absent for the past 30 years. As a result, the U.S. nuclear supply chain has diminished. With the potential for increasing interest in nuclear energy, there may be a potential opportunity to reenergize the U.S. nuclear manufacturing sector. This could be done with investment in state-of-the-art factories and processes, which would supply the special components necessary for nuclear applications.

Currently there are 62 nuclear power plants being built around the world (IAEA, 2012b), and there are 160 plants on order or planned and 329 projects proposed (World Nuclear Association, 2012d). In light of this level of activity, some U.S.-based suppliers have begun increasing their staff and capacity, and developing more manufacturing facilities. Also, the number of U.S. nuclear suppliers has increased substantially over the past few years. According to Berrigan (2010), "in excess of 15,000 new U.S. jobs have been created to date due to new nuclear plant activities" The potential demand for specialized goods and services creates substantial prospects for U.S. manufacturers, with the world market representing potential orders of "over $400 billion in equipment and services over the next 15 years," according to NEI estimates (Berrigan, 2010).

Information obtained by the NEI from companies managing three of the five leading U.S. nuclear projects indicated that they will purchase 60-80 percent of commodities and services from U.S. suppliers, and they already have purchased $2 billion of services and equipment from U.S. firms. They also have set labor and procurement goals of 75-90 percent of U.S. content, representing about $50 billion for the initial set of new nuclear plants (Berrigan, 2010).

Expansion of worldwide nuclear energy also has been of direct value to U.S. companies and workers. As of August 2010, U.S. companies had received export orders of more than $2.5 billion for services and equipment (Berrigan, 2010).

Employer Needs and Challenges

The Aging Workforce

NEI surveys indicate that 38 percent of nuclear utility employees (21,600 employees) will be eligible to retire in the 2009-2014 period, and 10 percent (6,000 workers) more may also require replacement for other reasons (Berrigan, 2010).

The aging of the nuclear workforce is evident in Figure 2.17. above, and highlighted in Figure 2.20. As Figure 2.20 indicates, the total potential workforce loss from retirement and other attrition could be as much as 48 percent of the total direct industry employment. Moreover, this is only a 5-year time horizon.

Other Workforce Challenges

Other workforce challenges faced by the U.S. nuclear industry are the basic education and skill levels of the youth that form the pool of potential future workers, the insufficient number of students entering engineering programs to adequately support the projected coming needs, the potential for an insufficient number of educators to meet the demand for properly prepared future workers, and the inability to fill nuclear workforce vacancies with foreign workers. Education and training are discussed in the following section.

In many of the energy sectors, it is possible to employ noncitizens when U.S. citizens are not available in sufficient numbers to meet industry demand. However, U.S. citizenship is required for most employment in the U.S. nuclear industry. This means that it is not possible to fill shortfalls in skilled U.S. workers with noncitizen workers. Therefore, it is crucial to educate and train U.S. workers in sufficient numbers to satisfy anticipated demand.

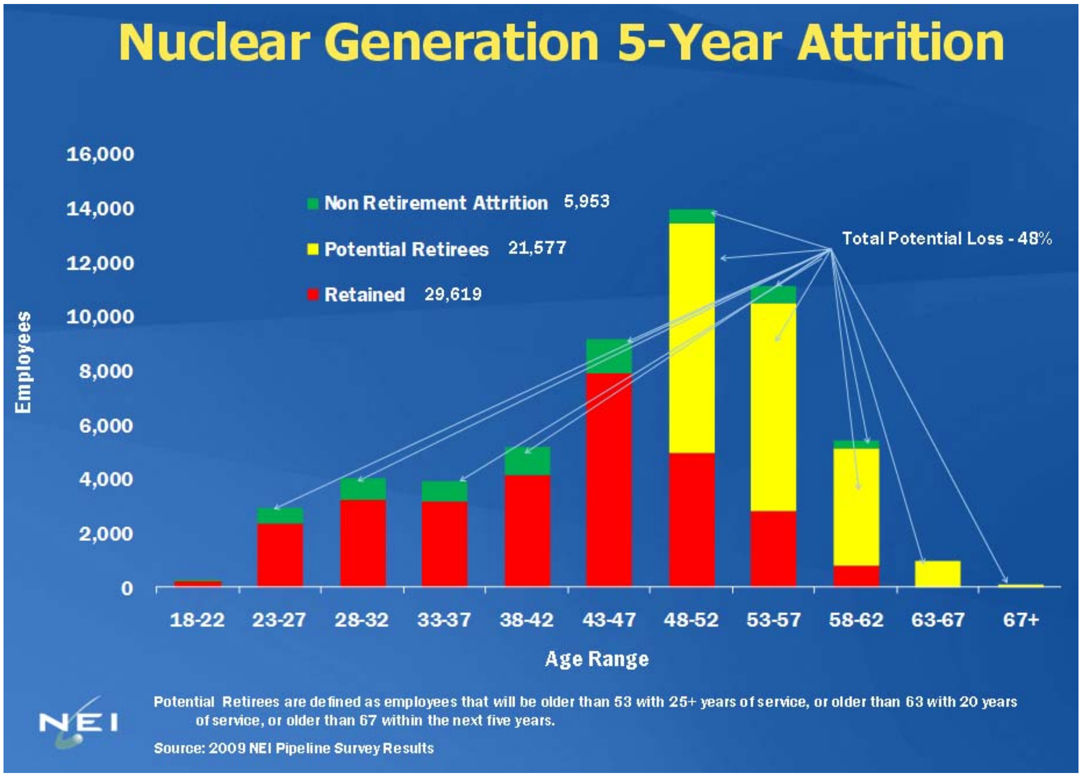


FIGURE 2.20 Nuclear generation 5-year attrition. NOTE: Potential retirees are defined as employees that will be older than 53 with 25+ years of service, or older than 63 with 20 years of service, or older than 67 within the next 5 years. SOURCE: Berrigan and McAndrews-Benavides (2011).

Education and Training

From technicians to degree program educators, job requirements in all sectors of the nuclear industry are highly demanding. For example, math is a very significant challenge for aspiring technicians.

Most blue-collar jobs in the nuclear industry tend to require a strong high school level background in the fundamentals of applied mathematics and applied science. These are areas of weakness in many U.S. high schools. According to a report of the National Energy Technician Education Summit (ATEEC, 2011), a system for correcting this problem is "collaboration among middle schools, high schools, and community colleges to improve students' science, technology, engineering and mathematics (STEM) skills."

The commercial nuclear industry is heavily involved with training new nuclear power workers. It is involved with 43 community colleges, more than 30 universities, 25 university research reactors, more than $90 million in federal grants, the National Academy for Nuclear Training (NANT), and 28 state energy consortia (Berrigan and McAndrews-Benavides, 2011).

The commercial nuclear power industry has created a program to systematically provide the higher education needed to prepare the next-generation nuclear workforce. This program has been developed to satisfy the workforce needs of the existing fleet of 104 operating reactors and also to be scalable to satisfy the workforce needs of new nuclear plants as they are built. The program has provided continuing support for university nuclear engineering programs and their infrastructure, and it also has centered on developing the Nuclear Uniform Curriculum Program (NUCP; Berrigan, 2010; Berrigan and McAndrews-Benavides, 2011). These same programs can serve to prepare workers for other aspects of the nuclear industry, such as decommissioning, uranium enrichment and fuel production, and storage and disposal of nuclear wastes.

Community Colleges

The NUCP is designed to be a systematic approach to education, using community colleges in key locations to offer a standard curriculum that is industry recognized and that is organized to meet the needs of the nuclear industry for new employees in key disciplines (Berrigan, 2010). Approximately 75 percent of the technical nuclear power plant staff with academic degrees have degrees from 2-year community college programs.

There are three components to the NUCP: (1) quantifying the industry needs and the supply of graduates from partner programs, (2) defining the curriculum, and (3) implementing the proper number of programs on a regional basis. The NUCP uses 43 community colleges across the United States. The courses they offer include radiation protection; operations; electrical, mechanical, and instrumentation and control maintenance; and chemistry. The NUCP leads to associate degrees; the program map is shown in Figure 2.21 (Berrigan, 2010; Berrigan and McAndrews-Benavides, 2011).

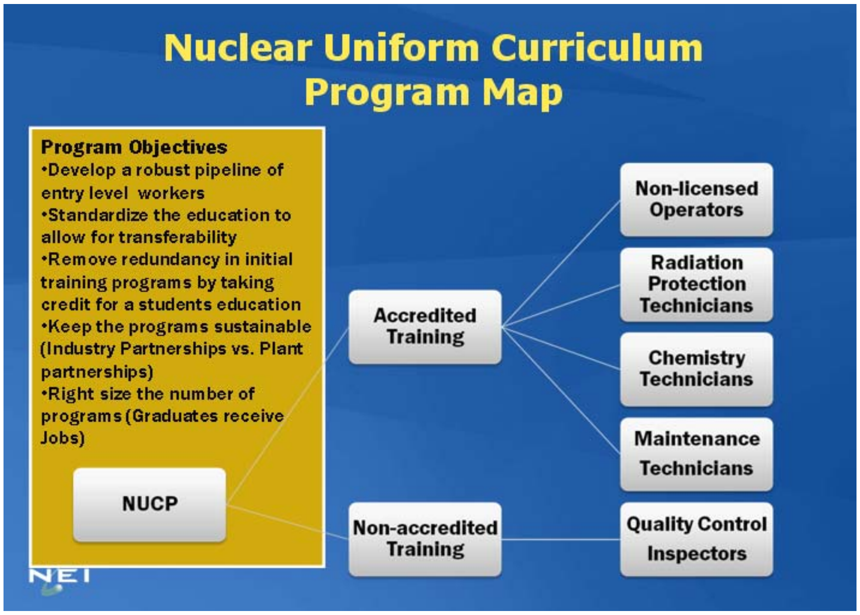


FIGURE 2.21 Nuclear Uniform Curriculum Program map. SOURCE: Berrigan and McAndrews-Benavides (2011).

The nuclear industry also works with the Center for Energy Workforce Development (CEWD) in order to leverage programs and sources across the utility sector, such as the 28 state energy workforce consortia (Berrigan, 2010; Berrigan and McAndrews-Benavides, 2011). The CEWD is a nonprofit consortium of electric natural gas and nuclear utilities and their associations, and it addresses the workforce needs of the energy generation, transmission, and distribution industry. This is a broader base than is addressed in this report, which focuses on the energy generation footprint. However, it is helpful to note the important approaches used by CEWD in their industry's workforce education and career pathways activities.

The CEWD and the Department of Labor have developed an Energy Competency Model for the energy generation, transmission, and distribution industry as a tool to provide a consistent definition of the competencies needed to perform work in the energy industry. (The NEI, a CEWD cofounder, worked with the other CEWD members on the model's development and it aligns with the NUCP.) It is designed to build from basic skills to more industry- and career-specific competencies (CEWD, 2010). Educational programs using this model will provide industry-accepted, stackable, transferable credentials, allowing the student to build to higher levels of professional performance and to be able to transfer with those skills to other jobs. The model is discussed further in Chapter 7 and is shown in Figure 7.5 of that chapter. The CEWD also has an entry-level Engineer Competency Model that has been vetted by the nuclear industry.

Someone with an interest in joining the entry-level nuclear workforce typically would take the CEWD curriculum in high school or as a preparatory class for their community-college NUCP program. They would complete their 2 years of nuclear-specific NUCP education and be hired by a nuclear utility, where they would finish their preparation with site-specific training prescribed by the guidelines of the Institute of Nuclear Power Operations (INPO, an industry organization for self-regulation; E. McAndrews-Benavides, NEI, personal communication, 2012).

The nuclear industry also has led the development of two new competency models for mid-career professionals (one for individual contributors and one for supervisors). They are applicable to all energy sectors and soon will be added to the CEWD Web site (E. McAndrews-Benavides, NEI, personal communication, 2012).

Universities

Engineering jobs in the nuclear power industry include civil/structural, electrical, materials, mechanical, nuclear, computer, instrumentation and control, fire protection, systems, and project management (NEI, 2012).[2] According to NEI survey data, the demand for engineers by degree for the commercial nuclear power industry is: 47 percent mechanical; 20 percent electrical; 10 percent nuclear; 4 percent civil; 3 percent chemical; 1 percent health physics and radiation, 12 percent other disciplines, and 3 percent uncertain. Also, additional nuclear engineers would be accepted if they would work in systems engineering, design engineering, and in the operations department. According to the NEI, the nuclear industry's educational needs include: stable nuclear engineering programs; mechanical, electrical, and civil engineers with both nuclear and power knowledge; stable federal grant opportunities for education programs; strong nuclear technology programs; and adoption of the CEWD pathways model by each state (Berrigan and McAndrews-Benavides, 2011).

NANT includes the training and educational activities of all U.S. nuclear companies that are members of the NANT and the INPO. The NANT Educational Assistance Program awards 125 scholarships annually to outstanding juniors and seniors in nuclear-related majors, and 20 fellowships to a group of institutions with graduate programs whose deans have submitted proposals.

Engineering and applied science jobs in the nuclear industry face a potential worker shortfall because the pipeline of students entering engineering is not adequate to support the projected needs. University enrollments in power and energy engineering courses are increasing, except for electrical power engineering, which is declining. However, correction of this shortfall will depend upon the availability of qualified faculty to provide the power engineering courses.

According to an Institute of Electrical and Electronics Engineers (IEEE) Power and Energy Society Report, there are fewer than five very strong university power engineering programs in the United States. A very strong program is defined as one with the following: four or more full-time power engineering faculty members; research funding per faculty member that supports a large but still workable number of graduate students; a broad set of undergraduate and graduate courses in electric power systems, power electronics, and electric machines; and sizable undergraduate and graduate student enrollment in those courses. The general lack of research funding has created difficulties; faculty members in existing classical power engineering programs find it difficult to meet university expectations, and engineering deans find it difficult to justify adding new faculty (IEEE PES, 2009).

However, these considerations do not apply to nuclear engineering programs, which have seen significant increases in DOE funding for university research programs. Several universities have launched new or have expanded existing nuclear engineering programs, because undergraduate enrollment in nuclear engineering has been growing over the past 10 years or so. Some of these students will go on to earn graduate degrees and become faculty members. Others with advanced degrees will likely seek employment in government-funded programs dealing with technical matters outside of nuclear power plant operations. However, for many nuclear power sector engineering jobs, engineers with electrical, mechanical, chemical, and systems

[2] Other careers (professional, technician, and skilled trades) are also listed here.

engineering degrees can meet the industry's needs if provided with additional instruction in nuclear topics (e.g., through a certificate program).

Conclusions and Recommendations

Conclusions

2.9 Future jobs that can be created over the next several decades by the U.S. nuclear power industry include commercial nuclear power plant construction and operation; uranium fuel enrichment, processing, and manufacturing; treatment and disposal of low-level waste; and decommissioning of shutdown power plants and other commercial facilities and materials. There also will be jobs in the U.S. supply chain that provides commodities, components, and services to the U.S. and international nuclear industries.

2.10 Within the current changing environment, forecasting the future of nuclear power plant construction is difficult and uncertain.

A. A scenario in which nuclear power would continue supplying 20 percent of the U.S. electricity holds the potential for 287,200-359,000 person-years of labor for building new nuclear power units, and 8,000-17,500 permanent full-time jobs to operate them, with additional supplemental jobs for maintenance and outages (Berrigan, 2010).
B. Other nuclear construction scenarios would yield smaller employment projections.
C. There will be many jobs in other sectors of the nuclear power industry that may not be directly affected by the progress of new nuclear power plant construction.

2.11. The workforce is aging, with the prospect of significant numbers of retirements within the next few years. Losses from retirement and other attrition will require replacement with skilled and properly trained and educated workers. Such losses cannot be recovered with noncitizen workers because citizenship is required for many jobs in the nuclear power industry. Moreover, the current pipeline for providing future U.S. nuclear workers is inadequate to meet expected needs.

2.12. The commercial nuclear industry has established a network of educational programs to create and reinforce the infrastructure needed to develop the next generation of the nuclear workforce.

2.13. Satisfying the skilled workforce requirements of developing activities in the U.S. nuclear energy sector will require correcting the weaknesses already identified in the U.S. educational system in STEM subjects at all levels, and strengthening the support for university-level research, which is a requisite for ensuring the sources of educators capable of providing technical instruction at the associate and bachelor's levels.

2.14. Increasing support for university-level research would further ensure this source of educators capable of providing technical instruction at the associate and bachelor's levels. Stabilizing federal grant opportunities would strengthen educational programs.

Recommendations

The following recommendation should be initiated as quickly as possible, and it is expected to be fully operational in the medium term. The recommended action is expected to continue for the long term.

2.4 While there certainly are highly motivated and disciplined young people, there may not be enough with these traits/personal skills to fill the jobs that already exist but remain empty. In pursuing the Shared Recommendations, training programs that involve stackable, industry-recognized credentials should be considered as an excellent approach to address this problem. (Short Term)

In addition to these recommendations, the Shared Recommendations for Chapter 2 (at the end of the chapter) also apply for the nuclear industry.

MINING

The Importance of Minerals

The Center for Strategic Leadership, U.S. Army War College addresses the importance of minerals to the U.S. economy and national security and introduces the evolving global aspect of minerals supply and demand which is paramount to mining and the mining workforce:

> *The vitality of a powerful nation depends upon its ability to secure access to the strategic resources necessary to sustain its economy and produce effective weapons for defense. This is especially true for the world's two largest economies, those of the United States and China, which are similarly import dependent for around half of their petroleum imports and large quantities of their strategic minerals.* Center for Strategic Leadership, U.S. Army War College (2011).

Minerals are essential for the existence and operation of products that are used by people every day. Virtually all forms of modern communication, transportation, energy provision, food processing, housing, and national defense require minerals and the materials developed from them (Table 2.5). In addition to the convenience and security offered by these kinds of products and the minerals they contain, minerals also support the economic standard of living in the United States (NRC, 2008b). The USGS estimated that the overall value added to the U.S. gross domestic product (GDP) in 2012 by major industries that consumed processed nonfuel mineral materials was $2.4 trillion. This contribution represented about 15.3 percent of the total U.S. GDP of $15.7 trillion in 2012 (USGS, 2013).

Table 2.5 Common or Essential Products and Some of Their Mineral Components

Product	**Selected** Mineral Components
Solar panels	
Semiconductor chips	Boron, gallium
Solar cells	Cadmium, gallium, germanium, indium, selenium, tellurium
Photovoltaic cells	Molybdenum, silica
Wiring	Copper
Wind turbines	
Magnets	Cobalt, rare earth elements (neodymium)
Batteries	Rare earth elements, nickel, cadmium, lithium
Cement	Limestone, gypsum
Steel	Zinc, iron ore
Cell phones	
Wiring, circuits	Copper, gold, palladium, platinum, silver, tungsten
Screen display	Indium
Cell towers, transmission	Tantalum, cesium
National defense and automobiles	
Specialty steels and alloys	Chromium, cobalt, columbium, manganese, molybdenum, nickel, tantalum, titanium
Wiring	Copper
Screen displays, magnets	Rare earth elements, gallium
Catalytic	Platinum, rhodium, rare earth elements

converters	
Optoelectronics, integrated circuits	gallium, platinum group metals

SOURCES: USGS (2006, 2013), NRC (2008a,b), Bleiwas (2010), Wilburn (2011), MII (2012a,b,c).

The USGS has monitored import reliance for decades and these data have shown an increase in the number of minerals for which the United States depends primarily or completely on foreign suppliers of the raw material (Figure 2.22). The emergence of rapidly growing new economies over the past several decades has also created competitive demand for the world's mineral supplies, resulting in commodity price escalations and fluctuations. The same period has seen an expansion of the number of locations of mineral production centers throughout the world. Whether or not the minerals in the products used every day in the United States are mined in the United States or abroad, research and innovation are important:

- To identify new mineral sources and develop and implement efficient mining practices in the context of environmental and social concerns for and impacts from mining;
- To identify potential mineral substitutes for products in which a particular mineral may become difficult to obtain;
- To develop knowledge in areas of recycling of mined products along various points of the mineral supply chain; and
- To qualify teaching faculty to educate and train workers to enter the mining field in a range of capacities to ensure the safety of both workers and the environment.

The present and future availability of a skilled workforce and its ability to meet the mineral security requirements of the United States are viewed in this context.

This section reviews the general mining sectors and their geographic distribution and scale; the current composition and demographic characteristics of the mining workforce within these sectors; information on future projections for consumption of mining products; and mining sector employment needs and challenges. The section finishes with an overview of approaches to mining workforce development.

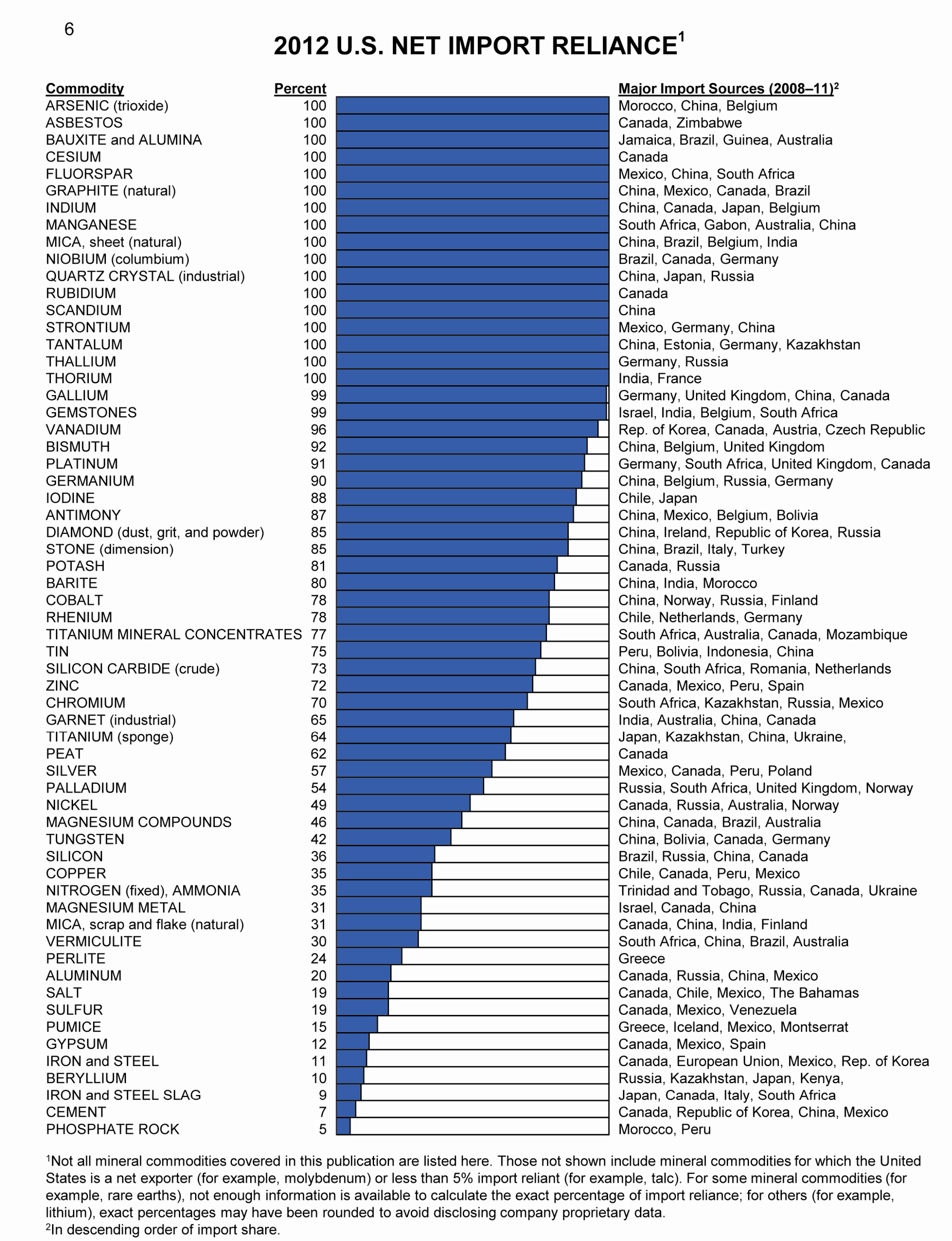


FIGURE 2.22 U.S. net import reliance for selected nonfuel mineral materials in 2011. U.S. import dependence has grown significantly during the past 30 years. In 1978, for example, the United States was 100 percent import dependent for seven mineral commodities. In 2000, the United States was 99-100 percent import dependent for 14 commodities. In 2011, mineral imports accounted for the supply of greater than 50 percent of U.S. apparent consumption of 43 mineral commodities. Of those 43, the United States was 100 percent import reliant for 19 mineral commodities. SOURCES: USGS (2013).

Distribution and Extent of Mining Activities in the United States

The mining industry, broadly defined, includes production of minerals on which the nation is largely self-reliant (such as sand, gravel, aggregate, and coal), global commodities for which the United States imports significant portions of its supply but nonetheless has some domestic production (metals, such as copper), and mineral products on which the United States is largely or completely reliant on imports (such as chromium, tungsten, cobalt, and the rare earth elements). The mining workforce can be grouped into one of four sectors:

- Building Materials: Including sand and gravel, crushed stone, and dimension stone, and extends to asphalt for paving and limestone for cement;[1]
- Energy: dominated by coal, but includes uranium;
- Industrial Minerals: including phosphate used for fertilizers and clays used in bricks and tiles;
- Metals: including economy-based metals such as iron, nickel, copper, and zinc, as well as specialty metals including molybdenum, gold, platinum, and rare earths with their specialized technical applications.

Although the general skill sets required by the workforce across these sectors have some broad similarities, there are differences, including the geographical distribution of employment opportunities, the markets the sectors serve, the operation scales, and rules and regulations that play significant roles in the ability of these sectors to meet their workforce needs at all levels.

For example, information from the USGS (Figure 2.23) shows thousands of mines, plants, and processing centers for minerals representing each of the mining industry sectors across the United States. More common mineral commodities with generally adequate local or domestic supply, such as building materials (sand, gravel, and crushed stone), are mined in all 50 states and are typically located near metropolitan areas and transportation corridors. The annual capacity of these mines is directly proportional to the population they can efficiently supply when considering transportation costs and competition. In contrast, mines providing mineral commodities, such as most industrial minerals, coal, and metals, are discovered and located in more unique geological settings. In the broader context, the links between these raw material production facilities—the direct exploration, drilling, and production—and their manufacturing counterparts are important to recall. Any issues that affect personnel at these production facilities, including their immediate direct and indirect support and management personnel, can lead to major issues in the continued operation of the production facilities with resulting impacts to those farther "downstream" (refining, smelting, processing).

[1] Note that in many labor analyses, sand and gravel mining activities are counted as a single category and stone as a separate category.

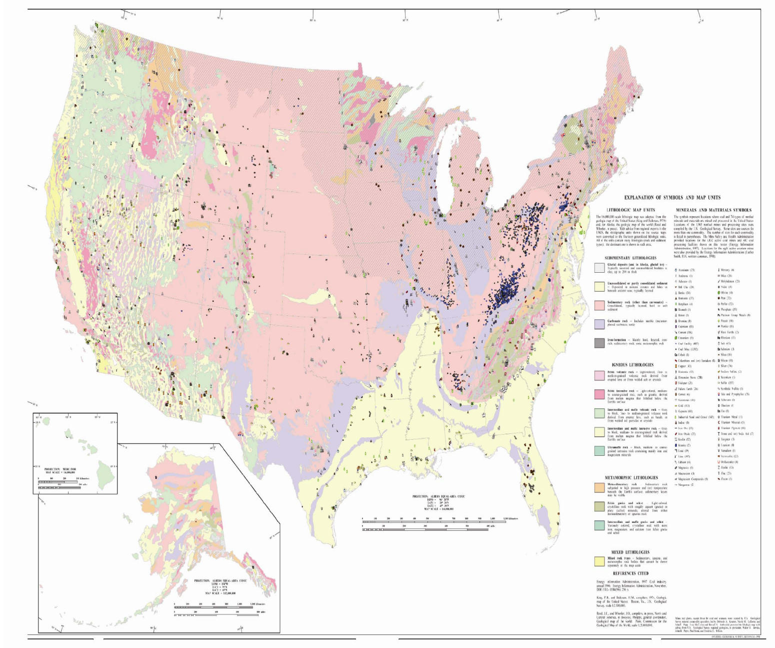


FIGURE 2.23 Locations of mines in the United States where coal and 74 types of nonfuel mineral and material resources are mined and processed. The map represents 1,965 nonfuel mines and processing sites (including metal and nonmetal mines), 1,832 active coal mines and 487 coal processing facilities, and 8 active uranium mines. Not shown is the distribution of ~10,000 sand and gravel, and stone mines. SOURCES: McWilliams et al. (2012. (source for the number of sand, gravel, and stone mines), Kramer et al. (2013).

The Mining Workforce

Data Sources

The mining workforce within each of the four sectors works within one of three complementary groups: in government agencies, which are responsible for permitting of activities and research; in academia, where basic and applied research is conducted and the skilled workforce is developed; and in the mining industry itself, which evaluates a broad spectrum of potential mineral resources that result in extraction and production of raw and processed mineral materials. The federal data used to describe the workforce in this section do not differentiate among these groups, and rather tend to identify the workforce associated directly with production at the mine. However, the skills and education needed to enter the professional workforce in either government or academia are discussed. Chapter 5 specifically addresses the topic of the government workforce in mining and energy.

Data on the U.S. mining workforce derive primarily from one of three federal sources: the Bureau of Labor Statistics (BLS), the Mining Safety and Health Administration (MSHA), and the National Institute for Occupational Safety and Health (NIOSH). NIOSH often employs the detailed data collected by MSHA in developing its occupational safety and health research and programs for the mining industry. However, at the close of 2012, NIOSH released the first comprehensive survey of the mining population conducted in 20 years, based on data that NIOSH collected in 2008 (McWilliams et al., 2012). These data complement the BLS and MSHA data, and are reviewed briefly in this chapter. Labor projections for mining are available from the BLS and Energy Information Administration (EIA); the EIA employs BLS data to generate its labor projections.

The MSHA data and BLS workforce data show slightly different counts in various parts of the mining workforce (see below). Appendixes A and B describe in detail the federal data sources used for this study, the data gleaned from these sources, and the limitations of the BLS and MSHA data. Briefly, the federal data sources rely on the North American Industry Classification System (NAICS) taxonomy to identify the industries within mining. However, the NAICS structure is somewhat restricted in the way it allows examination of the mining workforce. For example, certain NAICS categories do not differentiate among oil and gas, coal, and hard-rock mining labor descriptions, and outsourcing of energy- and mining-related activities to contractors is also not fully captured in the NAICS taxonomy, potentially leading to undercounting of certain parts of the workforce (see also Appendixes A and B). Furthermore, potential technological developments that may decrease the numbers of workers required at certain kinds of mines are not readily included in official projections of future mining workforce needs, although Woods (2009) suggests that technological advances, in general, may increase mine productivity and result in employment declines in the mining industry over time.

To place the differences among these federal data sets and the projections made from them in a broader context, the committee sought data and information for comparative purposes from additional sources, including university researchers, professional associations, and government data from Australia and Canada, each of which has robust domestic mining industries.

Size, Employment, and Characteristics of the U.S. Mining Workforce

The data discussed in this section focus on primary mine production. Primary production includes exploration, mine site development, mining (extraction of the mineral commodity), minerals processing (milling, washing, grading, and concentrating),); and metals production (smelting and refining). McWilliams et al. (2012) further delineates the NIOSH mine worker population into four broad categories: administration/professional (including engineers, geologists, safety experts, management); maintenance (including trades people such as electricians and mechanics); production (extraction of material from the mine, including mineral processing); and service/utility positions. Although the general categories are applicable across the four mining sectors, the details in the kinds of training and scale of the workforce at a mine within these categories will vary considerably depending upon the material being produced, for example, at a sand and gravel quarry operating above ground versus an underground metal mine.

Although not represented at this level of specificity for mining in any data set, government agency involvement with the mining industry is important to acknowledge and includes the following primary workforce fields (see also Chapter 5):

- Permitting and regulatory,
- Health and safety,
- Federal and state land administration, and,
- Research and data compilation.

The U.S. mining workforce is relatively small. For example, MSHA, which tends to report the highest employment numbers for the mining industry among the federal data sources, describes a mining workforce of approximately 392,700 for 2008 (representing about 0.25

percent of the U.S. workforce; summarized by Brandon, 2012[2]). Table 2.6 summarizes the 2008 employee counts by mining sector as drawn from the data sets of five different sources. This comparison was based on 2008 data because 2008 is one of the few years for which labor data are reported from each of the main public data sources. More current data are available from MSHA and BLS, but not for the same year. The degree to which the differences in the 2008 data sets are representative of all years is unknown. The differences among the various sources arise from what each source is counting and what each source reports for headcount.

TABLE 2.6 Comparison of Employment Source Data from Public Sources for 2008

2008	Coal	Sand & Gravel	Crushed Stone	Non-metal	Metal	Contractor Support*	**Total**
MSHA[a]	90,055	42,307	78,975	23,033	39,126	119,223	**392,719**
BLS[b]	80,600			107,200	39,900		**227,700**
EIA[c]	80,000	46,000			44,000		**170,000**
NIOSH[d]	70,007	32,144	70,965	19,349	39,083		**231,549**

[a]Data were compiled by NIOSH and include all employees and contractors in the benefaction process. MSHA contractors work at but are not employed by the mine. MSHA data may over count contractors who are employed at more than one mine (Brandon, 2012).
[b]Data are based upon workforce population data collected by census. Data do not include contractors who do not identify themselves by one of the NAICS codes (Brandon, 2012). “Nonmetal” category includes the workforce in the sand and gravel, and the crushed stone categories.
[c]Data are based upon BLS data. The sand and gravel category also includes some nonmetal (industrial mineral) labor. The crushed stone (aggregate) industry and most of the nonmetal industry are not included in EIA analyses.
[d]Data were collected by a national survey of the mining population.
SOURCES: Brandon (2012) for summaries of MSHA, BLS, and EIA data; original data sources include McWilliams et al. (2012) for NIOSH, Woods (2009) for BLS, EIA (2011a,b) for EIA.

MSHA head-count data for the mining sector from 1983 to 2010 indicate that mining employment has declined, most notably in coal (Figure 2.24). Contractor head count, on the other hand, has increased from 6 percent in 1983 to 30 percent in 2008. Table 2.7 provides a summary of the MSHA and BLS mining workforce employment data for 2008 and 2010, to examine the effects of the economic recession. Although the BLS data exhibit an undercount, both the MSHA and BLS data show a comparable percentage decline in mining employment from 2008 to 2010, similar to national declines in employment associated with the onset of the economic recession in 2008. This pattern was also observed in other countries with strong mining industries. Canada, for example, also reported a decline in employment in the mining industry over a similar time period, but indicated an increase in mining employment beginning in 2011 (Natural Resources Canada, 2012).

[2] The Brandon (2012) report was the product of collaboration among the Society for Mining, Metallurgy and Exploration (SME), National Mining Association National Stone, Sand and Gravel Association and Industrial Minerals Association-North America specifically as a contribution to this study and includes data collated from federal and private sources.

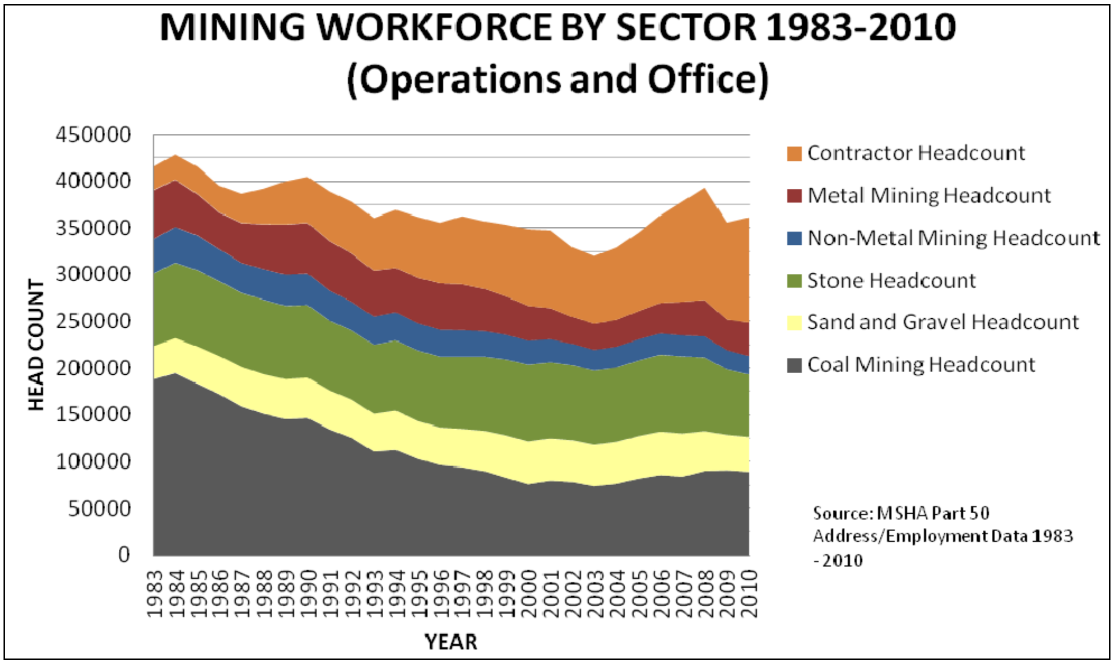


FIGURE 2.24 Cumulative U.S. mine labor by mine sector over time. Data from MSHA (2011a). SOURCE: Brandon (2012, Fig. 7, p. 9).

TABLE 2.7 MSHA and BLS Mining Workforce Employment Counts for 2008 and 2010

SOURCE	2008	2010	Change (%)
MSHA	392,719	361,176	−8.0
BLS	237,043	217,300	−8.3

SOURCES: BLS (2011d), MSHA (2011b); presented in Brandon (2012, Table B1, p. 24)..

Wages in the mining industry vary according to occupation, but are generally comparable to or slightly higher than those in other major industries (Tables 2.8 and 2.9).

TABLE 2.8 Top 10 Industries in Employee Earnings

Rank	Industry	Average Earnings ($/hr)
1	Computer and electronic products	32.12
2	Transportation equipment	28.56
3	Mining and logging	27.34
4	Construction	25.23
5	Durable goods	24.72
6	Machinery	24.14
7	Goods-producing	23.97
8	Primary metals	23.55
9	Beverages and tobacco products	23.51
10	Manufacturing	23.22

NOTE: “Mining” in “Mining and logging” includes the oil and gas industry. Estimates for March 2010. SOURCE: BLS (2010).

TABLE 2.9 Comparison of Mean Annual Salaries Among Selected Skilled and Semi-skilled Occupations in Mining and Other Industries, May 2011

NAICS Title	Occupation	Mean Annual Salary ($)
Forestry and Logging	General and operations managers	90,240
Oil and Gas Extraction	General and operations managers	151,880
Mining (except Oil and Gas)	General and operations managers	111,170
Utilities	General and operations managers	120,020
Construction of Buildings	General and operations managers	121,180
Oil and Gas Extraction	Mining and geological engineers, including mining safety engineers	124,600
Mining (except Oil and Gas)	Mining and geological engineers, including mining safety engineers	84,110
Utilities	Mining and geological engineers, including mining safety engineers	102,610
Federal, State, and Local Government	Mining and geological engineers, including mining safety engineers	84,960
Oil and Gas Extraction	Electrical and electronics engineering technicians	78,480
Mining (except Oil and Gas)	Electrical and electronics engineering technicians	60,890
Utilities	Electrical and electronics engineering technicians	63,590
Construction of Buildings	Electrical and electronics engineering technicians	51,400
Forestry and Logging	Crane and tower operators	41,700
Oil and Gas Extraction	Crane and tower operators	57,430
Mining (except Oil and Gas)	Crane and tower operators	45,800
Utilities	Crane and tower operators	57,350
Construction of Buildings	Crane and tower operators	52,860

NOTE: Each NAICS title did not necessarily have entirely comparable occupational categories in each case. The occupations selected are for general comparison only for occupations requiring a range of education and training levels. SOURCE: BLS (2011b).

A detailed description of data gleaned for this study for the mining workforce from federal data sources (BLS and MSHA) is provided in Appendix B. The descriptions below summarize mining employment data for coal mining and for mining activities other than coal mining. References for the following two sections include BLS (2011a,b, 2012a,b), and MSHA (2011a,b).

Coal Mining Employment Data

For coal mining, the unique NAICS codes reflect coal mining activities and support activities for coal mining. The support activities are similar to activities performed by coal mining operators, but are performed on a contract or fee basis. In Appendix B, Table B.20 shows 2010 average annual coal mining employment by sector (private and federal, state, and local governments), and Table B.21 provides an historical view of average annual employment across sectors for 2005-2010. Employment in these two coal mining activities totals 89,252 for 2010; all in the private sector. Since 2005, coal mining employment has grown at an annual rate of 1.9 percent, representing an increase in employment of about 8,000 for 2005-2010. Coal mining did not experience a decline in employment during the recent recession (see Figure 2.24). Table C.30 in Appendix C provides 2010 private sector employment estimates for the 20 largest occupations in the coal mining industry (excluding support activities).

Demographic information for the coal mining industry workforce is provided in Table C.28 of Appendix C. The data indicate that this industry has few women and little racial and ethnic diversity, compared with the U.S. workforce. Women compose 6 percent of the workforce and Black/African Americans and Hispanic/Latino workers each constitute less than 0.5 percent. The median age in this industry is 46.4 years (older than the U.S. workforce), with slightly more than 51 percent aged 45 or older.

The MSHA data indicate a total operator employment of 89,209 and total contractor employment of 46,324 (total 135,533). The comparable 2010 BLS figure (based on BLS, 2011d) is 89,252. The data suggest that the BLS figures may be undercounting nonfuel mining employment. The undercounting may be due in large part to limitations associated with the NAICS taxonomy that result in the undercounting of contractor employment. In particular, if a mining contractor engages in more than one activity and the primary activity is not the provision of mining services, the NAICS code for this establishment will not fall under mining and the corresponding employment will not be included as part of mining.

Specific details of the coal industry, including workforce information, are summarized in Virginia Center for Coal and Energy Research (2008).

Mining Employment Data Other Than Coal Mining

The NAICS codes used by BLS that are unique to mining other than coal mining reflect the activities of metal ore mining, nonmetallic mineral mining and quarrying, support activities for metal mining, support activities for nonmetallic minerals (except fuels) mining, and primary metal manufacturing. In Appendix B, Table B.17 shows 2010 average annual employment by sector (private and federal, state, and local governments) for each of these activities, and Table B.18 offers an historical view of average annual employment across sectors over the period 2005-2010. Considering the first four of these NAICS codes (excluding primary metal manufacturing), which deal with the extraction of resources, the total employment across these NAICS codes for 2010 is 128,048.

Nonmetallic mineral mining and quarrying is the largest of these four industries, followed by metal ore mining. Although employment declined in all of the nonfuel mining industries for 2008-2010, metal ore mining and support activities for nonfuel mining had annual growth rates of more than 4 percent for 2005-2010. Tables C.21 and C.22 in Appendix C show average annual nonfuel mining employment for 2005-2010 for the private sector and local government, respectively. Tables C.25 and C.26 in Appendix C provide 2010 employment estimates for the 20 largest occupations in the metal ore mining and nonmetal mining industries, respectively.

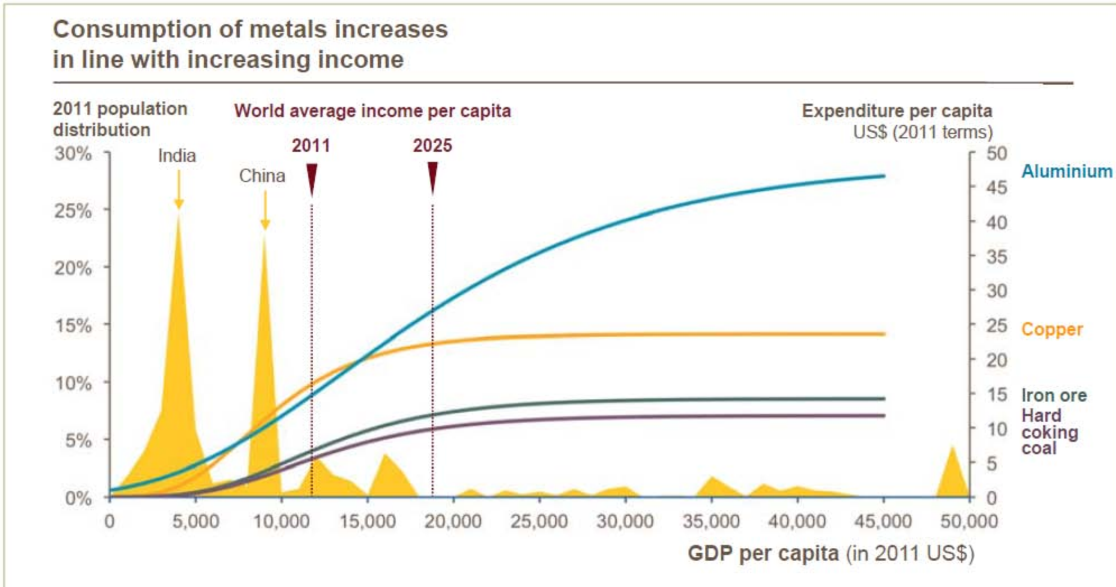
Demographic information for 2010 is available for a subset of the nonfuel mining workforce (see Table C.23 in Appendix C). For the nonmetallic mineral mining and quarrying industry, compared with the overall U.S. workforce, women compose a relatively small percentage of its workforce. This industry also employs few Blacks/African Americans and Asians, but Hispanic or Latino workers represent 12.5 percent of this industry (compared with the overall U.S. workforce at 14.3 percent). Comparable data were not reported for the metal ore mining industry. An important note is that the nonfuel mining workforce is older than the U.S. workforce. Nonmetallic mineral mining and quarrying has a median age of 47.8 and metal ore mining has a median age of 43.4 (compared with 42.0 for the U.S. workforce); 57.3 percent of the nonmetallic industry and 51.4 percent of the metal ore industry are 45 years of age or older.

The MSHA data show employment of 225,643 in 2010, with 160,146 reflecting employment at nonfuel mining operators and the remaining 65,497 reflecting employment at nonfuel mining contractors. As noted previously, the comparable BLS figure (from BLS, 2011d) is 128,048, suggesting that the BLS figures are undercounting nonfuel mining employment.

Mineral Consumption Market Patterns

The production of mineral commodities links closely to the standard of living in a particular jurisdiction, as well as the demand for the raw materials and the prices those materials command (Woods, 2009). Rising standards of living in emerging economies and increasing human population, generally, have been accompanied by increased metals and industrial minerals use (Rogich and Matos, 2008). As a developed economy, the consumption of mineral commodities in the United States is high and has increased with population growth. This is also true for developed economies globally. Menzie et al. (2003) summarized work that examined the ties among population, GDP, and mineral consumption in the 20 most populous countries. These authors suggested that rapid growth in mineral consumption would occur over the subsequent two decades, due particularly to increased growth in consumption in developing countries. In one example that reviews per capita consumption of major metals such as iron (and coking coal to produce iron), copper, nickel, and aluminum, marked increases in consumption occur concomitant with increase in per capita income (Rio Tinto, 2012; Figure 2.25).

In Canada and Australia, the positive relationships observed among growth in population, GDP, and mineral demand are being met with increased mineral production and increased employment in the mining industry (Lowry et al., 2006; Natural Resources Canada, 2012). New mining employees are also needed to address the anticipated retirement of many workers in the mining sector (Lowry et al., 2006). In the United States, high metal prices due to demand on the world market for various products have encouraged some U.S. mining companies to increase production at existing mines and to restart production at others. Demand in the country is also anticipated to increase for sand, gravel, and crushed stone (Woods, 2009). BLS analysis suggests, however, that the continued expansion of the demand for both metal and nonmetal mine products may be tempered by longer-term stabilization of prices and the strength and stability of the industries that use these products (Woods, 2009).



Source: Global Insight for population distribution; Rio Tinto estimates for commodity expenditure profiles.
Note: Expenditure profiles are based on Rio Tinto estimates of global income and consumption relationships and average real terms prices between 1990 – 2006. Iron ore and hard coking coal expenditure calculated based on crude steel demand projections, assuming all met by blast furnace production at historic average export prices.

FIGURE 2.25 Consumption of major metals and coking coal increases in concert with increasing income. Also shown is the percent of global population with respect to per capita income. The U.S. population is the yellow peak at the extreme right of the diagram. SOURCE: Rio Tinto (2012, p. 40).Used with permission from Rio Tinto.

As an energy source, EIA historical data and projections indicate that domestic coal production is expected to decline through 2015, after which production is expected to grow at an average annual rate of 1.0 percent through 2035 (Figure 2.26 and Table 2.10). Through 2015, low prices for natural gas, increasing coal prices, a lack of electricity demand growth, and increased generation from renewable sources are expected to restrain coal production in the United States. Tied to this growth in production, coal mining employment is expected to grow at least through 2018 (Woods, 2009).

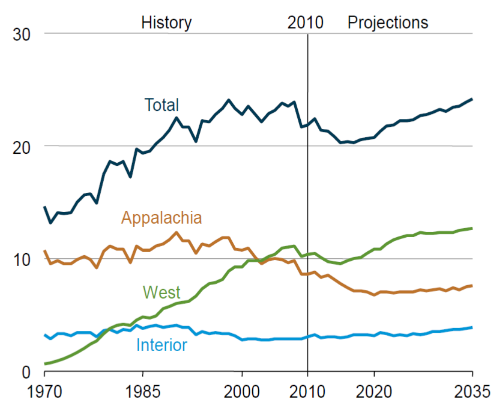


FIGURE 2.26 Coal production by region, 1970-2035, Reference case (quadrillion Btu). SOURCE: EIA (2012a, Fig. 118, p. 98).

TABLE 2.10 U.S. Coal Production, Reference Case (Million Short Tons per Year)

	2009	2010	2015	2020	2025	2030	2035	Annual Growth 2009-2035 (%)
Appalachia	343	336	300	262	271	282	291	−0.6
Interior	147	156	151	159	163	181	198	1.0
West	585	592	542	613	684	703	722	0.8
East of the Mississippi	450	446	407	377	383	409	431	−0.1
West of the Mississippi	625	638	586	657	735	757	781	0.8
Total	1,075	1,084	993	1,034	1,118	1,166	1,212	0.4

NOTE: Includes anthracite, bituminous coal, subbituminous coal, and lignite. SOURCE: EIA (2012a, Table A15, pp. 160-161).

Employer Needs and Challenges

BLS projections for private-sector employment are available for a subset of the nonfuel-mining-related NAICS codes—metal ore mining, nonmetallic mineral mining and quarrying, and primary metal manufacturing. These projections are given in Table B.19 of Appendix B. In nonmetallic mineral mining and quarrying, employment is expected to increase by 11,600 between 2010 and 2020, but it is expected to decline by 8,300 in metal ore mining, resulting in a net increase of 3,300 jobs in nonfuel mining. BLS projections for coal mining are shown in Table B.22 of Appendix B, which indicates that, by 2020, private-sector employment in the coal mining industry (excluding support activities) is expected to decrease modestly to 77,500. Other analyses of the future mining workforce using a variety of data follow.

A study of workforce challenges in the coal industry by the Virginia Center for Coal and Energy Research (2008) made workforce projections for the coal mining industry out to 2030. Their projections estimate the total number of U.S. coal miners to be 92,301 in 2020, and 112,487 in 2030. The projection for 2020 employment in the study is somewhat higher than the more recent BLS projection, potentially due to undercounting of the total employment in the BLS data, as discussed previously (Virginia Center for Coal and Energy Research, 2008). In comparison, EIA projections indicate that total employment in coal mining could be 86,517 in 2020, 115,651 in 2030, and 128,608 in 2035 (EIA, 2011b).

The domestic mining industry faces several challenges in attempting to anticipate and meet future workforce needs, even under conditions of very modest growth. The most critical issue is the aging of the workforce as it relates to the mining industry and mining-related faculty at institutions of higher education and a paucity of candidates to replace them. Foreign competition for U.S. talent in the mining industry and a current lack of perceived need for new workers in the domestic mining industry exacerbate the problem of the aging workforce.

Because of the net loss of mining-related faculty over the past decades, the nation's capacity to teach mine engineering professionals in the higher-education system is compromised. The general mining workforce confronts a comparable issue, but the immediate problem is probably less acute.

The mining workforce has been aging faster than the U.S. workforce since 1978, with the mining workforce being 6.5 years older than the U.S. workforce by 2008 (see Figure 6.4 in Chapter 6). The challenge of replacing large numbers of experienced, retired workers in any industry is widely discussed. In addition to confronting the replacement of at least some of the large, anticipated number of retiring mine workers, the mining industry and safety and health professionals confront the additional challenge of ensuring the safety and health of both new, less experienced workers, as well as the older, more seasoned mine workforce (see Chapter 6; see also Fotta and Bockosh, 2004). Moreover, more than half of the present workforce will have retired by 2029 (Brandon, 2012), creating a skill and knowledge gap if not addressed by the education and training system.

Additional factors that may dissuade potential employees from joining the U.S. mining workforce present challenges to employers in the private and public sectors and touch in different ways upon those with professional degrees, those in skilled trades, and those who work directly with mineral production. These recruitment challenges are particularly important as the mining industry seeks strong leadership to address the changing global dynamics in the minerals industry, while seeking innovative ways to increase safety, and efficiency within the context of increasing environmental and social concerns directly linked to mining.

The labor-intensive nature of the work, the remote locations and challenging physical environments of some mines may be considerations that influence all potential workers to different degrees. The cyclical nature of the industry and the legacy of disruptions to the local environment experienced by some communities in historic mining districts may be factors for all workers, but could potentially have greater influence on those with advanced degrees who may have a broad range of options in the job market. Finally, because minerals are a global commodity, factors that affect mining in other parts of the world can have an effect on the domestic mining workforce. In addition to the market influences discussed above, professional-level talent, in particular, may seek the best professional opportunities that also offer the most competitive compensation, whether in the United States or overseas.

Mining Workforce Development

Mining workforce development is considered important, especially in light of the likely gap in skilled workers resulting from the combination of growth of the overall industry and a large group of workers entering retirement age. The competency lattice in Figure 2.27 (based on committee experience) shows the development of technical and social competencies within the blue boxes and the approximate age of an individual at these stages of development (arrows on the right side of the figure). Important points to note are the following:

- Professional competencies are built on a platform of personal competencies learned from childhood.
- Topical workplace competencies, including work habits, typically begin developing with the first opportunities for internships in the late teens.
- Industry competencies begin accruing with graduation from a university and the first few years practicing disciplines learned at the university, say by age 25.
- Specific expertise is typically evident 8 to 10 years out of the university.
- Competencies continue building over a working career.
- Current recruiting focuses on developed and proven talent. Virtually all companies are focused on this diminishing talent pool.

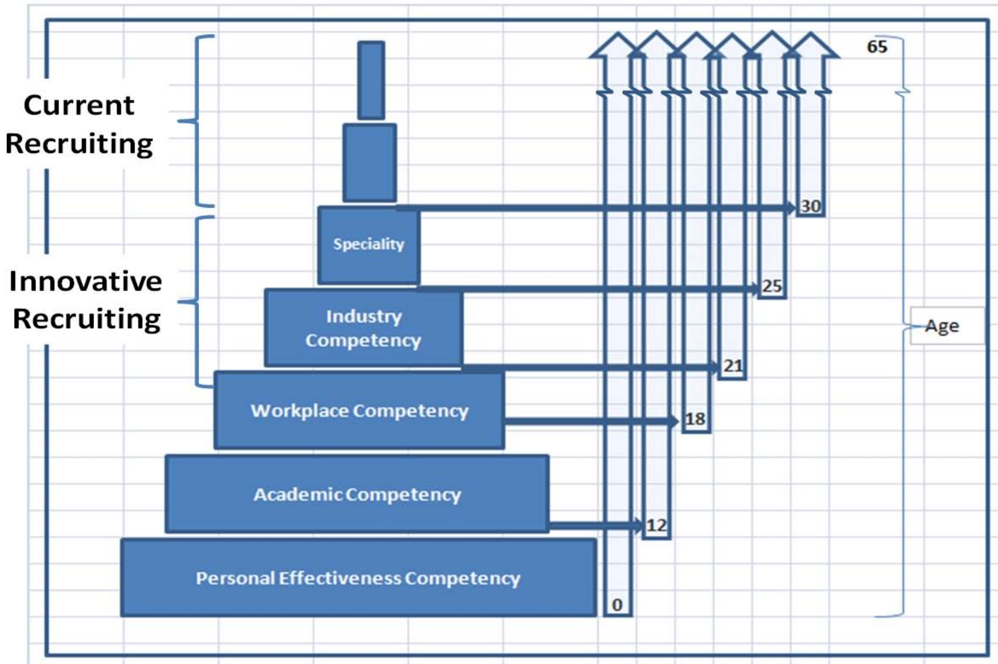


FIGURE 2.27 Competency lattice. SOURCE: Courtesy of Leigh Freeman.

This view of workforce development also demonstrates the time factor in expanding the U.S domestic workforce and in replacing the retiring baby boomers. It also presents a potential opportunity to identify unique workers at an earlier stage of development, enabling possible acceleration in filling gaps generated by retiring, highly skilled workers. The distribution of the workforce by industry subsector and levels of education and training has been compiled by a member of the committee (L. Freeman, Table 2.11) for comparison with the competency lattice.

TABLE 2.11 Distribution of the Mining Workforce by Industry Subsector and Levels of Education and Training, Relative to the Competency Lattice. The first column contains the required education/training in years and the first row of data indicates the distribution of total jobs (in thousands) across the industry subsectors.

	Coal	Metals	Industrial Minerals	Sand & Gravel	Crushed Stone	Contractor Support	Consultants	Government	Education	Total Work-force
Total jobs/1000	90	40	25	40	80	100	20	50	1	446
Required Education/ Training (yrs)										
8	1%	1%	1%				5%	5%	20%	4
6	4%	4%	4%	5%	5%	5%	30%	30%	40%	32
4	15%	15%	15%	10%	10%	10%	25%	25%	20%	58
2	25%	25%	25%	10%	10%	10%	15%	15%	10%	68
1	25%	25%	25%	20%	20%	20%	10%	10%	5%	88
0.5	20%	20%	20%	30%	30%	30%	5%	5%	2%	32
0.2	5%	5%	5%	10%	10%	10%	5%	5%	2%	32
0.1	4%	4%	4%	10%	10%	10%	4%	4%	1%	30
0	1%	1%	1%	5%	5%	5%	1%	1%		13
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	

NOTE: Total jobs data are from MSHA. For simplicity, levels of education and training are denominated in terms of time reflecting an approximate interval necessary to earn a degree or level of necessary competencies, which may be recognized by a formal certificate. Changes in required training/education levels: more complex equipment and automation will require higher levels of maintenance and operating skills. Increasing social complexity (social license and multicultural workforce) will require more training/education. SOURCE: Courtesy of Leigh Freeman.

The way in which engineering and science professionals develop through their professional careers is illustrated in Figure 2.28. Some 70 percent of graduating mining engineers begin their careers in production-related jobs. Having established this practical base, they move on to fill other roles in the industry. For example, a mine safety inspector for the government would clearly gain invaluable skills with some previous work experience in mine production. Although this figure was developed for mining engineering, it serves as a conceptual proxy for the development process for other engineering and science professionals in the mining industry.

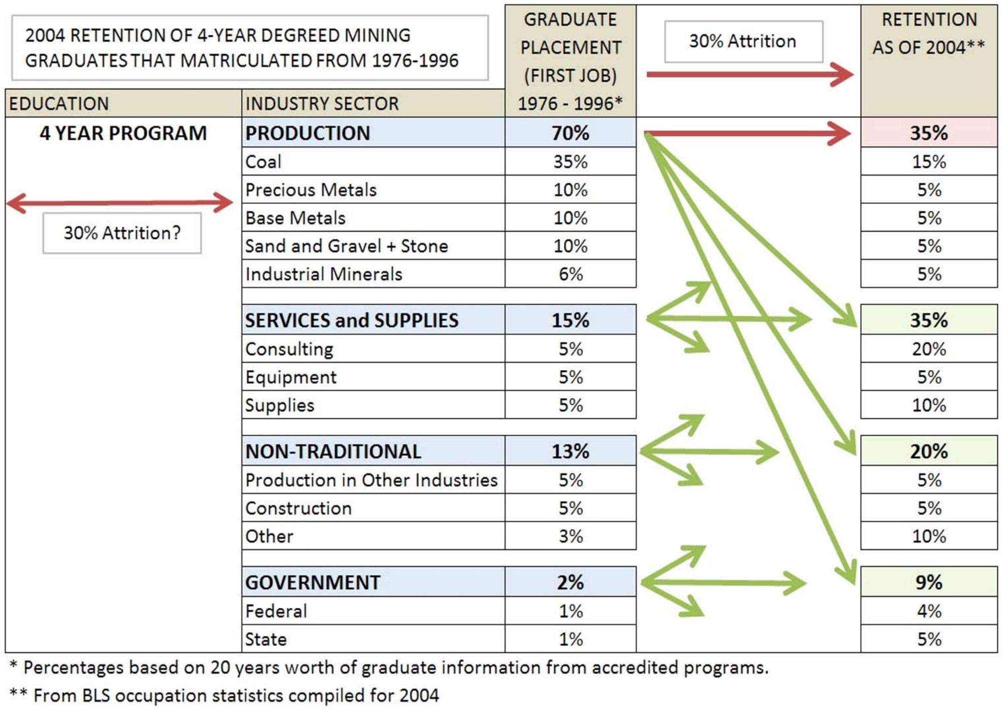


FIGURE 2.28 Progression of degreed professionals in the mining industry over time. SOURCE: Brandon (2012, Fig. 12, p. 15).

Education

> *While market responses may eventually cover some of the apparent gap between the short-term demand for workers and the supply of new hires, the time lag of market responses, the very large number of anticipated workforce openings, and the need for technology innovation entail larger commitments than the market alone is able to address and suggest the need for government engagement in the matter of professional training.* (NRC, 2008a)

An average of approximately 125 B.S. degrees in mining engineering has been awarded annually for the past 25 years from U.S. colleges and universities (Figure 2.29). SME estimates the sustaining B.S. graduation rate to be 300 to 350 per year. The number of accredited mining and mineral engineering programs has also declined, from 25 in 1982 to 14 in 2007 (SME, 2007, 2011).The number of faculty has also declined, from approximately 120 in 1984 to 70 in 2007. This translates into an average of 5 faculty at each of the 14 programs, each awarding 9 B.S. degrees per year. Relative to other engineering disciplines, these programs are small and may be more vulnerable to financial pressures experienced by universities. Furthermore, the major proportion of the current technological leadership in U.S. institutions of higher education is approaching retirement without an obvious source of qualified replacements.

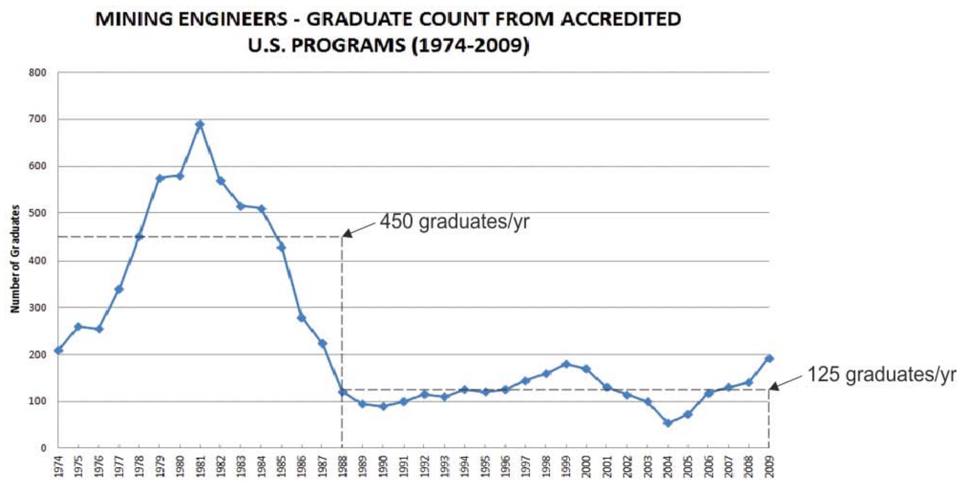


FIGURE 2.29 Number of mining engineer B.S. graduates from accredited U.S. programs (1974-2009). SOURCE; Brandon (2012, Fig. 15, p. 19).

These statistics for mining engineers serve as a proxy for graduates of other mining-focused disciplines, such as mineral processing, extractive metallurgy, economic geology, exploration geophysics, and geochemistry for which statistics are not available. Demographics for these specialty disciplines appear to be similar to those of mining. Importantly, the majority of workers at a mine are in skilled trades and in production, where the training and education are not received at 4-year institutions. Community colleges and trade schools are important components of the overall development of a qualified workforce in the mining industry. The training at these and other institutions is addressed in more detail in Chapter 7.

University faculty in mining engineering is also aging, and it is expected that a large number will be eligible to retire by or around 2020 (Poulton, 2012). Although these retirements are not mandatory, anticipated loss of at least some of these senior faculty members in the coming decade, combined with low doctorate production, may place some programs in danger of losing faculty positions. This situation at universities has been exacerbated to some degree by the relative absence of consistent federal research funding to support graduate programs at mining schools since the closure of the U.S. Bureau of Mines in 1995. However, the increased attention in recent years by Congress and federal agencies, such as the USGS and DOE, to the issue of critical minerals and materials has renewed interest in minerals issues. One example of this increased interest has been the establishment (January 2013) of a Critical Materials Energy Innovation Hub by the DOE.[3] The Critical Materials Hub, led by Ames National Laboratory and a team of six university research partners, other national laboratories, and several industry partners, will have continued support for an initial period of 5 years to focus on mineral processing and material manufacturing and engineering issues. Although the Hub will not address the primary supply of minerals through mining research or the development of primary mineral resources at new or existing mines, the kind of partnership the Hub represents, supported by the federal government in partnership with industry and research institutions, is a constructive model to examine in the effort to renew U.S. expertise in minerals and mining, or earth resources engineering. A model for new centers for interdisciplinary research in earth resources engineering to address the research challenges in this field, to attract new students to these programs, and to develop the professional expertise that will be required by the mining industry, is described in more detail in Chapter 7. Global research in the minerals sector today is otherwise

[3] http://www1.eere.energy.gov/manufacturing/rd/critical_materials_hub.html.

dominated by Australia and Canada. AMIRA[4] and Mining Technology lead the way in Australia, and CMIC leads in Canada.[5]

Innovation

Innovation in key areas of the process of mining and exploration could potentially enable a smaller workforce to provide a larger supply of minerals and metals (from domestic and global sources). Upstill and Hall (2006) looked at the pattern of innovation in the global minerals industry, including structure and drivers for change. These authors found that the global minerals industry ranks highest among all industry sectors in research and development expenditures. Specifically, they observed that conventional studies on research and development expenditures fail to include design activities and engineering development, continuous improvement by equipment manufacturers, and expenditures for mineral exploration. Four principal areas of innovation suggested by the authors include minerals exploration, mining/extraction, mineral/metal processing, and environmental innovations. These four innovation areas are viewed in concert with continued work in improvements in worker health and safety. An example of the effects of innovation on productivity is presented in Box 2.6.

BOX 2.6
Impacts of Innovation

Throughout most of the 20th century, the United States was the largest copper producer in the world. Chile is now the largest as a result of decades of exploitation of competitive-grade copper deposits. In the period between 1970 and 1985, U.S. copper output declined by nearly a third and its share of production from the western world dropped from 30 percent to 17 percent. This drop in production was accompanied by a 70 percent drop in employment. A revival in the U.S. copper industry was subsequently spurred by innovation, and by 1995, output was 72 percent above its 1985 level.

The revival of the U.S. copper industry is attributed primarily to *innovations in work productivity* related to technological innovation at individual mines. This finding is significant because it suggests that changes in understanding the specific mineral endowment (deposit) was not as decisive as factors relating to the productivity of the workforce at the mine.

One of the most important innovations was the technical development of the solvent extraction/electrowinning (SX/EW) process. The SX/EW process is oriented specifically toward the recovery of copper from low-grade ores such as waste piles of copper ore minerals that typically accumulate at a mine site. The implementation of this technical process resulted in a competitive advantage for historically important copper-producing companies and countries that had developed fairly substantial waste piles of previously unexploited and unrecoverable (from an economic viability standpoint) copper ore.

In essence, waste rock associated with a century of mining was converted from a liability to an asset. This development allowed the United States to sustain domestic copper production in spite of the fact that many of the richest domestic deposits had been substantially depleted.

From a public policy standpoint, Tilton (2003) suggests that such innovations shift the role of government

> *from ensuring that society gets its fair share of the wealth created by mining . . . to creating an economic climate conducive to the innovative activities of firms and individuals. In short, public*

[4] Australian Mineral Industry Research Association. See www.amira.com.au/
Mining Technology, Australia. See http://www.miningtechnologyaustralia.com.au/lead-focus
Canadian Mining Innovation Council. See http://www.cmic-ccim.org/en/about/cmic_about_us.asp

[5] See Australian Mineral Industry Research Association, www.amira.com.au/; Mining Technology, Australia, http://www.miningtechnologyaustralia.com.au/lead-focus; Canadian Mining Innovation Council, http://www.cmic-ccim.org/en/about/cmic_about_us.asp.

policy focuses more on how to increase benefits flowing from mining and less on how to divide them. (Tilton, 2003)

SOURCE: Tilton (2003).

Impediments to innovation are borne across industry, government, and academia—investment in research (both government and industry), decrease in the capacity of universities to conduct research in these areas, and a tendency to focus on short-term profit margins rather than long-term investments in research and their benefits. An important recommendation from the NRC (2008a) report on critical minerals suggests that a very important role can be played by federal agencies—including the National Science Foundation, Department of the Interior (including the USGS), Department of Defense, DOE, and Department of Commerce—to develop and fund activities that would encourage innovation related to critical minerals and materials and increase the understanding of global mineral availability and use. The report notes that, absent such federal efforts, the nation may not be able to anticipate and react to potential restrictions in the mineral markets.

Public Policy and Regulation

A stable, competent, innovative workforce is the foundation of secure access to strategic resources. Borrowing from a well-established Australian vision advocating policy as it relates workforce:

> *A productive workforce needs to be a skilled workforce. The Minerals Council of Australia (MCA) advocates building an uninterrupted, sustainable education and training pathway to increase workforce participation, workforce diversity and workforce skills, regardless of the business cycle in the industry. The MCA is developing and implementing national strategies to ensure the adequate supply of skills to the industry and to increase minerals industry labour productivity by: Advocating public policy and institutional capacity building for improved delivery in the tertiary education sector – both the university sector and the vocational education and training sector (VET) – in minerals industry related areas* (MCA, 2012, p. 3)

An early example of the recognition of policy to support minerals supply was the formation of Land Grant Colleges in 1862 to provide sustaining financial support for the development of talent and research in applied sciences and engineering (Morill Act of 1862[6]), and the Mining Law of 1872[7] to facilitate access to federal lands for mineral extraction.

The effectiveness of these monumental policies to support the domestic minerals industry as a foundation for the growing U.S. economy has eroded over many decades, while the importance of a stable mineral supply to the U.S. economy and national security has remained.

This erosion occurs, while today, some of the most populous countries in the world with emerging economies institute policies to secure mineral resources. Their goals are consistent U.S. efforts of the late 1800s and early 1900s, although their policies vary substantially. Global change in minerals policy by large emerging economies has put the supply of critical minerals to the United States at risk. See the following discussion on rare earth elements (Box 2.7) as an example.

The influence of politics and policy on mineral availability ranges from the regulatory regime in a given country to global geopolitics, global trade, and diplomacy (Box 2.7).

[6] http://memory.loc.gov/ll/llsl/012/0500/05350503.tif
[7] http://memory.loc.gov/ll/llsl/017/0100/01330091.tif

BOX 2.7
Renewed Interest in Development of Domestic Deposits of Rare Earth Elements: The Influence of Export Restrictions from China

The United States has relied essentially on imports to meet its needs for rare earth elements (REEs) since the mid-1990s. REEs have widespread applications for advanced technologies and renewable energy. It is reported that China has 37 percent of the world's REE deposits, but it has provided 97 percent of the world supply until recently. Because of the low pricing of REEs from China, the costs to pursue the process of permitting a new REE mine in the United States had been difficult to overcome (Brandon, 2012; additional background information on China's REE industry and its implications is provided by Hurst, 2010.) In mid-2011, China placed major restrictions on the export of REEs, which spurred more widespread interest in identifying and developing U.S. REE resources. For example, Molycorp, Inc. reopened the Mountain Pass REE mine in California in 2011 (Brandon, 2012). However, new REE deposits will potentially take years to identify and develop.

Conclusions and Recommendations

Conclusions

2.15 Using BLS data, the total employment for nonfuel mining is estimated to be about 128,000, and about 89, 300 for coal mining (totaling about 217,300). MSHA data show total employment for nonfuel mining to be about 225,600, and about 135,500 for coal mining (totaling roughly 361,100). (The BLS data undercount employment, largely because of limitations associated with the NAICS taxonomy that result in the undercounting of contractor employment.)

2.16 Employment projections are limited. BLS projections for private-sector employment for the NAICS codes of metal ore mining and nonmetallic mineral mining and quarrying indicate a net increase of 3,300 jobs by 2020. BLS projections also indicate that private-sector employment in the coal mining industry (excluding support activities) is expected to decrease modestly by 2020.

2.17 Other projections estimate the total number of U.S. coal miners will be about 92,300 in 2020 and about 112,500 in 2030, and the EIA projects that total employment in coal mining could be about 86,500 in 2020, 115,700 in 2030, and 128,600 in 2035.

2.18 Natural resources remain a critical component of the U.S. economy.

2.19 The various stakeholders have diverse, sometimes conflicting, interests:

- Governments seek security of resource supplies and employment for citizens.
- Government agencies conduct permitting and regulation oversight functions that must balance economic, environmental, and social imperatives, especially in developed economies.
- The workforce seeks employment, but with an increasing sense of balance with social/family components, especially in developed countries.
- The mining industry seeks growth and profitability, employing and distributing its financial and technical capital in risk/reward environments it deems prudent.
- Universities support departments that can generate substantial grant money and other sources of funding, and that can attract high-quality students.

2.20 Increased global demand for resources has created a shortage of many minerals and metals, as evidenced by a step-change in prices.

2.21 A talent crisis for professionals and workers is pending, and already exists for faculty, driven by two main factors—an aging workforce and international competition for talent. Both will precipitate fundamental changes in the cost of talent at all skill and education levels, but particularly for those positions requiring the most highly trained or educated practitioners.

2.22 Innovation in the mining business, broadly including the technology, science, and social domains, will be necessary to minimize the negative impacts of increased global demand for many minerals and metals, an aging workforce, and a pending talent shortage. This applies equally to industry, government, and educational institutions.

2.23 Significant stakeholders, including industry participants, academic institutions, and the government, could focus attention on issues relating to the discovery, cost, and supply of minerals and metals, and create an atmosphere of enthusiasm, stirring creativity. Such an effort could result in a renewed focus and interest in the industry, spurring increased enrollments in mining and geology departments at universities.

2.24 Shifting domestic U.S. demographics alone are expected to create a workforce shortage that is unlikely to be offset by increasing efficiencies. Australia, with similar trends as the U.S., offers strong evidence for an emerging shortage here.

2.25 Mining is important. Mining jobs are regionally distributed, generally well paying, and available across the full spectrum of job skills and educational requirements. Mining products form the foundation of the economy and add significantly to the GDP, and many are critical for national security. Information provided by the federal government, and particularly the USGS, for the collection, summary, and analysis of data and information related to mining in the U.S. economy, including commodity availability, production costs, and the supply of important and critical minerals through the full mining cycle are important to understanding the evolution of minerals and mining. Such data and information are also critical to the analysis of mining jobs and the mining workforce.

Although federal offices are applying their resources to collect and analyze reliable mineral data and information, the complexity of the global mineral market and the speed with which minerals, mining, and mineral products evolve are expected to require the collection and provision of increasing amounts and types of data with greater speed. The positive effects of this kind of enhanced information could be envisioned, for example, with respect to the way in which BLS classifies mining jobs. Currently, BLS does not use classification codes that allow a nuanced description of mining jobs that accurately reflects the variations in and evolution of the mining industry that might otherwise be informed by a more detailed federal analysis of the complex global character of minerals, mining, and mineral products.

Collection and provision of the summary kinds of detailed, reliable information noted above could most effectively be envisioned as being derived from a central federal source, such as the USGS, which has an established history of this kind of data collection. Such a federal entity would be a valuable BLS collaborator, serving as a source of comprehensive mining data and information that could assist the BLS in defining and updating classification codes and in informing BLS data collection, analysis, and projection efforts.

Recommendations

Some issues are critical and acute, requiring immediate solutions. Industry is most capable of a quick response by providing financial and leadership support to address short-term solutions until government and educational institutions are aligned to address medium- and long-term solutions. (Short term is defined as 2 years or less, medium term as 2-5 years, and long term as more than 5 years.)

2.5 The committee recommends that industry leadership consider that they could be facilitated by a fact-collecting and advisory entity (nonlobbying) composed of leadership from all extractive sectors, including metals, coal, industrial minerals, aggregates, and also possibly relevant governmental and educational institutions. Ideally, this entity would have an international perspective as well. (Short Term)

2.6 Such an entity could also help in the development of industrywide competency models, facilitating better alignment of educational and training programs with industry needs. (Medium Term)

With respect to higher education for "professions at risk," including mining engineering, extractive metallurgy, and economic geology (including geochemistry and mining geophysics), the teaching faculty for mining in the United States is insufficient to meet current and future needs. The system to replace these critical faculty is unsustainable and in need of major change.

2.7 Industry should consider providing financial and leadership support to sustain a critical teaching capacity until medium- and long-term solutions can be developed and implemented. (Short Term)

A holistic view of the workforce across all extractive industries in the context of competencies clearly indicates that the majority of workforce issues are served by a similarly educated and trained workforce, with STEM education as a foundation. With few exceptions, the training and educational capacity can be adapted to the changing needs of the extractive industries and government.

2.8 The committee recommends that industry and educators develop metrics and track training and education capacity at all levels to simply develop a comprehensive and talented workforce in the context of a "competency lattice." (Short Term)

2.9 Industry and educators should work together to develop a workforce capable of supporting the minerals sectors to serve the entire U.S. economy, including addressing all anticipated scenarios. (Medium and Long Term)

In addition to these recommendations, the Shared Recommendations for Chapter 2 (below) also apply for the mining industry.

SHARED RECOMMENDATIONS FOR CHAPTER 2

The following recommendations apply across the mature industries in this chapter, and they address a range of actions that are complementary. As noted in Chapter 3, they also apply across the emerging industries in that chapter. These "shared" recommendations are more general than the industry-specific recommendations presented in the various industry sections of the chapter because they can be applied across all of these industries. They also indicate that these industries share many common issues and basic solutions.

All of the Shared Recommendations should be initiated as soon as possible, and they are ordered and labeled in terms of when they would be expected to become fully operational. All are expected to continue for the long term. Short term is defined as 2 years or less, medium term as 2-5 years, and long term as more than 5 years.

Shared Recommendation 1: To address the growing demand for trained workers, industry, potentially with government support, should take an active part in developing the workforce of the future by working closely with educational institutions at all levels. Active involvement could include, but would not be limited to, developing a curriculum that trains individuals to be "job ready" upon completion of their certification or degree. This effort would benefit from being a national initiative and having a local/community focus. In pursuing this initiative, it would be important to consider, encourage, and emulate existing educational success stories, such as the programs supported by the National Science Foundation at community colleges, and the Truckee Meadows Community College program. The other educational success stories noted in Chapter 2 that are focusing on minority outreach also would be instructive for this broader initiative. (Short Term)

Shared Recommendation 2: To ensure that there are enough faculty now and in the pipeline, who are qualified to work and teach at the cutting edge of technology, the committee recommends that the government and industry consider entering into partnership to provide joint support for research programs at U.S. universities, with the goal of attracting and better preparing students and faculty, promoting innovation, and helping to ensure the relevance of university programs. (Short Term)

Shared Recommendation 3: The committee recommends that the industrial parties who are working with educational institutions on workforce education and training, along with the Department of Education, urge educators to encourage students to seek STEM disciplines, and to consider realigning education in the K-12 curriculum to emphasize STEM education, with existing and future educators being better trained in STEM disciplines. (Short Term)

Shared Recommendation 4: To provide a needed enhancement of the workforce, the committee recommends that industry and educators pursue efforts to attract nontraditional workers (who predominantly are minorities and women) into the energy and mining fields. This initiative would benefit from being a broad, national initiative and having a local/community focus. In pursuing this initiative, it would be important to consider, encourage, and emulate existing educational success stories, such as those with a focus on minority outreach (noted in Chapter 2). (Medium Term)

Shared Recommendation 5: Industry and educators should also pursue efforts to attract more of the traditional workforce into the energy and mining fields. This initiative also would benefit from being a national initiative and having a local/community focus. Educational success stories, such as those highlighted in this report, could also offer insights for this initiative. (Medium Term)

3

Emerging Sectors

INTRODUCTION

The renewable sectors of solar, wind, and geothermal energy and the sector of carbon capture, use, and storage (CCUS), which includes geological carbon sequestration, are not as mature or as long established as the sectors of oil and gas, nuclear energy, and mining discussed in Chapter 2. These sectors are still emerging and their pieces of the future U.S. energy quilt are still evolving. These emerging sectors are the subject of this chapter.

The following discussions of solar, wind, and geothermal energy, as well as CCUS, generally contain an overview of typical systems and related technologies, market trends, industry overview and profile, public policy and regulatory issues, occupational categories, career pathways, employer needs and challenges, workforce education and training, potential impact of innovation, conclusions, and recommendations. This chapter also highlights an example of a successful geothermal education program that could be emulated for other energy and mining sectors.

Recommendations of importance for each of the emerging industries in this chapter, along with the information and data to support them, are provided within their respective chapter sections. In addition to these industry-specific recommendations, a set of Shared Recommendations that apply across the industries in this chapter are presented at the final section of the chapter.

A point to note that is common to all of these emerging sectors relates to the availability of reliable workforce estimates and projections. As noted in Chapter 1 and described in Appendix B, this report primarily uses data from the Bureau of Labor Statistics (BLS) to profile the workforce. However, to examine the energy and mining workforce, there are shortcomings with using BLS data. The dominant limitation is the way in which the North American Industry Classification System (NAICS) system handles the emerging sectors. Whereas there are NAICS codes that are helpful in understanding the more mature industries covered in Chapter 2, the emerging industries are not represented by unique NAICS codes, making it currently infeasible to examine or project the workforce in each of these areas using BLS data. This limitation may be mitigated in time as the NAICS codes are updated. As an example of this possibility, in the 2012 version, separate NAICS codes are available for solar electric power generation, wind electric power generation, and geothermal electric power generation. Unfortunately, these changes will not make their way into all of the data sources available from the BLS and other agencies for several years.

Workforce information, data, and projections from sources other than BLS are used and discussed as appropriate in each of the emerging sector sections. There are variations among data from different sources, and these differences are noted in the discussions that follow.

A few general points are worth noting. Workforce estimates are prepared by The Solar Foundation (TSF, which regularly conducts a solar jobs census), the American Wind Energy Association (AWEA, which regularly prepares wind market reports), and the Geothermal Energy Association (GEA, which reports on the geothermal industry). Such data are presented from these and other authors. Also, TSF provides near-term workforce projections, GEA provides scenario-based workforce projections, and government entities (the National Renewable Energy Laboratory [NREL] and Department of Energy [DOE]) have conducted studies that include long-range workforce projections for solar and wind, respectively, based on specific scenarios. Such data are given from these and other authors. The projection time frames vary widely among the different data sources.

Industry market trends and projections are helpful in providing insights into possible workforce trends. Because the Energy Information Administration (EIA) is the source of energy statistics from the U.S. government, EIA data are used to show industry market trends and projections out to 2035. Trend information from TSF, AWEA, GEA, the Interstate Renewable Energy Council (IREC, for solar), and others are also presented.

The data in this report were collected by different entities for different purposes using a variety of methods and workforce definitions, making direct data comparisons difficult and inexact. Additional information about these data can be obtained from their referenced reports and papers.

SOLAR ENERGY

Introduction and Overview of Solar Power Systems

Three major categories of solar power systems are discussed—photovoltaics (PV),, solar heating and cooling (SHC),, and concentrating solar power (CSP). PV systems convert solar power directly into electric power. SHC systems convert solar energy into thermal energy that can be used to heat potable water, heat and cool buildings, and heat swimming pools. CSP systems are thermal electric systems that first convert solar energy into thermal energy to produce high-temperature steam, and then the steam is used to drive a turbine generator to produce electric power.

Photovoltaic Systems

The PV effect is the underlying phenomenon that allows PV systems to be effective electric power systems. When they are part of a complete electrical circuit and subjected to sunlight, PV (or solar) cells produce direct-current (dc) electricity. Many types of semiconductor materials can be used to make PV cells, but silicon is by far the most common. The typical silicon wafer is treated (doped) with both boron and phosphorous.

The PV cell is the basic building block of PV power systems. Manufacturers electrically connect the cells and enclose them in a laminate structure to form PV modules, which are the principal product sold by PV manufacturers. System designers and integrators combine modules in series and parallel configurations to form PV arrays with a desired current and voltage output.

A PV system that operates in parallel with the electric utility grid is referred to as utility interactive or grid tied. In this configuration, an inverter converts the array's dc output into alternating current (ac) and serves as a power conditioning unit to ensure high-quality electrical output. The ac signal from the inverter typically is connected to the utility grid in an electrical service panel, and from there is routed to the electrical loads. If the PV system output exceeds the total demand from the loads, the excess power flows into the utility grid, and the owner of the PV system is credited by the utility company for the metered electricity fed into the grid.

Batteries or other types of energy storage systems can be used with grid-tied systems. Systems with backup storage are more common in areas that are susceptible to extended power outages. During utility outages, stored energy can be used to supply critical loads for a selected period of time. However, most grid-tied PV systems do not have backup storage and if an outage occurs, the inverter automatically shuts down and no PV-generated power is available.

Stand-alone PV systems are not connected to the grid and most require energy storage, typically batteries. Their design requires an analysis of all electrical loads and a specification of the number of days of storage required to provide needed electricity for periods lacking sunshine.

The range of dc power output from residential PV arrays is typically 1-10 kW. Systems may be stand-alone or grid tied, and system size is often driven by incentive programs offered in various states and by utility companies. The design and installation of small commercial PV systems is very similar to that for residential systems, and they may be in the range of 10-100 kilowatts (kW) or higher. Large commercial PV systems range from greater than 100 kW to several megawatts (MW).

The combination of lower PV costs and an increasing number of states with renewable portfolio standards (RPSs) has led many utility companies to pursue utility-scale systems that range from 1 MW to hundreds of megawatts (Figure 3.1). Also, it often takes less than a year to obtain permits and build multimegawatt PV systems, generating great interest among utility companies.

Solar Heating and Cooling

SHC systems convert sunlight into thermal energy for a variety of applications; most commonly for heating water, heating and cooling buildings, and heating swimming pools. Flat-plate collectors may be glazed and insulated for heating potable water in buildings, or unglazed and not insulated for heating swimming pools. Evacuated tube or concentrating collectors can be used for higher-temperature applications, including industrial process heat. Passive building design is used to control the amount of solar thermal energy entering a space and storing it for later use. Solar thermal energy can also be used to drive an absorption chiller to actively cool buildings.

Concentrating Solar Power

Large concentrating solar power systems are becoming increasingly attractive to utility companies for large-scale electric power generation as costs decrease. There are a number of CSP plants operating and under construction, totaling a few gigawatts. These systems receive solar energy over a large area using either mirrors or concentrating collectors, and focus it onto a target of much smaller area. Depending on the level of concentration, temperatures above 1,000^{o}F can be attained in a working fluid. The thermal energy can produce steam to drive a turbine generator, which then produces electric power. CSP systems can be paired with more traditional turbine generators, possibly in conjunction with another fuel source. Figure 3.1 shows the construction of concentrating collectors for a CSP system in Florida. These collectors are the building blocks for Florida Power and Light's 75-MW Martin Solar Plant CSP system that came online in 2010.

FIGURE 3.1 (*Left*) Utility-scale PV system . (*Right*) Construction of concentrating sollectors for the Martin Solar Plant (a concentrating solar power system). SOURCE: (*Left*) http://solarpanelspower.net/solar-power/the-politics-of-solar-power. (*Right*) Sherwood (2011).

Solar Market Trends

Workforce trends follow market trends, so market trend information is a helpful indicator of potential workforce trends. Solar markets have been and continue to be very strong, mainly due to financial incentives from federal, state, and local governments, and electric utility companies. These incentives have produced significant demand for solar products. In 2010, the number of new solar installations completed was 124,000, including both solar electric and solar thermal systems, representing an increase of 22 percent, from 2009. The solar energy capacity installed in 2010 was 981 MW of dc electricity and 814 MW of thermal energy (Sherwood, 2011). As described below, the solar market has continued to grow since 2010 (Sherwood, 2012, SEIA/GTM, 2012a).

Financial and other incentives that drive the solar market vary considerably among the states. Therefore, the more robust solar markets are concentrated in relatively few states with the greatest incentives. Nationally, the 30 percent federal business investment tax credit (ITC) has been extended through December 31, 2016. This, along with recent legislation allowing utilities to take advantage of it, should result in continued near-term growth in solar markets.

Figure 3.2 is a snapshot of solar market trends for solar PV, SHC, and solar pool heating for the first decade of the 21st century. In terms of numbers of installations per year, note that the most dramatic growth was for grid-tied PV, which was significantly higher than for off-grid. Note also that the number of solar pool heating installations declined over the last half of the decade, primarily due to the collapse of the housing market and the associated decline in new home construction. For all four categories, the solar market grew from approximately 30,000 to nearly130,000 installations per year over the decade (Sherwood, 2011).

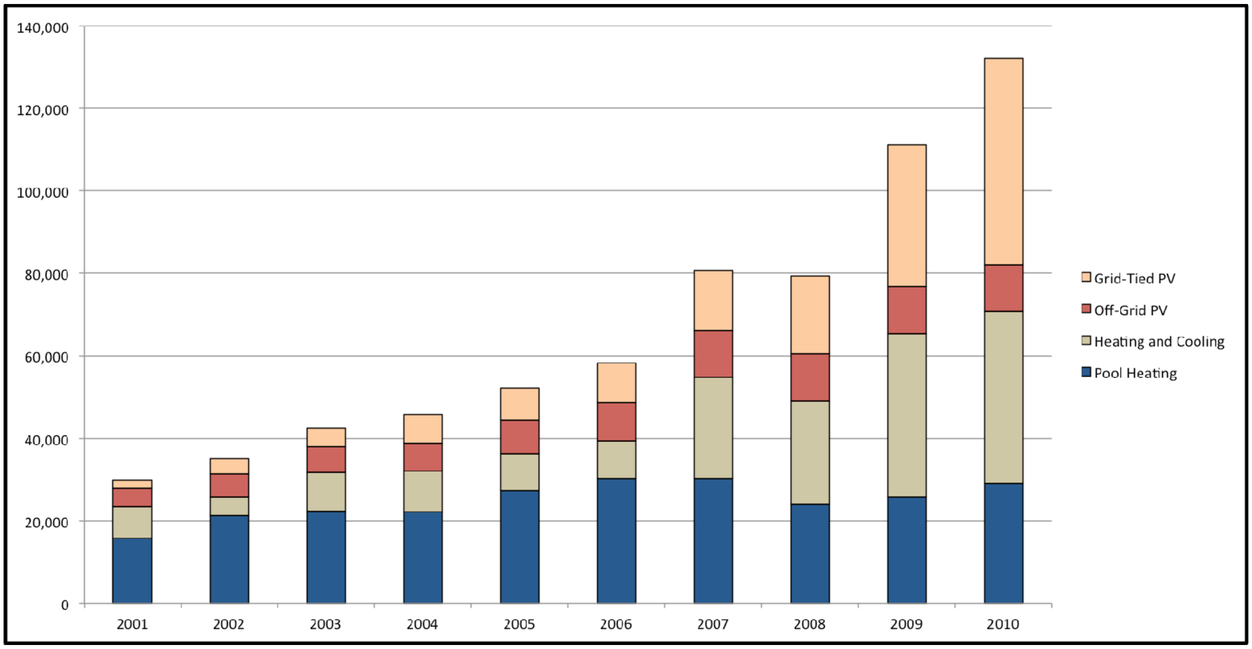


FIGURE 3.2 Number of U.S. installations per year by technology sector (2001-2010). SOURCE: Sherwood (2011).

Photovolatics

Grid-tied PV applications fall into three sectors: residential, nonresidential (i.e., commercial, government, and military installations), and utility-scale. Figure 3.3 shows the breakdown of annual installed capacity for these sectors for 2002-2011.

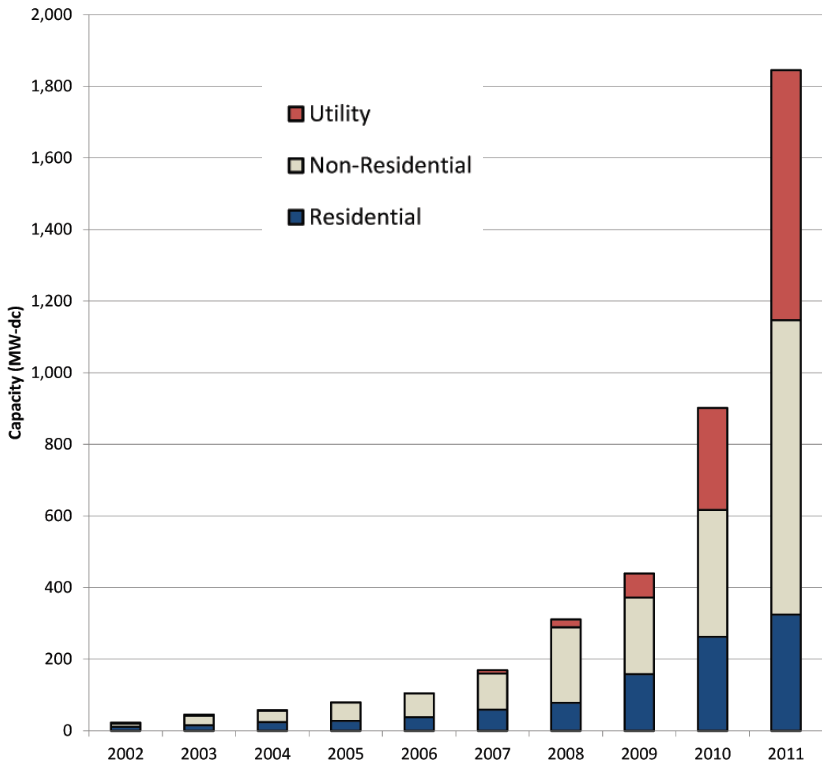


FIGURE 3.3 Annual installed capacity of U.S. grid-connected PV installations by sector (2002-2011). SOURCE: Sherwood (2012). Used with permission from the Interstate Renewable Energy Council.

More than 64,000 grid-tied PV systems were installed in 2011 (a 30 percent increase from 2010). From Figure 3.3, note that the capacity of grid-tied PV system installations more than doubled in 2011 compared with 2010. Both the increase in the number of utility-scale systems and the sizes of these systems accounted for this tremendous growth. The total installed capacity in 2011 alone was 1.845 GWdc, which was more than 10 times the capacity installed 4 years earlier in 2007. The cumulative installed capacity of grid-tied PV by the end of 2011 was 4 GWdc (Sherwood, 2012).

The average size of grid-tied systems has been growing in all three PV sectors. Average size varies from state to state and depends on available incentives, interconnection requirements, net metering regulations, and other factors. In 2011, PV installations represented 7 percent of all new electricity generation installed that year in the United States (Sherwood, 2012)

The growth trend in annual installed capacity was 848.5 MWdc in 2010, 1,886 MWdc in 2011, and 1,992.4 MWdc through the first three quarters of 2012. The cumulative PV capacity in the United States at the end of the third quarter of 2012 was 5.9 GWdc. The solar industry is projecting installations for 2012 to be 3.2 GWdc—a 70 percent annual growth rate for the year (GTM/SEIA, 2012b).

Solar Heating and Cooling

Solar thermal systems can be used to heat and/or cool buildings, heat water for swimming pools, and heat water for various industrial processes. Figure 3.2 shows the number of annual installations for SHC and for solar pool heating. In 2010, the total annual installed capacity for

SHC of buildings was nearly 160 MW-thermal. Solar water heating installations increased by 6 percent in 2010 compared with 2009, and 84 percent were in the residential sector. The annual installed capacity for solar pool heating was around 650 MW-thermal in 2010, with about 90 percent in the residential sector. In 2010, the capacity of solar pool heating installations grew 13 percent compared with 2009, but it is still 30 percent less than the peak reached in 2006 (Sherwood, 2011).

Concentrating Solar Power

In CSP systems, the thermal energy in a working fluid can be used to generate bulk electric power for utilities. From 1992 until 2006, there was very little CSP activity. However, because of RPSs, other incentive programs, and technology improvements, there is renewed interest among utilities in CSP systems. In 2010, only a 75-MW Florida Power and Light CSP plant and a small plant in Colorado were installed (Sherwood, 2011). However, a number of new and very large CSP power plants are in the planning or construction stages and are expected to be completed between now and into 2017. These plants include seven in California and one each in Arizona, Colorado, and Nevada, with a total ac power output of 2.737 GWac. (GTM/SEIA, 2012b).

Cost and Price Trends

Of all of the solar technologies, the greatest actual and potential cost reductions have been in PV systems. In 1976 the average cost of a PV module was approximately $60 per watt (using 2005 U.S. dollars) (USPREF, 2012). By 1985, the average cost was approximately $6.50 per watt (Mints, 2008), and by 2010, PV module costs averaged $1.70 per watt (Mints, 2011). In 2012, some module costs had dropped to below $0.90 per watt! With the rapid development of new materials and improved manufacturing, costs will continue to decline. The new SunShot Initiative, led by DOE, has set a goal of reducing PV module costs to $0.50 per watt, and to reduce installed PV system costs for utility-scale applications to $1 per watt by 2020 (Friedman, 2011). Figure 3.4 shows the price reduction goals for PV module, power electronics, balance-of-system, and installed system costs to achieve the SunShot Initiative goal.

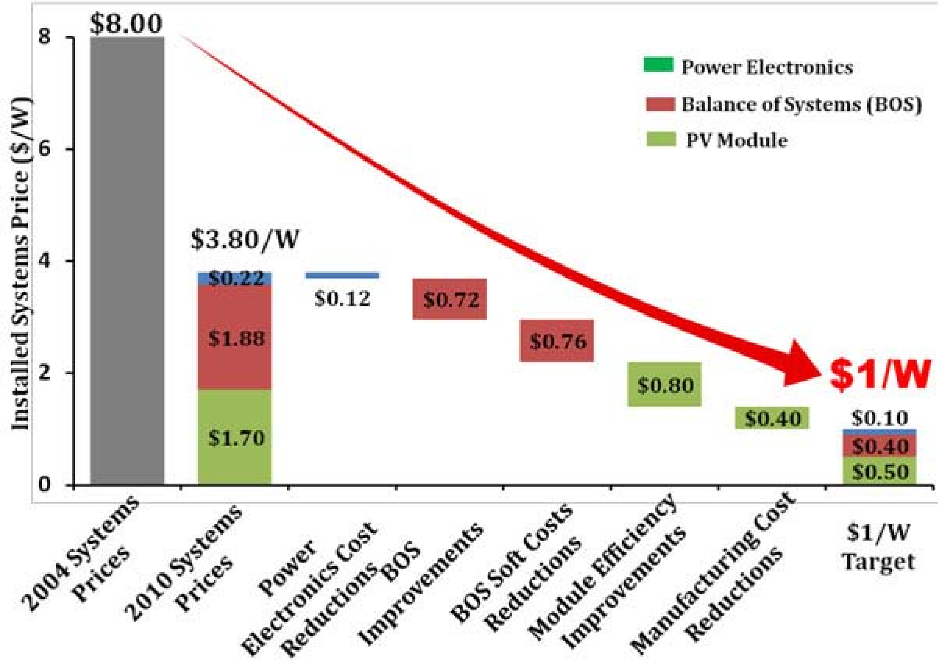


FIGURE 3.4 Price reductions to achieve the SunShot Initiative goal of $1/watt PV system costs.
SOURCE: Friedman (2011).

Market Projections

Given current U.S. economic conditions and the dependence of the solar market on government policies and incentive programs, it is difficult to project the size of solar markets in the long term. In the committee's judgment, trends over the past 10 years indicate the following:

- Solar pool heating capacity peaked in 2006. This market is partly driven by residential construction (which is not expected to fully recover soon) and the cost of installations is not expected to drop appreciably. Therefore, no significant near-term growth is anticipated.
- The solar heating and cooling system market should continue to grow at a moderate rate as the price of conventional energy continues to rise. Federal, state, and utility incentive programs can favorably influence these markets, but no technological breakthroughs leading to significant cost reductions are anticipated.
- Large CSP systems can help meet the requirements of RPSs for states that have them. Because they work best in areas with a high percentage of direct sunlight, significant growth in CSP is anticipated in the southwestern United States.
- Of the solar technologies, PV technology offers the greatest opportunity for significant growth in the near and long term. PV costs are decreasing rapidly, making PV more attractive to all major user sectors. Also, since PV power production is well aligned with peak utility demand, utilities are increasingly attracted to the technology. Grid parity is expected to be reached within the current decade, whereby PV-generated electricity will be cost-competitive with conventional generation. When that occurs, even higher rates of growth in PV markets can be expected, with utility companies leading the way.

The EIA has projected the solar thermal and solar PV net summer capacity and electrical generation for the electric power sector, as well as the solar PV net summer capacity and electrical generation for end-use generators through 2035. (see Table 3.1). Table 3.1 shows expected strong growth in the solar energy sector (especially for solar PV) through 2035. Note that the values for net summer capacity (GW) shown in the table should not be confused with the *rated* capacity of installed solar PV at standard test conditions (see notes following the table).

TABLE 3.1 Solar energy generating capacity and generation (EIA Reference case).

	2009	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**Annual Growth 2010-2035 (%)**
Electric Power Sector								
Net summer capacity[a] (GW)								
Solar thermal	0.47	0.47	1.36	1.36	1.36	1.36	1.36	4.3
Solar PV[b]	0.15	0.38	2.02	2.03	2.30	2.97	8.18	13.0
Generation (*billion* kWh)								
Solar	0.74	0.82	2.86	2.86	2.86	2.86	2.86	5.1
Solar PV[2]	0.16	0.46	3.61	3.62	4.37	6.16	20.19	16.4
End-Use Generators[c]								
Net summer capacity[a] (GW)								
Solar PV[b]	1.22	2.05	8.98	11.19	11.69	12.41	13.33	7.8
Generation (*billion kilowatthours*)								
Solar PV[b]	1.93	3.21	13.88	17.4	18.22	19.4	20.91	7.8

[a]Net summer capacity is the steady hourly output that generating equipment is expected to supply to system load (exclusive of auxiliary power), as demonstrated by tests during summer peak demand.
[b]Does not include off-grid PV. On the basis of annual PV shipments from 1989 through 2009, EIA estimates that as much as 245 MW of remote electricity generation PV applications (i.e., off-grid power systems) were in service in 2009, plus an additional 558 MW in communications, transportation, and assorted other non-grid-connected, specialized applications. The approach used to develop the estimate, based on shipment data, provides an upper estimate of the size of the PV stock, including both grid-based and off-grid PV. It will overestimate the size of the stock, because shipments include a substantial number of units that are exported, and each year some of the PV units installed earlier will be retired from service or abandoned.
[c]Includes combined heat and power plants and electricity-only plants in the commercial and industrial sectors; and small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid.
SOURCE: EIA (2012a, Table A16, pp. 162-163).

Solar Industry Overview and Profile

Structure and Location of the Industry

The structure of the solar industry across its entire value chain consists of the following areas:

- **Fundamental and Applied Research.** Fundamental or basic research is performed primarily by scientists and engineers with advanced degrees, and resides mostly at universities and research laboratories. Applied research is closer to product or process development and may include industry researchers in addition to those mentioned above.
- **Product Development**. This area is much more industry-based, involves concept development, value propositions, component design, and process design for manufacturing and production. It is typically represented by a variety of business engineering and scientific professions. Most have either a baccalaureate or graduate degree.
- **Manufacturing**. This group is industry based and includes a more diverse workforce. Much of the engineering involves process development, automation, lean manufacturing, computer control, and robotics. Test, evaluation, and quality assurance are important requirements for all manufacturing, and the associated workforce consists of a variety of operators, technicians, and professionals with 2- or 4-year degrees.
- **System Design**. Designers of large PV and CSP systems typically have a baccalaureate or graduate degree in engineering and are responsible for selecting, sizing, and integrating components and hardware into a solar system that meets both functional and operational requirements, and complies with all applicable codes, standards, and industry-accepted practices. Designers of residential and small commercial PV and SHC systems may be required to have an engineering license in some jurisdictions, but a 2- or 4-year technical degree may be sufficient in others.
- **Marketing, Sales, and Distribution**. Most of the workers in this group would have a 4-year degree in a relevant field.
- **Construction and Installation**. This is the largest group in the solar workforce and it consists of practitioners from a wide variety of construction trades, including electricians, plumbers, roofers, HVAC (heating, ventilation, and air conditioning), mechanics, carpenters, iron and steel workers, and glazers. Completion of a construction trades apprenticeship or similar vocational program, including both classroom instruction and on-the-job training, is the typical background requirement for this group of workers.
- **Operation and Maintenance**. This group consists primarily of workers with a technical background and possessing skills in computers, controls, instrumentation, measurements, diagnostics and troubleshooting, and service and repair. Workers would normally have a 2- or 4-year technical degree.

The heaviest concentration of U.S. solar activity, establishments, and jobs is in California, which currently employs approximately 25 percent of the solar workforce (TSF, 2011). The top 10 states in terms of the number of establishments are California, New Jersey, Pennsylvania, New York, Arizona, Texas, Florida, Colorado, Massachusetts, and Ohio.[1] In terms of installed PV capacity, the top 10 states are California, New Jersey, Arizona, New Mexico, Colorado, Pennsylvania, New York, North Carolina, Texas, and Nevada.

[1] The term "solar establishments" refers to the range of solar activities, including installation, manufacturing, sales and distribution, project development, and other (i.e., utilities, financial, legal, etc.).

Size and Employment

In the absence of BLS data, TSF's National Solar Jobs Census series is considered the most comprehensive study on solar jobs. The Census 2012 identified 119,016 solar workers as of September 2012 (TSF, 2012). Approximately 90 percent of workers who satisfied TSF's definition of a solar worker (i.e., someone who uses at least 50 percent of their time for solar-related activities) spent 100 percent of their time for solar work. Thus, although these are not full-time equivalent (FTE) jobs, these are considered "direct" jobs and the 50-percent metric is a reasonable proxy for measuring the solar workforce. The reason for this definition is that some jobs—for example, that of an electrician working for an electrical contractor—may involve both solar and nonsolar activities. If the solar activities over the year constitute 50 percent or more of the electrician's time, then the job is counted as one solar job. Therefore, the number of FTE solar jobs is somewhat less than 119,000.

Despite the weak economy, the number of solar jobs grew approximately 13.2 percent between August 2011 and September 2012, which is about six times the employment growth rate for the nation as a whole. Table 3.3 shows the changes for various job categories.

TABLE 3.2 Solar Job Categories, Numbers of Jobs, Growth Rates, and Projections for 2010-2013

Subsector	**2010 Jobs**	**2011 Jobs (Revised)**	**2012 Jobs**	**2011-2012 Growth Rate** (%)	**2013 Projected Employment**	**2012-2013 Expected Growth Rate** (%)
Installation	43,934	48,656	57,177	17.5	68,931	21
Manufacturing	24,916	37,941	29,742	21.6	32,313	9
Sales and distribution	11,744	13,000	16,005	23.1	19,549	22
Project development			7,988	—	9,098	14
Other	12,908	5,548	8,105	46.1	9,551	18
Total	93,502	105,145	119,016	13.2	139,442	17

SOURCE: Adapted from TSF (2012).

Challenges

There are a number of challenges to the growth of solar markets. They include a lack of economic growth; dependence on federal, state, and utility incentives in a depressed economy; limited consumer knowledge of solar products, applications, and their benefits; difficulty in obtaining financing for solar projects; and a shortage of an adequately trained workforce.

Public Policy and Regulation Issues

Solar industry growth over the last decade was in large part due to government and utility policies, related incentive programs, and regulatory changes that occurred. Some of the more important of these are RPSs, solar-specific set-asides, solar renewable energy credits and credit multipliers, net metering, the federal investment tax credit, and third-party ownership of solar systems.

RPSs[2] provide states with the means to increase renewable energy generation by requiring utilities and other retail electric providers to supply a specified minimum amount of their customer load with electricity from renewable resources. The primary goal of RPSs is to stimulate market growth and renewable technology development so that renewable energy will become economically competitive with conventional generation sources.

Currently, 29 states plus the District of Columbia and 2 territories have RPSs, and 8 states and 2 territories have renewable portfolio goals (but no standard). California has the most ambitious RPS, calling for 33 percent of electric generation from renewables by 2020. However, only 16 states and the District of Columbia require a specific percentage or amount of energy to be supplied by solar. Such a requirement is called a solar-specific set-aside.

With respect to solar renewable energy credits, most states with RPSs are involved in the trading of renewable energy certificates (RECs). RECs provide a way for states to track the amount of renewable energy being sold, and to financially reward those producing electricity using renewable energy. To promote a specific type of renewable energy, such as solar, some states offer a multiplier to the RECs earned. For example, instead of receiving one credit for each unit of electricity produced from renewable energy, a state may choose to offer two or three credits if the unit is produced from solar (as opposed to another form of renewable energy).

Net metering is a policy allowing owners of electric power systems, such as homeowners with PV systems, to receive retail credit for the electricity they produce that is fed back into the grid for use by other customers. This policy provides an economic incentive for consumers to purchase solar systems, and it can be implemented either by the utility or at the state level.

Another important incentive is the federal investment tax credit (ITC), which provides up to 30 percent of the total capital costs of a solar project. The ITC provides financial support to consumers who purchase solar systems and to the solar industry in building manufacturing plants, developing a solar workforce, and investing in large-scale solar electric power plants. It also allows regulated utilities to claim tax creditscredit, and it has been an important element in the development of utility-scale solar systems.

Third-party ownership of solar systems has been another major driver of the solar market. For this model, a third-party owner uses a power purchase agreement (PPA) to build, own, and operate a PV system on a customer's property, and then sell the PV-generated power back to the customer at an agreed-upon rate. It is attractive to customers who want to support solar power production, but who also want to avoid the initial costs and the responsibilities for constructing, operating, and maintaining the system.

Economic Impact

The development of the solar markets, industry, and workforce has been very heavily dependent on incentive programs as part of federal, state, and local government policies, as well as those of individual utilities. The economic impact of these incentive policies cannot be overstated. Without them, technologies such as PV could not compete with conventional generation at the present time in most locations. With incentives and the associated economies of

[2] A source for up-to-date information on RPSs and other incentive programs is the *Database on State Incentives for Renewables and Efficiency*, IREC and the North Carolina Solar Center (online and constantly updated). Available at www.dsireusa.org (accessed on April 23, 2012).

scale, the cost of PV modules has fallen dramatically from about $6.50 per watt in 1985 to less than $1.70 per watt in 2010 (Mints 2008, 2011), and to less than $0.90 per watt in some cases in 2012. In addition to PV modules, the costs of power electronics costs of and both mechanical and electrical balance-of-system costs have also fallen, reducing overall system costs to levels that make them more attractive to various user sectors. The national goal is for PV to achieve grid parity with conventional generation by 2020, at which point federal and other subsidies will not be nearly as important as they are today. If current cost reduction trends continue, this goal may be achieved.

Solar Workforce Occupational Categories

The *National Solar Job Census 2012* (TSF, 2012) identifies six different occupational categories among solar establishments surveyed, including installation, manufacturing, sales and distribution, project development, and other. In addition, DOE contracted with the Interstate Renewable Energy Council (IREC) to develop an interactive solar career map that identified 36 specific occupations in four different occupational sectors. Table 3.4 was constructed using information from both sources. The left column of the table lists the occupational categories from the census, and the right column lists specific solar jobs for each category.

Table 3.3 Solar Jobs for Selected Occupational Categories

Occupational Categories	Specific Job Titles
Installation	Solar installation contractor; dedicated solar installers and technicians; electricians, roofers, plumbers, and HVAC technicians with specific skills in solar installations; mechanical assemblers and installation helpers
Manufacturing	Engineers of all types; advanced manufacturing technicians; computer numerical control operators; process control technicians; quality assurance specialists; production and operation workers; first-line supervisors or managers of production and operation workers; sales occupations; accountants, accounting clerks and finance staff; marketing staff
Sales and distribution	Sales and marketing professionals; accountants, accounting clerks and finance staff; engineers of all types; administrative assistants and clerical workers; in-house legal staff
Project development	Solar project planners and developers; project managers; engineers of all types; residential and small commercial solar system designers; solar system integrators; architects and residential designers; site assessors; procurement specialists; construction cost accountants; financial specialists; attorneys with solar and/or environmental expertise
Other	Research and development scientists and engineers; interconnection engineers; engineering and service technicians; troubleshooting and diagnostic specialists

SOURCES: DOE (2011), TSF (2012)

Solar Career Pathways

A common view within the industry is that renewable electric technologies, such as solar technologies, attract students and other potential workers because of the industry's positive image. Potential workers are enthusiastic about the so-called "clean energy industry," a positive factor for the solar workforce.

As part of its SunShot Initiative, the DOE contracted with the IREC for a Web-based Solar Career Map[3] (DOE, 2011) that describes job opportunities in the solar industry. It includes 36 solar occupations in four sectors (component development; system design; marketing, sales, and permitting; and installation and operations) and at three levels (entry, mid, and advanced). For each occupation, it gives information about the job, including desired skills, competencies, education and training, median salaries, and career pathways. This interactive online career lattice allows users to explore opportunities for entering a specific solar occupation, and to identify possible routes for lateral career changes and career advancement.

Employer Needs and Challenges

Occupational Outlook

Because it is difficult to project future solar markets, it is difficult to project future jobs. Significant efforts to obtain current snapshots of the solar workforce are recent—for example, TSF's National Solar Jobs Census series (TSF, 2010, 2011, 2012). Such workforce surveys and analysis efforts offer only short-term projections. As useful as these efforts are, work remains to achieve a complete picture of the solar workforce. As the 2012 census (TSF, 2012) notes, its estimates do not include all jobs in the government, academic, nonprofit, or workforce development sectors, or many of the R&D and other types of employers that do solar work, and so, employment and firm counts are to be considered as a minimum baseline. The report also notes the lack of federal government (BLS) workforce data, and the difficulties encountered in categorizing solar workers (TSF, 2012).

As described in Appendix B, this report strives to rely primarily on workforce data from the BLS. However, data are not currently available for a NAICS code that is unique to the solar industry, making it infeasible to examine or project the solar workforce using BLS data. This limitation may be mitigated in time as the NAICS codes are updated. In the 2012 version of the NAICS, a separate code is available for solar electric power generation, but this change will not make its way into all of the federal data sources for several years.

It is very difficult to reliably project workforce estimates far into the future from the data that are now available. Table 3.1, above, offers a possible indication of future solar market trends, based on EIA projections. It shows expected strong growth in the solar sector (especially for solar PV) through 2035. Workforce trends are expected to follow market trends. In addition, NREL performed a study to consider the implications of reaching the SunShot Initiative's targets (NREL, 2012). According to the study, if the level of solar development defined in the study's

[3]Available at http://www1.eere.energy.gov/solar/careermap/

SunShot scenario[4] were achieved, 290,000 new solar jobs could result by 2030 and 390,000 by 2050.

Near-term workforce estimates are available. As noted above, data from TSF (2012) indicate about a 13.2 percent growth rate in solar jobs between August 2011 and September 2012. This was almost 6 times higher than the national average growth rate of 2.3 percent. The report projects a significant growth rate 17 percent in 2013 in all subsectors (See Table 3.5).

TABLE 3.5 Growth rate of solar jobs (TSF, 2012).

Growth	%	New Jobs
Installation jobs	21	11,754
Manufacturing jobs	9	2,571
Sales and distribution	22	3,544
Project development	14	1,110
All other sectors	18	1,446
Total	17	20,426

Required Occupational Knowledge and Skills

Occupational analysis is used to determine the duties, tasks, knowledge, skills, and traits for a given job—commonly using a DACUM (Developing a Curriculum), typically involving focus group meetings with high-performing, veteran workers who can thoroughly define the job. An important DACUM output is a job task analysis, specifying the tasks, knowledge, and skills required in the job. A similar method of job analysis is job profiling. ACT has developed a database that includes occupational profiles for 18,000 professional and blue-collar jobs (ACT, 2012).[5]

The North American Board of Certified Energy Practitioners (NABCEP), Underwriters Laboratories University (ULU), the Electronics Technicians Association International (ETAI), and the National Roofing Contractors Association (NRCA) have all developed task analyses for PV installers that are used for training and certification. NABCEP also has developed task analyses for solar thermal installers, small wind installers, and PV technical sales persons that are used in their certification programs. The IREC uses these task analyses as a basis for accrediting training programs and certifying instructors and master trainers.

Through the national Solar Instructor Training Network (SITN), new courses and programs are being developed and offered by educational and training institutions around the United States. Most focus primarily on training PV installers and use the task analysis developed by NABCEP. Also, the Center for Energy Workforce Development (CEWD) has developed a competency model for the energy industry—see Figure 7.5 in Chapter 7 and the related discussion (Randazzo, 2011).

The SITN is encouraging partnering educational institutions to adapt the CEWD competency model in developing their solar education and training curricula. Standardized core requirements based on the competency model should lead to a better educated and more skilled workforce.

[4] The SunShot scenario assumes that the SunShot Initiative's targets will be reached by 2020. The targets are for installed system prices of $1 per watt for utility-scale PV systems, $1.25 per watt for commercial rooftop PV systems, $1.50 per watt for residential rooftop PV systems, and $3.60 per watt/W for CSP systems with a capacity of up to 14 hours of thermal energy storage.

,[5] Available: http://act.org/workkeys/analysis/occup.html

Hiring Difficulty, Educational Preferences, and Workforce Opportunities

The 2011 Solar Jobs Census (TSF, 2011) indicated that more than 50 percent of solar company respondents expressed either great difficulty or some difficulty in hiring solar designers or engineers, solar installation managers or project foremen, solar sales representatives or estimators, solar water or pool heating installers or technicians, and PV installers or technicians. For manufacturing and for sales and distribution jobs, over 50 percent of the respondents indicated that there were too few qualified applicants for the job openings (TSF, 2011).

For training PV installers (the solar occupation in most demand) over a third of the solar company respondents to the survey (TSF, 2011) indicated that they preferred graduates of construction trade apprenticeship programs, similar to the 5-year electrician apprenticeship programs offered by the more than 300 International Brotherhood of Electrical Workers (IBEW) training centers around the U.S. According to 2012 Solar Jobs Census (TSF, 2012), with job growth expected, opportunities for employment in ranked order are sales and distribution; installation; other (e.g., finance, legal services, and research and development); project development; and manufacturing. The 2012 census also indicates that the largest category of new solar workers includes technical or production-related positions, followed by management, administrative, and sales jobs.

Education and Training

In 2008, several organizations, including the IREC and the Florida Solar Energy Center, conducted focus group meetings with industry representatives and highly experienced faculty to identify the most pressing needs for solar training. The result was a prioritized list of training needs, as follows: system installers, system designers and engineers, licensed contractors, building code officials, sales and site assessment personnel, architects and building designers, utility personnel, and construction cost accountants (Ventre and Weissman, 2009). Education and training for these occupations fall into one of three categories: vocational/construction trades; 2-year technical; and 4-year professional.

The construction trades are best suited to installing solar electric and thermal systems, and training is usually provided by vocational technical institutes, construction trade associations, community colleges, and solar energy research and educational entities. (PV system installation is primarily electrical construction, and thermal system installation is an extension of plumbing skills.) Organizations such as the National Joint Apprenticeship and Training Committee (NJATC), jointly sponsored by the International Brotherhood of Electrical Workers (IBEW) and the National Electrical Contractors Association (NECA), have made efforts to infuse PV training into their electrical apprenticeship programs. The Independent Electrical Contractors (IEC) Association has made similar efforts, and other groups also have made significant efforts to affect installer training.

Two-year technical programs at community colleges that produce trained technicians are well suited to the needs of solar occupations. Associate in applied science degrees stress applied technology for a specific occupation. Associate in science degree programs also stress technology for career education, and the degree credits can be applied to a 4-year program, such as a bachelor of science in engineering technology (BSET, or BET).

Four-year professional education is also important. Professional-level occupations in solar energy include business administration, project management, finance and accounting, and computer science. The most prevalent profession in solar energy (and energy systems in general) is engineering (all disciplines). The BSET prepares students to apply engineering principles to product improvement, design, manufacturing, and engineering operations. The bachelor of science in engineering provides a strong foundation for graduate school and research, and it prepares students to apply advanced mathematics, science, and engineering principles to design, product development, manufacturing, test and evaluation, and project management.

The professional science master's degree is a very attractive alternative for those desiring to combine the strong aspects of a master's of business administration degree with solar engineering. Such a combination provides an excellent background for project development, project management, and solar business administration and management.

With the broad spectrum of training needs, community colleges can play a special role. In addition to vocational, apprenticeship, certificate, and associate degree programs, community college offerings include 2+2 programs with 4-year institutions, and 2+2+2 programs among high schools, community colleges, and 4-year institutions. Also, solar education and training can be and is being incorporated into well-established programs, such as construction technology, industrial technology, and engineering technology.

Some states have actively supported solar education and training. For example, New York through the New York State Energy Research and Development Authority, and Florida through its Workforce Florida Banner Centers and the Florida Solar Energy Center, have actively supported education and training of the solar workforce for many years. Moreover, the solar industry has relied heavily on public funding support for workforce development, a lack of which would contribute to a greater shortfall of qualified solar workers.

Solar Instructor Training Network

Beginning in 2009, DOE has supported development and implementation of the SITN, consisting of nine regional training providers (RTPs) throughout the United States (DOE, 2012a). The RTPs provide faculty at partnering educational institutions with instruction and resources to develop courses and programs that address the urgent need for high-quality, locally accessible education and training. The IREC is the national administrator for the SITN. Since its inception, the SITN has trained more than 700 faculty members, representing more than 200 institutions. The RTPs train trainers representing institutions within their regions. The majority of the institutions are community colleges, but vocational-technical institutes and some high schools are represented. Participating institutions are encouraged to work closely with the solar industry in their vicinity. Efforts are made to train faculty at institutions where there is a market for students to be trained in solar energy.

The IREC is in the process of developing a compendium of best practices documents for renewable energy training. Five have been published, including *Curriculum and Program Development*, and several others are nearing completion (IREC, 2012). IREC has developed a menu of courses based on the NABCEP job task analysis for PV installers that provides educational institutions and training organizations with a variety of options for integrating solar installer content into existing certificate and/or degree programs (Sarubbi and Ventre, 2012).

Training Accreditation and Instructor Certification

The IREC is the North American licensee for the Institute for Sustainable Power Quality (IREC ISPQ) Standard 01022: 2011, which has been the basis for accrediting solar, renewable, and energy-efficiency training programs and continuing education providers, and for certifying master trainers and instructors teaching renewable energy courses. The goal of IREC credentialing is to provide evidence that graduates from accredited training programs achieve the necessary knowledge and skills to be successful. The IREC also uses the ISPQ standard to certify master trainers and instructors that teach solar courses. The categories of ISPQ certification are independent master trainer, affiliated master trainer, independent instructor, and affiliated instructor. In addition to the above standard, IREC Standard 14732: 2012,[6] General Requirements for Renewable Energy and Energy Efficiency Certificate Programs, has been extensively reviewed and was recently promulgated. This new standard was developed in partnership with the American National Standards Institute (ANSI) to assess credit and noncredit energy-related certificate programs for ANSI-IREC accreditation. Accreditation requirements include a systematic program plan, summative examination, and rigorous auditing and surveillance.

Practitioner Certification

Practitioner certification provides assurance that solar workers have met qualification requirements. Several organizations are involved in certifying and/or approving practitioners.

The NABCEP certifies four types of practitioners: PV system installers, solar water and pool heating system installers, small wind system installers, and PV technical salespersons. NABCEP certification of additional solar occupations is in the planning stage.

The ULU trains and certifies PV installers. Unlike many training organizations, the ULU requires that participants be licensed electricians, electrical contractors, or building officials with significant and relevant background knowledge and skills.

The ETAI approach to training and certification is unique. It includes a variety of pathways to attain one or more of three levels of PV technician status. The approach combines technical education with many of the same features of apprenticeship training for electricians, but with more grounding in alternative energy and a strong focus on PV technology.

The NRCA, through its Roof Integrated Solar Energy, Inc. Certified Solar Roofing Professional (RISE CSRP) program, has developed a task analysis specifically to certify roofers that install solar systems. The task analysis is the basis for both training and certification.

[6] http://www.irecusa.org/2012/09/ansi-irec-program-issues-first-set-of-energy-efficiency-and-renewable-energy-certificate-program-accreditations/

Innovation

Incremental Innovation

Much of the innovation in solar thermal technology has been incremental; most resulting in new materials, better components, more efficient designs, improved manufacturing processes, and a more skilled workforce. Because SHC systems are reliable, work well, and are economically attractive, continued growth is expected for the foreseeable future.

For concentrating systems, incremental innovation has been the rule. Higher concentrating solar collection and advances in thermal-to-electric conversion technologies may provide more options for utility-scale power generation. In any case, innovation is expected to continue and applications are expected to grow.

Most of the advances in PV technology have been incremental. Much of the research done by national laboratories and universities has focused on developing higher-efficiency cells at lower costs. Crystalline silicon has been the industry's mainstay for most of its history, and advances in efficiency and cost reduction have been significant. Research and development of a variety of thin-film materials and tandem cell configurations have produced many new and better-performing modules. Consequently, the cost of PV modules has been reduced substantially. The cost of the power electronics used to invert and condition the power output of PV systems also has been decreasing dramatically. This trend is expected to continue, with PV technology becoming increasingly competitive with conventional generation, coupled with the maturation of the industry, leading to more specialization and higher labor efficiencies.

Transformational Innovation

Predicting technological breakthroughs or transformational innovation is difficult. In addition to research on a variety of III-V and II-VI materials for PV cells, other technologies being investigated include thermophotovoltaic cells, intermediate-band solar cells, super tandem cells, hot carrier cells, optical up-and-down conversion, and organic PV cells (Messenger and Ventre, 2010). Considerable progress also has been made in microinverters that extend their lifetimes to over 20 years, making ac modules much more attractive to many users. And, automation will continue to reduce labor intensity. However, it is questionable whether any of these activities will result in transformational innovation.

However, two other possibilities should be considered. One is the Smart Grid (Chapter 4). The existing grid needs significant improvement to make best use of solar and wind power. All aspects of the Smart Grid would add value to large-scale solar and wind generation, transmission, and distribution, and the resulting enhanced connection to solar and wind sites would help mitigate the effects of weather variability. The Smart Grid could be transformational, and accelerated Smart Grid development would accelerate the realization of its potential benefits.

Finally, it should be noted that grid parity between conventional generation and PV power production is a tipping point that appears to be rapidly approaching, especially for utility-scale applications. Once achieved, transformational changes could occur in the generation and distribution of electricity. Concentrating PV collectors, which are now being offered to utility companies, will reduce costs even more. With the average time to permit and build a 1,000-MW PV power plant being approximately 1 year, compared with a minimum of 5 years to more than 10 years for conventional power plants, significant changes may be forthcoming.

Conclusions and Recommendations

Conclusions

3.1 The *National Solar Job Census 2012* (TSF, 2012) estimates that there are about 119,000 solar workers. Approximately 90 percent of workers who satisfied The Solar Foundation's definition of a solar worker (i.e., someone who uses at least 50 percent of their time for solar-related activities) spent 100 percent of their time on solar work. Projections of the future solar workforce are difficult to make, but DOE's *SunShot Vision Study* projects that, if the SunShot Initiative's system price targets are met by 2020, 290,000 new solar jobs could be supported by 2030.

3.2 Photovoltaic system sales have experienced continued exponential growth for the past 10 years, including during the recent economic downturn. Continued growth is expected for the foreseeable future, thus leading to more solar jobs.

3.3 The power output of PV systems is closely aligned with peak demand from utility customers for many service areas for much of the year, thus making PV systems more attractive to utilities and spurring growth in solar markets and the solar workforce.

3.4 The Smart Grid would facilitate increased integration of solar sources, bringing more systems online and reducing power swings caused by source variability, further enhancing the attractiveness and competitiveness of solar electricity generation and leading to more solar jobs.

3.5 Solar market growth, and hence workforce growth, has been and still is heavily dependent upon government policies and incentive programs.

3.6 The amount of solar subsidies is small compared with those for conventional fuels. Subsidies, incentives, investments in promising emerging technologies, and manufacturing innovations have resulted in significant cost reductions in PV systems, thus yielding better returns on investments. With continued federal and state government financial support, solar electric technologies should achieve grid parity and be competitive with conventional electric power production before 2020. When parity is achieved, significant increases in solar job growth can be anticipated.

3.7 A 1,000-MW PV power plant can be permitted and installed in 1 year, leading to not only significant clean energy production, but also significant job creation. Considering that 18,000 MW of PV power modules were shipped worldwide in 2010 alone, the energy and job creation potential of solar technology is enormous.

3.8 There is a shortage of adequately trained workers for the solar energy industry.

3.9 An interactive solar career map with 36 solar-related occupations and pathways for career placement, change, and advancement is available online to help education and training providers and those seeking employment.

3.10 Workforce education and training are being comprehensively addressed, and include construction trade apprenticeship, 2-year technical degree, and university-level professional training programs. The Solar Instructor Training Network coordinates nationwide education and training programs where needed for target audiences. The Interstate Renewable Energy Council accredits solar and energy-efficiency training programs and certifies master trainers and instructors. It also has developed a compendium of best practices documents for renewable energy training.

3.11 Historically, the solar industry has relied heavily on public support for workforce development. Without this support, there will be an even greater shortfall of qualified solar workers.

Recommendations

The following recommendations should be initiated as quickly as possible and some will take longer than others to become fully operational. The recommendations have been ordered and labeled in terms of when they would be expected to be operational. Moreover, recommendations 3.2, 3.3, 3.4, 3.5, and 3.6 are sequential and are ordered in accordance with when each step should be taken. The recommended actions are expected to continue for the long term.

3.1 The committee recommends that the Department of Energy continue to support solar workforce development programs, including the national Solar Instructor Training Network, and the updating of the Web-based interactive Solar Career Map. (Short Term)

3.2 For the purpose of building a stronger, more diverse, and higher-quality solar workforce, the solar industry should encourage certification of practitioners by the North American Board of Certified Energy Practitioners, and the pursuit of industry- and state-approved stackable credentials through construction-trade, vocational-technical, community college, and university certificate and degree programs. (Medium Term)

3.3 Solar content should be integrated into the curricula for traditional occupations that meet solar workforce needs, thus making education and training institutions more efficient, effective, and flexible in responding to changing solar markets. (Medium Term)

3.4 Accreditation of renewable-energy and energy-efficiency education and training programs and certification of instructors should be pursued using well-accepted, high-quality standards, such as the IREC ISPQ Standard 01022: 2011 and the IREC ANSI Standard 14732: 2013. (Medium Term)

3.5 The Department of Energy should ensure that education and training institutions inform their placement offices, faculty, and students, as well as local workforce development agencies, about the DOE's interactive Solar Career Map, its use, and its benefits to those seeking employment. (Medium Term)

3.6 The committee recommends that professional associations encourage industry, government, educational and vocational institutions, unions, and other organizations involved in solar workforce education and training to develop a robust and flexible education and training infrastructure for the solar energy workforce, rather than basing decisions on uncertain projections. This is best accomplished by using competency models, such as those developed by the Center for Energy Workforce Development, and by embedding needed content and curricula into existing educational and training programs. This can be done for the construction trades, technicians, and both technical and business professionals. This approach will facilitate a nimble workforce that will be able to quickly react to unfolding demands in the market. (Long Term)

In addition to these recommendations, the Shared Recommendations (at the end of the chapter) also apply for the solar industry.

WIND ENERGY

Introduction

Modern wind-powered electricity generation systems transform the kinetic energy of wind into electrical energy. However, conversion of wind energy for practical use has a long history.

Large wind turbines used to generate electricity were first used widely in the U.S. after World War II. The Organization of the Petroleum Exporting Countries (OPEC) oil embargo of the late 1970s spurred wind turbine technology development in the United States and elsewhere. Federal and state credits offered during the 1980s to the 2000s significantly stimulated the use of renewable resources, including wind, in the United States.

According to the Global Wind Energy Council, at the end of 2011, installed wind-generated electric power capacity was almost 238 GW worldwide. The United States is the No. 2 ranked country in installed capacity, accounting for approximately 20 percent of that total (nearly 47 GW at that time). The United States led the world in installed capacity until 2010, when it was overtaken by China (GWEC, 2011, 2012).

Overview of Wind Power Systems

Figure 3.5 shows a typical utility-scale turbine, along with a diagram of the major components in a wind turbine. The diagram on the left shows the size of a typical (around 1.5 MW) turbine rotor and tower compared to a Boeing 747. Newer turbines are in the 2- to 5-MW class, and offshore turbines may be as large as 10 MW. The diagram on the right shows the main components of a typical indirect-drive turbine, including pitching rotor blades, main shaft and bearing, speed-increasing gearbox, generator, and controller. The diagram depicts older-style turbines that employ induction machines and gearboxes. Newer turbines, although still using induction machines (albeit of a different type), have electronic power converters that match the power generated by variable wind speed to grid frequency and voltage.

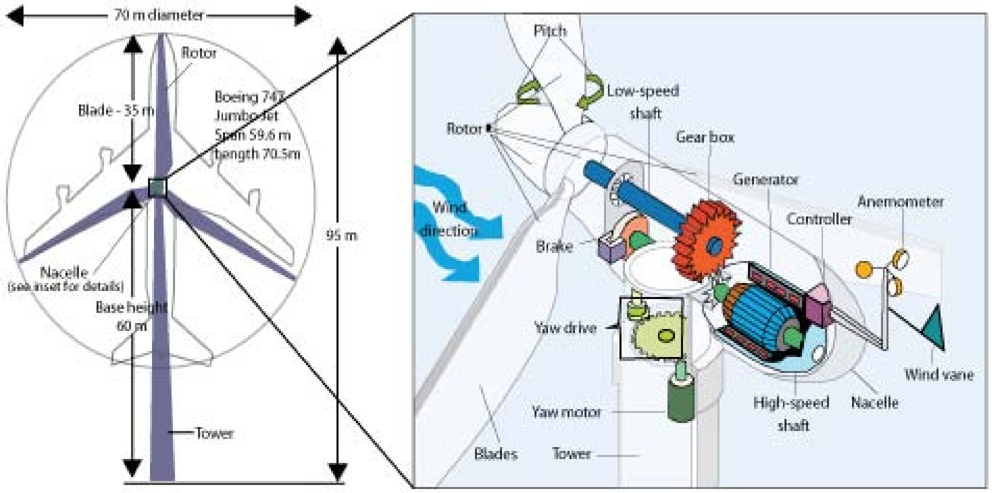


FIGURE 3.5 Typical 1.5-MW-class wind turbine system. SOURCE: Wilburn, (2011, Fig. 1, p. 2).

The latest generation of turbines is "direct drive." That is, there is no speed-increasing gearbox. Instead, synchronism is achieved primarily by the use of solid-state power converters. In addition, the generators employ permanent magnets to create a synchronous field that is independent of the operating speed and torque on the machine. These turbines are lighter, have fewer moving parts, and are more reliable, easier to install, and require less maintenance.

In much of Europe, onshore wind turbines are placed near communities, on farmland, and elsewhere. In the United States, they are most commonly installed in collections known as "wind farms" (see Figure 3.6). Wind farms allow power collection and single ties to the grid. They also maximize space utilization and often share space with farming or other activities. Placing wind farms in remote areas also tends to reduce community resistance to the sight of wind turbines.

FIGURE 3.6 Wind farm. SOURCE: http://www.dis.anl.gov/projects/windpowerforecasting.html. Used with permission from U.S. DOE's Office of Science.

Mineral Use in the Wind Turbine Industry

Minerals used in the fabrication, construction, and connection of utility-scale wind turbines include iron, steel, copper, and aluminum. In addition, some newer turbines use ceramic magnets that contain barium or strontium, and high-energy-density rare-earth magnets containing neodymium and boron (Wilburn, 2011).

High-energy-density permanent magnets are used to create high magnetic flux densities in efficient generators. Turbines with direct-drive systems rather than gearboxes have the potential to reduce operation and maintenance costs. Indirect-drive generators operate at a multiple of blade rotor speeds, but direct-drive turbine generators rotate at the same speed as the blade rotor. Because generated power is proportional to rotor speed and magnetic flux density, high-energy-density permanent magnets are critical to the development of direct-drive systems.

Because the vast majority of turbines in service and now being sold have wound rotor generators, only a relatively small amount of rare-earth materials is currently used in the wind turbine industry. The composition of the market at the end of 2008 is shown in Table 3.4 (Wilburn, 2011).

TABLE 3.4 Market Share of Wind Turbines by Generator Type in 2008.

Turbine Generator Type	Percent of Market
Double-fed induction generator (wound rotor)	73
Induction generator (cage rotor)	14
Direct-drive generator (wound rotor)	11
Direct-drive generator (permanent magnet)	2

NOTES: Numbers represent percentage of wind turbines under contract for development in 2008. SOURCE: Data from Wilburn (2011).

Because generators designed to use permanent magnets tend to be to lighter than other generators that also use power electronics rather than gearboxes to achieve grid control, the use of permanent-magnet materials is likely to increase. Rare-earth magnets have a higher energy product (a measure of the energy that a magnetic material can supply to an external magnetic circuit) than ceramic magnets, and so generator fields constructed from permanent magnets can be lighter and more efficient. According to Wilburn (2011), leading manufacturers, including Vestas, Siemens, and GE, are all introducing direct-drive permanent-magnet generators for their turbines. As a result, it is reasonable to expect that the share of generators with permanent-magnet fields, and therefore employing rare-earth materials, will increase significantly.

According to DOE, the use of major minerals by weight in a typical wind turbine is 89.1 percent steel, 1.6 percent copper, and 0.8 percent aluminum (DOE, 2008). The U.S. Geological Survey (USGS) extrapolated estimates for a typical turbine and matched them to the DOE's "20 Percent by 2030" plan to reach 20 percent of electricity generation to be produced from wind by the year 2030 and estimated the average annual use of minerals needed from 2010 to 2030. A summary of the results published by USGS is shown in Table 3.5 (Wilburn, 2011). The table shows the average annual material requirement, without consideration of recycling and recovery.

TABLE 3.5 Approximate Average Annual Material Requirements for 2010-2030 for Wind Turbines in Order to Meet the U.S. Department of Energy's Goal of 20 Percent Wind Energy by 2030

Mineral	10^6 kg
Steel	1,500
Cast iron	310
Copper	40
Aluminum	21
Neodymium	0.38

SOURCE: Adapted from Wilburn (2011, Table 5, p. 12).

Although the quantities of most of the materials listed in Table 3.6 are relatively small compared with the market, the amount of the rare earth mineral neodymium needed is of concern because of source limitations and market conditions.

Wind Market Trends

Wind power generation growth in the United States is shown in Figure 3.7. Although growth has slowed in the last 2 years, 6.81 GW of wind power was installed in the United States during 2011 (Swift, 2012). PPAs are being signed in the 5- to 6-cents/kwh range, making wind competitive with new natural gas generation (GWEC, 2011).

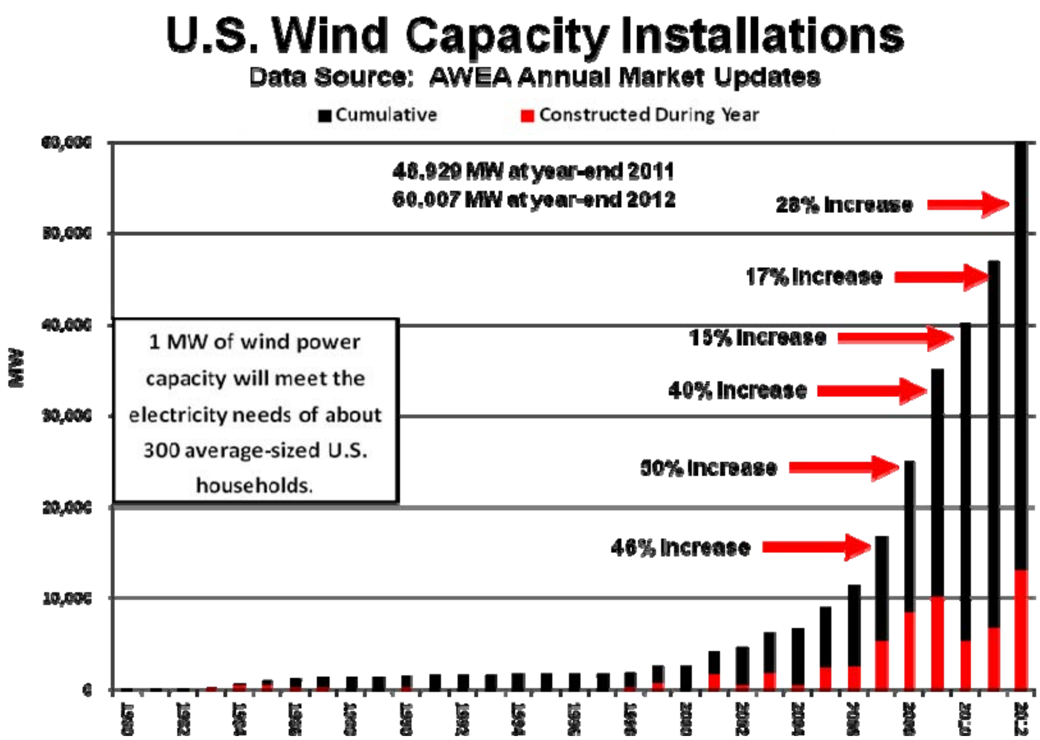


FIGURE 3.7 Growth of wind power installed capacity in the United States. SOURCE: Swift (2012). Used with permission from A. Swift and R. Walker, Texas Tech University.

The year 2010 showed a significant slowing of wind growth. The DOE 2010 Wind Market Report sums up the situation succinctly:

> *The U.S. wind power industry experienced a trying year in 2010, with a significant reduction in new builds compared to both 2008 and 2009. The delayed impact of the global financial crisis, relatively low natural gas and wholesale electricity prices, and slumping overall demand for energy countered the ongoing availability of existing federal and state incentives for wind energy deployment (Wiser and Bolinger, 2011, p. iii).*

In spite of the economic situation, wind power capacity grew by 15 percent in 2010 and 17 percent in 2011.

Installation of offshore wind power plants has commanded significant industry attention over the past several years, yet none of the new U.S. power installation was offshore. However, by the end of 2011, there were 15 proposed offshore projects and a proposed offshore transmission line (AWEA, 2012a).

In 2011, the manufacturer with the largest U.S. market share was GE, at slightly over 40 percent. GE was followed in order by Vestas (slightly over 20 percent), and Siemens (12.5 percent), with a total of over 73 percent of the U.S. market. Mitsubishi, Gamesa, Suzlon, and Clipper together had 21.3 percent of the U.S. share. (AWEA, 2012a) GE, Vestas, Siemens, Mitsubishi, Gamesa, and Clipper have significant manufacturing capability in the United States. The manufacturers also are supported by a growing list of supply-chain companies. According to DOE, imports of wind power equipment were down from 65 percent of total supply in 2005-2006 to about 40 percent in 2009-2010. In addition, exports of wind power equipment from the United States increased by a factor of 9 from 2007 to 2010 and continue to increase (Wiser and Bolinger, 2011). In 2011, 48 percent of the sales capacity of domestic manufacturers went to external markets (AWEA, 2012a).

These manufacturing additions, coupled with the economic downturn, have led to overcapacity in several areas of turbine manufacturing. Nevertheless, the American Wind Energy Association (AWEA) estimates that the wind energy sector employed 75,000 workers at the end of 2010 (AWEA, 2011a) and in 2011 (AWEA, 2012b).

Market Projections

Projections from the EIA anticipate strong growth in wind power generation through 2035 (see Figure 3.8 and Table 3.7). As Figure 3.8 shows, most of the expected increase in renewable capacity through 2035 will come from wind, but solar and biomass (not considered in this report) generation will increase at faster annual rates. In the EIA's Reference case, wind capacity is expected to nearly double from 2010 to 2035.

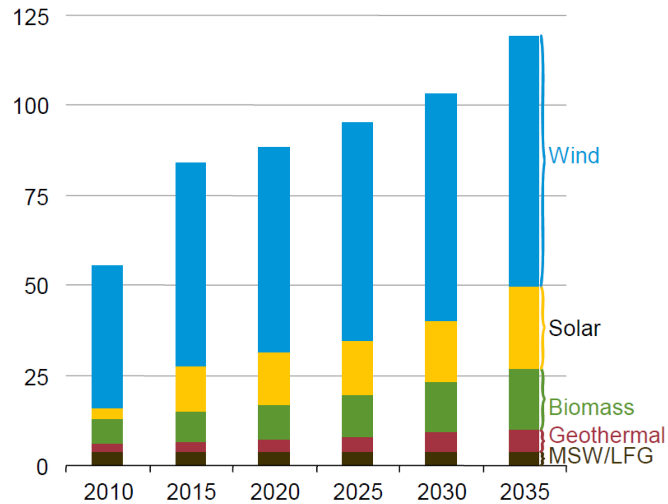


FIGURE 3.8 Nonhydropower renewable electricity generation capacity by source, including end-use capacity, 2010-2035 (GW). SOURCE: EIA, (2012a, Fig. 100, p. 90).

TABLE 3.7 Wind Energy Generating Capacity (EIA Reference Case)

	2009	**2010**	**2015**	**2020**	**2025**	**2030**	**2035**	**Annual Growth 2010-2035 (%)**
Electric Power Sector								
Net summer capacity[a] *(GW)*								
Wind	34.52	39.05	54.26	54.31	57.57	60.29	66.65	2.2
Offshore wind	0.00	0.00	0.20	0.20	0.20	0.20	0.20	–
Generation *(billion kwh)*								
Wind	73.88	94.49	150.22	150.34	160.73	169.64	189.92	2.8
Offshore wind	0.00	0.00	0.75	0.75	0.75	0.75	0.75	–
End-Use Generators[b]								
Net summer capacity[a] *(GW)*								
Wind	0.18	0.36	2.25	2.57	2.60	2.65	2.74	8.5
Generation *(billion kwh)*								
Wind	0.24	0.47	2.88	3.31	3.36	3.44	3.56	8.5

[a] Net summer capacity is the steady hourly output that generating equipment is expected to supply to system load (exclusive of auxiliary power), as demonstrated by tests during summer peak demand.
[b] Includes combined heat and power plants and electricity-only plants in the commercial and industrial sectors; and small on-site generating systems in the residential, commercial, and industrial sectors used primarily for own-use generation, but which may also sell some power to the grid. SOURCE: EIA (2012a, Table A16, pp. 162-163).

Industry Overview and Profile

The U.S. wind power industry includes utility-class generation used mainly in large wind farms and smaller-scale generation used in distributed applications, such as community wind, in and around industrial sites, and within cities. The economics of wind power favor utility-scale generation, and so wind farms and manufacturers of large wind turbines dominate the market. This market, in turn, is dominated by 10 large turbine manufacturers backed by a significant supply-chain network. However, consolidation in manufacturing is likely to occur in the current market.

Despite the economic slowdown and difficulties in accessing project financing, nearly 7 GW of wind power was installed in the United States in 2011 (AWEA, 2012b). Total U.S. capacity was nearly 47 GW at the end of 2011 and over 60 GW by the end of 2012 (AWEA, 2012a, 2013), and the United States remains a major player in the global wind market, with nearly 16 percent of the world's new capacity. China surpassed the United States in total installed wind generation capacity in 2010 and remained the global leader in 2011. Although it is true that wind power installations in the United States slowed in 2009 and 2010, it is worth noting that the United States is still ahead of schedule if it is to meet the 20 percent wind power generation by 2030 plan that was described by the DOE (DOE, 2008).

As shown in Figure 3.9, 39 states plus Puerto Rico now have installed wind power. Several more states are considering wind power installations, particularly if offshore wind becomes a reality here. Texas leads the other states with more than 12 GW of installed capacity, followed by California, Iowa, Illinois, and Oregon. However, Texas, California, Kansas, Oklahoma, and Illinois led the way in new installed capacity in 2012 (AWEA, 2013).

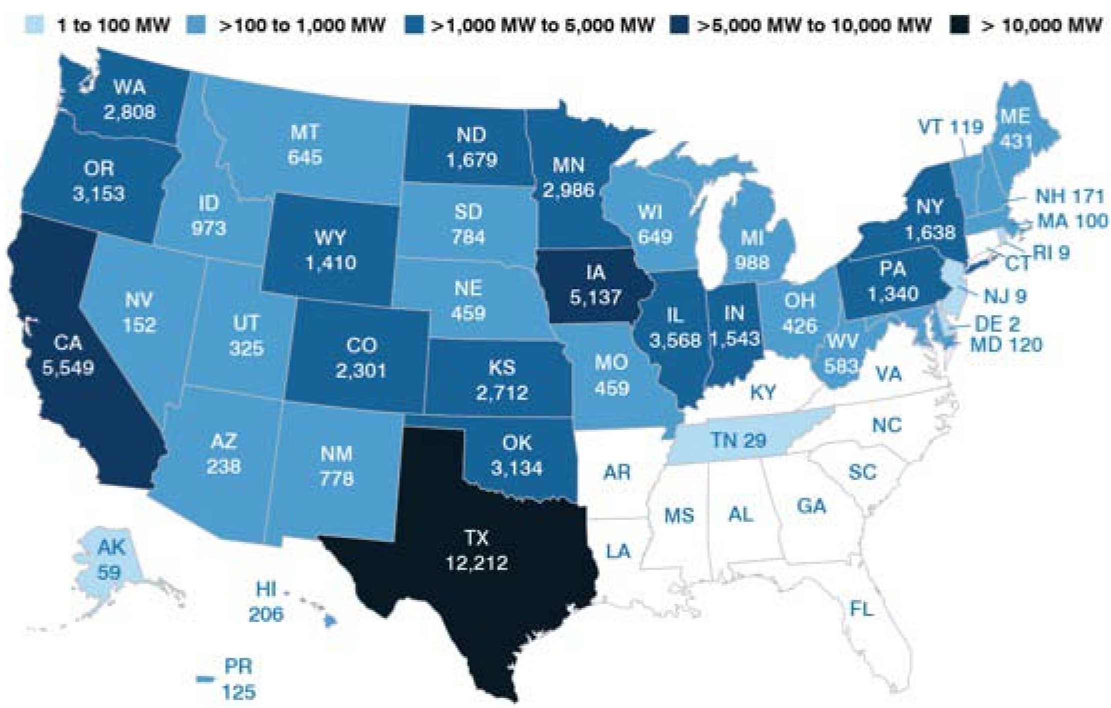


FIGURE 3.9 Wind power distribution by state. SOURCE: AWEA (2013).

While 39 states and Puerto Rico have utility-scale installations, 43 have wind-related manufacturing and many of these are in states without operating wind power. As a result, every state in the United States has a job market that is affected by the wind power industry. (AWEA, 2012a)

In 2008 and 2009, the AWEA counted approximately 85,000 jobs in the wind sector. In 2010, that number dropped by 10,000, to 75,000 (AWEA, 2011a) and held steady in 2011 (AWEA, 2012b). There were some bright spots in 2010, however. Employment in manufacturing, operations, and maintenance increased somewhat. Unfortunately, these increases were more than offset by losses in the service and installation sectors. (AWEA, 2011a) In 2011, the industry featured significant new installation, and it provided support for manufacturing, construction, engineering, development, and transportation jobs, with 30,000 jobs in manufacturing (AWEA, 2012a).

The distribution of jobs by state follows the installed capacity and manufacturing. Iowa, Texas, Illinois, Ohio, and Colorado have the most wind power jobs. However, two states with no installed wind generation capacity at all, North Carolina and Florida, have a large number of wind-related manufacturing jobs compared with most other states. The overall distribution of wind power employment is illustrated in Figure 3.10.

In 2006, DOE estimated the number of jobs needed to support the plan for 20 percent wind energy by 2030 (DOE, 2008). Their estimate for 2011 is low by nearly 50 percent and that difference tracks with the fact that installations are ahead of the 20 percent by 2030 capacity growth estimates. Even though significant time has passed since the estimates were made, and even considering the downturn that was not predicted in these estimates, there is some inherent conservatism that makes these numbers still useful for looking at the future workforce needs. (Employment projections are discussed in detail further in the chapter.)

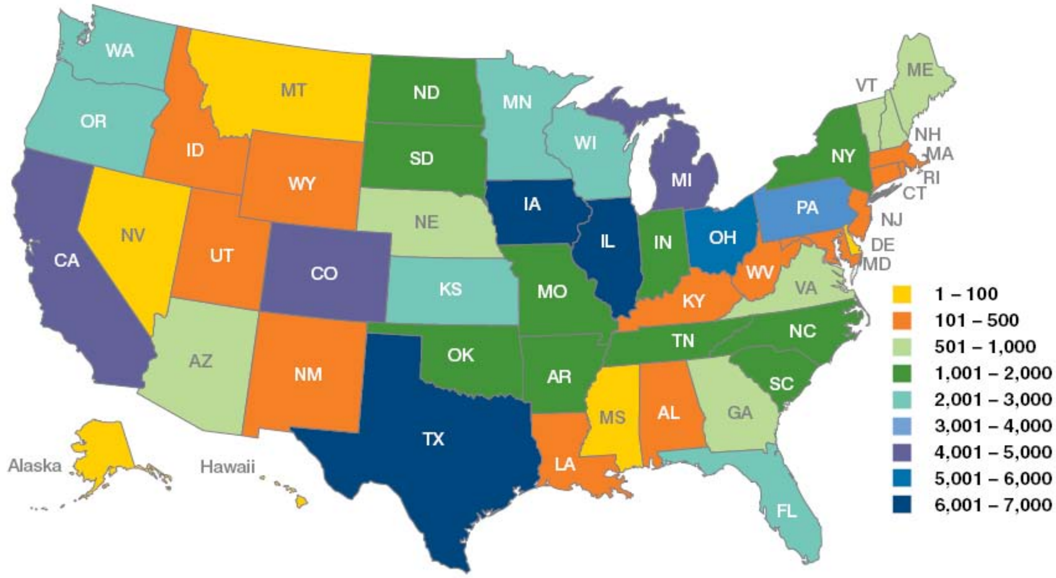


FIGURE 3.10 Wind power employment distribution by state. SOURCE: AWEA (2012a, Fig. 55, p. 50).

Public Policy and Regulation Issues

By far the largest public policy issues facing the wind power industry are the renewal by Congress of the production tax credit for wind power production and access to transmission capacity in areas with good wind resources. The production tax credit was scheduled to end in 2012, but was reinstated in January 2013. However, the impact of this uncertainty was already being felt. In early January 2012, faced with the uncertainty created by the lack of renewal, Vestas announced that up to 1,600 jobs would be lost in the United States from Vestas manufacturing and other activities. It is possible that other manufacturers would consider a similar scaling back, based on the lack of a consistent U.S. tax policy regarding wind power production.

The impact of this on the market will be partially offset by state-mandated RPSs). Twenty-nine states and Washington, D.C. had RPSs as of June 2011, and, according to the DOE, these standards will drive installation of wind power at the rate of 4 to 6 GW per year for the near future (between 2011 and 2020; Wiser and Bolinger, 2011).

New transmission lines totaling 8,800 miles were added in 2010, and 3,100 miles remain under construction. In addition, more than 39,000 miles of new transmission lines are projected to be built by 2020. (Wiser and Bolinger, 2011).) An example of these projects is the Texas competitive renewable energy zone (CREZ) transmission project that will ultimately result in the ability to transmit more than 18 GW of wind power from West Texas and the Panhandle to the central and eastern metropolitan areas of Texas.[1] (Public Utility Commission of Texas, 2010)

Also in Texas, significant interest in coastal wind resources has resulted in the construction of several large wind farms that mitigate the transmission issues by being closer to the population centers and they produce power more closely aligned with demand.

Workforce Occupational Categories

Wind power occupational categories are listed in Tables 3.8 and 3.9. Table 3.8 lists the engineering categories and Table 3.9 lists other categories.

TABLE 3.8 Wind Power Engineering Occupational Categories.

Tower and foundation design	CE
Road design	CE
Structural and blade design, testing	CE/ME
Surveyors	CE
Geotechnical engineer	CE
Geotechnical testing	GEOL/CE
Environmental management	CE/Env. Eng.
Construction-project management	CE
Project development	
Safety and environmental health	
Wind turbine design	ME
Power system integration and substation design	EE/ME
Interconnection design/collection system design	EE

[1] http://www.texascrezprojects.com/projects.aspx (accessed September 13, 2012).

Lean manufacturing for components and assembly	IE/ME
Site operations managers	ME/EE
Predictive maintenance specialists	ME/IE
SCADA Project engineers	EE/CS
Safety engineer	IE

NOTES: CE = civil engineering, CS = computer science, EE = electrical engineering, Env. Eng..= environmental engineering, GEOL = geology, IE = industrial engineering, ME = mechanical engineering, and SCADA = supervisory control and data acquisition. SOURCE: Adapted from Swift (2012).

TABLE 3.9 Other Wind Power Occupational Categories

Resource assessment specialist
Wind / power production data analyst
Wind / wind power forecasting
Technical sales and marketing
Project development
Utility liaison / interconnection experts
Community liaison
Regulatory / government liaison
Operations and maintenance management and supervision
Risk management and assessment
Supply-chain management
Manufacturing oversight / management
Energy analysis / energy auditing
GIS specialists / cartographers

NOTE: GIS = geographic information systems. SOURCE: Adapted from Swift (2012).

In addition to the categories listed in Tables 3.8 and 3.9, particular expertise is required in site environmental analysis and measurement, permitting, and site and geological survey. Offshore wind farms will require the above categories with marine specialization, along with designers and operators of offshore transportation and construction equipment. These categories do not include the skills required in the indirect-supply-chain workforce, including design and manufacture of connection equipment, temporary access roads, transportation, and other supply-chain fields. (The wind labor distribution by broad job type is shown further on in Figure 3.11.)

Wind Career Pathways

A common view within the industry is that renewable electric technologies, such as wind technologies, attract students and other potential workers because the industry has a positive image. Potential workers are enthusiastic about working in a so-called “clean energy industry.” This is a positive factor for the wind workforce.

The standard routes to employment and advancement in the wind industry are shown in an online, interactive, wind industry career map.[2] These follow the job categories noted above. The career map is divided by educational attainment and into four subsectors: manufacturing,

[2] http://www.iseek.org/industry/energy/careers/careers-in-wind.html (accessed September 13, 2012). The Web site was produced and is maintained by iSeek, which is a Minnesota partnership.

installation, general operations and maintenance, and R&D/other. The “other” subcategory includes areas such as site assessment and project planning and execution. The career map also shows typical pay associated with wind careers, and “clicking” on a job title links the user to detailed information about the job (iSeek, 2012). Much has been written on careers in the wind power industry, and this information can be readily referenced (DOE, 2001; CBIA, 2009; DMACC, 2009; Hamilton and Liming, 2010; Voinovich School of Leadership and Public Affairs, 2011; Oregon Green Career Pathways, 2012).

The skills and competencies required by the wind power industry have been researched and documented extensively. In particular, BLS has prepared a comprehensive report on careers in wind energy (Hamilton and Liming, 2010). The sections in the report that are relevant to competency, training, and education are summarized below. The BLS broke the wind industry down into phases as in a project: manufacturing, project development, operation and maintenance, and support.

Manufacturing

Large wind turbines are manufactured by large original equipment manufacturers (OEMs). Many types of engineers and general manufacturing labor are needed to manufacture the components of turbines. Engineering fields needed for wind turbine research, development, and manufacturing include aerospace, civil, electrical, electronics, environmental, health and safety, industrial, materials, mechanical, and engineering technicians. Most engineers enter the industry with a bachelor’s degree or higher. For general manufacturing jobs, duties include work by machinists, computer-controlled machine tool operators, assemblers, welders, inspectors, and industrial production managers (Hamilton and Liming, 2010). For example, aerospace engineers design and evaluate the aerodynamics of the blades and rotors, and computer-controlled machine tool operators utilize highly technical equipment to cut and form components. The education and training of the manufacturing side of wind generation varies, depending on the job each person is performing. In any case, most workers are subject to a good deal of on-the-job training specifically designed for wind turbine design and manufacturing (Hamilton and Liming, 2010).

Project Development

Building a wind farm requires years of planning and development. Land acquisition specialists, asset managers, and logisticians are needed for acquiring and administering the land to be used for a wind farm and for coordinating the transportation of materials to the site. These occupations usually require at least a bachelor’s degree with related experience and, once on the job, the employees receive specialized training. In addition to acquiring land, the permitting process and environmental impact studies require a breadth of expertise, including atmospheric scientists, wildlife biologists, geologists, and environmental scientists. Many of the scientists preparing studies and working on permitting carry an advanced degree such as a Ph.D. and many are certified or licensed in their respective field (Hamilton and Liming, 2010).

Construction of wind farms is complex and requires a number of different and skilled construction workers. Construction laborers and equipment operators carry out much of the infrastructure construction from access roads to foundations for the turbines. Crane operators are essential to erecting the tall structure and its components. In addition, electricians are required for connecting the internal electrical components and for connecting the turbine to the grid itself.

While construction labor does not require specific education or training, many workers receive training through apprenticeships and on-the-job with experienced workers. In the case of electricians, most learn their skills through apprenticeships and many states require that they pass an examination of electric theory and codes (Hamilton and Liming, 2010).

Project managers oversee the entire construction of the wind farm, from siting to installation; they oversee and manage the varied array of contractors and subcontractors. Project managers work for large construction firms, the energy companies themselves, or land owners. They also are responsible for the safety of workers on the site. Management positions usually require a bachelor's degree in construction management, business management, or engineering, and advanced degrees are becoming more prevalent (Hamilton and Liming, 2010).

Operation and Maintenance

Wind turbine service technicians (wind techs) handle the day-to-day servicing and maintenance of the wind turbines. For the first 2-5 years, OEMs provide service and maintenance under warranty and often employ wind techs for this period (Wittholz and Pan, 2004). There also are companies that specialize in turbine maintenance and provide their services to the owners of wind farms. Wind techs are responsible for all parts of the turbine, including the blades, rotors, and nacelles. Because wind farms are generally in remote locations, wind techs typically travel frequently or live in remote locations for extended periods. As a relatively nascent industry in the United States, training and education for wind techs are limited. Employers are increasingly emphasizing a wind-specific education, and formal training programs are developing. Community colleges and technical schools are starting to offer certificate programs (1 year) and degree programs (2 years) in wind turbine maintenance, and professional organizations such as AWEA are working on guidelines for the core curriculum and necessary skills (Hamilton and Liming, 2010).

Supporting Occupations

Many other occupations also support wind power. Even though many companies in the wind turbine supply chain are not focused on wind power alone, some of their workers do support wind power; for example, foundry workers turn raw materials into turbine components. In addition, other needed professional and administrative personnel include human resources specialists, accountants and auditors, lawyers, managers, secretaries, and receptionists. Custodial, maintenance, and security personnel are also necessary (Hamilton and Liming, 2010).

Summary

The direct job skills required in the wind power industry are, to a significant degree, the same as skills in other large sectors of the workforce. For example, the skills required to build a wind farm are similar to skills found in heavy construction, power plant development, and the communications and utility industries. The skills needed by the manufacturing subsector are similar to the skills in the manufacture of heavy equipment and utility equipment. Apart from the specialized requirements of project planning, resource assessment, particular environmental issues, and specialized safety skills, most jobs in the wind industry can be accomplished by workers with appropriate backgrounds and moderate on-the-job or short, intensive, specialized training. The problem in finding the appropriate wind workforce is the same one that afflicts the rest of the U.S. energy industry—there are not enough workers with the background training, skills, and experience to fill all of the jobs—and so the wind sector competes with other energy sectors, manufacturing, and construction for workers from a shrinking pool of talent.

Employer Needs and Challenges

Total U.S. employment in the wind energy sector stands at around 75,000 (Figure 3.11). Jobs have been added to the wind industry at a brisk pace since 2007. For example, during 2008 and one of the most severe economic downturns in U.S. history, the wind industry created 35,000 jobs. In addition, and in spite of persistent high unemployment, wind employment continues to grow. According to WindEnergyJobsInfo.com, "many top wind energy companies are projecting solid growth for wind energy jobs through 2020 due, in large part, to both public support and private investment."[3] An estimated 310 FTE manufacturing sector jobs, 67 jobs in contracting and installation, as well as 9.5 annual jobs in operation and maintenance are provided by each 100 MW of installed wind power capacity (North Carolina Wind Working Group, 2008).

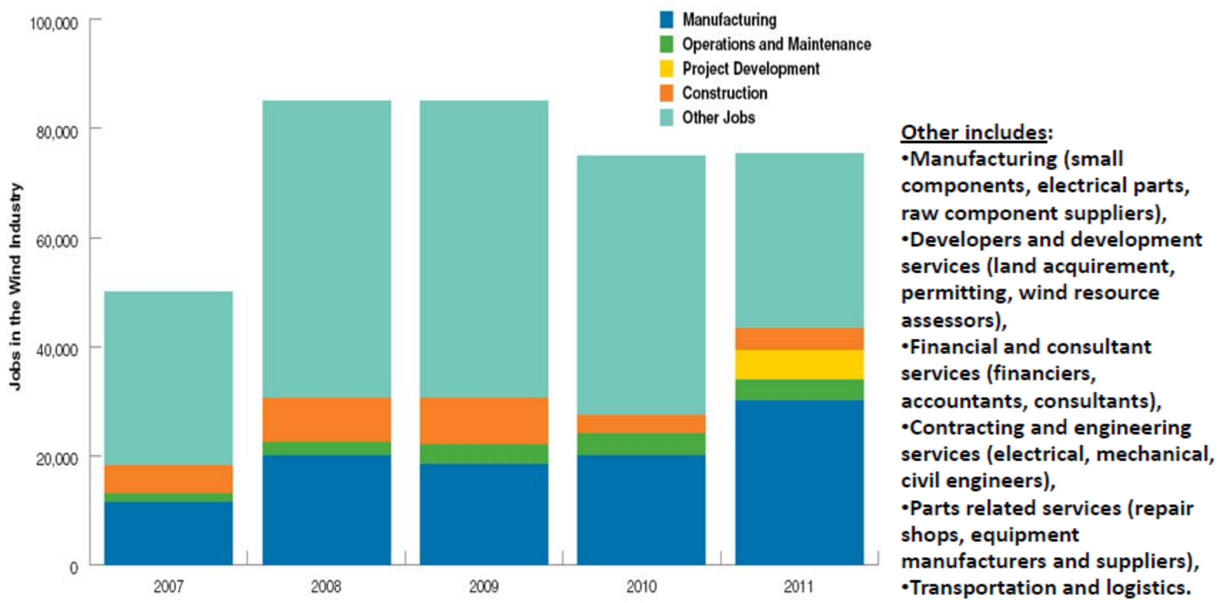


FIGURE 3.11 Wind industry jobs. SOURCE: Adapted from AWEA (2012a, Fig. 54, p. 49) and Swift (2012).

The following employment projections (Figure 3.12) are based on sustained market growth, industry's own projections, and estimates based on the DOE's *20% Wind Energy by 2030* report. Figures 3.11 and 3.12 show that actual employment has outpaced DOE's estimates by a factor of 2.

---

[3] http://www.windenergyjobsinfo.com/ (accessed May 22, 2012).

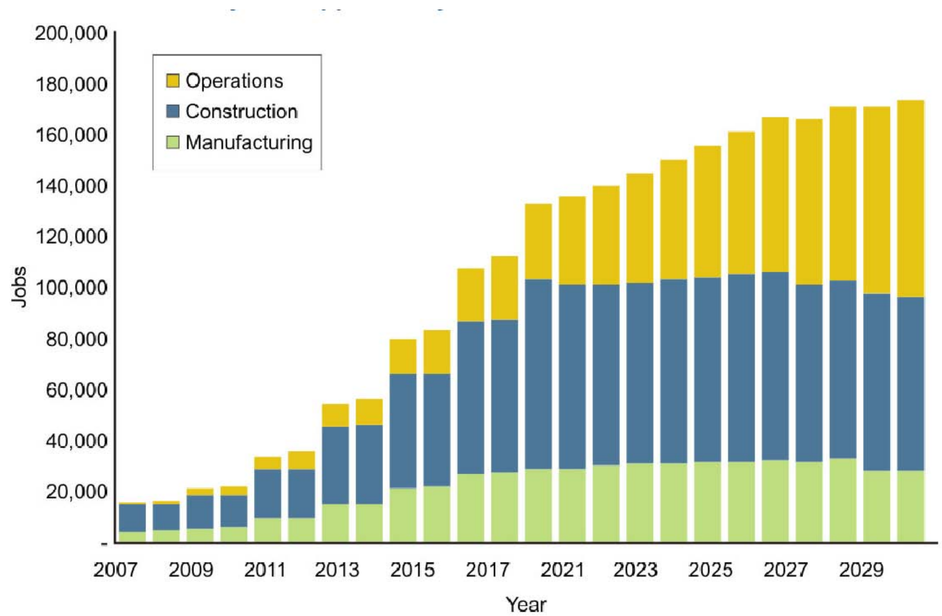


FIGURE 3.12 Direct manufacturing, construction, and operations jobs supported by the 20 percent wind scenario. SOURCE: DOE (2008, Fig. C-6, p. 209).

However, wind industry growth is currently mired in project finance, policy, and energy use growth issues. The wind power industry experienced a slowdown in 2010 for the first time in many years. Again, according to renewableenergyworld.com, "With less access to the large amount of capital needed to build projects, the industry installed just 539 MW of capacity in the first quarter of 2010, the lowest number since 2007" (Runyon, 2010).

Also, as noted earlier, the wind industry is having difficulty finding the properly prepared workers it needs, and it competes with other energy sectors, manufacturing, and construction for workers. Moreover, with the aging of the overall U.S. workforce, a large part of the professional and technical wind workforce will retire in the next 10 years. There are concerns in the business, academic, and technical communities about the nation's ability to adequately replace the retiring workforce. This further challenges the wind power industry to fill jobs with trained workers.

While many of the occupations delineated above are not wind- specific, the growth of the industry is creating the need for wind-specific knowledge. From manufacturing to maintenance, many different occupations are needed that require a breadth of construction, engineering, and technical knowledge and education.

Education and Training

Wind Education: K-12

Wind education in the K-12 classroom ranges from specific curricula for each level of K-12 to extracurricular material and competitions specific to wind energy education. Good national-standards-based curricula have been produced at the elementary, intermediate, and secondary school levels. Examples of strong, organized approaches to the development and dissemination of wind curricula in the United States are the National Energy Education

Development (NEED) Project, Energy for Educators, and KidWind/WindWise.

NEED is a nonprofit educational association established in 1980 to promote an energy-conscious and educated society. It is supported by a combination of educators, the energy industry, and public employers. NEED materials are correlated to the National Science Education Content Standards and all state standards. Curriculum guides, teacher guides, and student guides cover all grade levels. Their *Wonders of Wind* Teacher Guide and Student Guide are geared for the elementary level, and their *Wind for Schools* Curriculum Guides also encompass intermediate and secondary levels[4] (NEED.org, 2012).

Energy for Educators[5] is a project sponsored by the Idaho National Laboratory (Energy for Educators.org, 2009). Its Wind for Schools program, DOE's Wind Powering America program and the National Renewable Energy Laboratory install small wind turbines at hosting rural elementary and secondary schools. They also are developing Wind Application Centers at institutions of higher education. In the schools, teacher training and hands-on curricula facilitate the study of the wind turbine with interactive and interschool wind-related research activities. Students in the Wind Application Centers help with the assessment, design, and installation of the school wind systems, and serve as wind energy consultants. These students also are active in the classroom work and other engineering projects related to wind energy. This experience helps prepare them for wind-related employment after graduation. Wind for Schools projects are now in 11 states (Alaska, Arizona, Colorado, Idaho, Kansas, Montana, Nebraska, North Carolina, Pennsylvania, South Dakota, and Virginia). Wind Powering America prepares a list of known school wind projects (DOE, 2012d).[6]

KidWind[7] is a national organization that has trained more than 7,000 teachers through full- and half-day workshops and other presentations on wind energy and through KidWind student wind turbine model competition topics. KidWind estimates that more than 500,000 students have been affected, and the AWEA wind company members sponsored the third year of a national KidWind turbine model building competition at the national AWEA conference in June 2012. KidWind has trained 66 WindSenators (train the trainer teachers) in 21 states and elsewhere. KidWind has held training sessions in 40 states, Costa Rica, Canada, Chile, the United Kingdom, and Ireland. WindWise[8] is part of KidWind and it serves as the formal curricular arm used to train teachers. KidWind reports that 80 percent of teachers trained implement the wind materials in the classroom after going through workshops.

Wind Education: Community Colleges and Universities

There are many energy- and wind-related programs in community colleges. A list of the environmental and energy-related programs can be found on the National Science Foundation Advanced Technology Environmental Education Center Web site.[9] Although many colleges purport to have wind programs, there are only a few that meet the rigorous criteria of AWEA for programs to educate wind turbine technicians. On the basis of a skill set developed by AWEA, the AWEA Seal of Approval Program evaluates academic programs to ensure that they

[4] http://www.need.org/Curriculum-Guides-by-Grade-Level (accessed September 13, 2012).
[5] http://www.energyforeducators.org/index.shtml (accessed September 13, 2012).
[6] http://www.windpoweringamerica.gov/schools_wfs_project.asp (accessed September 13, 2012).
[7] http://learn.kidwind.org/ (accessed September 13, 2012).
[8] http://learn.kidwind.org/windwise (accessed August 2, 2012).
[9] http://ateec.org/ (accessed September 13, 2012).

adequately prepare students to be entry-level wind turbine service technicians. Programs are evaluated on content provided by the AWEA Seal of Approval Review Committee. The program does not provide certifications or accrediting credentials; it identifies programs that properly teach the skills considered important by AWEA members. The Seal of Approval is for specific courses of study at each school and does not apply to a school's entire wind curriculum. The programs that have received the AWEA Seal of Approval are listed by AWEA (2012a).[10]

The *Texas Wind Energy Industry Workforce Assessment Report* (Baker et al., 2011), released in December 2011, focuses on the current state of the wind industry in Texas, with respect to quantitative and qualitative industry needs and higher education preparation. Much of the report is a compilation of survey data from wind industry stakeholders and academic leaders from 2- and 4-year colleges or universities throughout Texas. With a predicted growth rate of 36 percent for full-time employees in wind energy in Texas over the next 5 years, it is not surprising that more than 68 percent of respondents from 4-year colleges indicated that their institutions anticipate offering a wind energy or renewable energy program by 2016.

Although renewable energy degrees are offered at some 4-year colleges, programs specific to wind and other renewable energy technologies are more commonly offered by community colleges, where new educational programs and curricula can be developed quickly in response to emerging trends in the job market (King, 2011). Most are certificate programs that produce technician-level jobs. The Texas workforce report notes that, for entry-level wind energy jobs in the state, the demand for such 1- or 2-year certificate or degree holders versus those entering the workforce with a baccalaureate degree is about equal. Most academic leaders reported a placement rate for program completers at 90 percent or greater.

Texas produces more energy from wind power than any other state, and as the wind energy industry continues to grow in Texas, educational programs are beginning to follow suit. Texas Tech University in Lubbock offers the state's first 4-year degree program in wind energy that combines mechanical education with managerial training in an effort to better prepare students for a wide variety of careers in the wind industry. Courses range from design and construction to policy and atmospheric science. Graduate students and professionals can also expand their skill set by pursuing one of two graduate certificate programs at Texas Tech, each of which includes 15 credit hours of graduate-level coursework. The technical graduate certificate is designed for students interested in technical aspects such as engineering and design, while the managerial graduate certificate is designed for students interested in supervisory roles.

Other wind energy education programs and courses also are available. Texas State Technical College has partnered with Texas Tech to offer a 2-year degree and several certificate opportunities under the Wind Energy Technology Program. The program focuses on operation and maintenance of electrical, pneumatic, communication, computer, control, or hydraulic systems related to wind turbine function, and a 2-MW turbine offers hands-on experience. The University of Texas at Brownsville offers a certificate program (Commercial Electrician– – Small Wind Turbine Technology). The Center for Global Energy, International Arbitration, and Environmental Law has been established by the University of Texas at Austin's School of Law to offer students a way to study the law, policy, and commercial aspects of energy production, protection of natural resources, and dispute resolution.

---

[10] http://www.awea.org/learnabout/education/awea_soa/index.cfm(accessed September 13, 2012).

A glance at the interactive, online map posted by the DOE[11] (2012c) that shows the locations of 167 wind energy education and training programs across the nation resembles other maps showing those areas of the United States that have the most wind. It quickly becomes apparent when tracing some of these institutional programs to learn the details about them that very few details are available. Part of the confusion is rooted in the myriad of options available for wind energy training at many different levels and from many different sources. In some cases, only a certificate program is offered, albeit through an accredited, 4-year institution. In other cases, certain community colleges offer programs ranging from the certificate level to a 2-year associate's degree, a 4-year B.S. or B.A. degree, and in some cases even an M.A./M.S. degree. Another complicating factor derives from the option to pursue wind technician training through facilities that are not community colleges per se, such as the EcoTech Institute in Colorado or California Wind Tech. In fact, California Wind Tech's Web site announces its intention to open a branch in San Angelo, Texas, in 2013.

AWEA maintains an accessible database of wind energy educational programs—the Educational Programs Database (AWEA, 2012d).[12] Windustry® is a nonprofit organization that promotes opportunities for wind energy for rural areas, and it maintains a list of postsecondary programs for degrees and training certificates with a focus on wind energy systems or renewable energy systems including wind (Windustry, 2012).

Conclusions and Recommendations

Conclusions

3.12 Despite the downturn in the economy, the impact on project financing, and uncertainties in tax treatment of wind power, installations of wind power continue and are significantly ahead of long-term predictions.

3.13 Strong growth in wind power generation is anticipated through 2035, with wind capacity expected to nearly double from 2010 levels, and with most of the increase in renewable capacity through 2035 expected to come from wind.

3.14 Wind power market growth is heavily dependent upon government policies and incentive programs, as well as access to transmission capacity in areas with good wind resources.

3.15 The wind power industry employs 75,000 workers.

3.16 Opportunities for employment across the wind workforce, both skilled and professional, are considered to be bright and will continue beyond 2030.

3.17 As with the overall aging U.S. workforce, a large segment of the professional and technical wind workforce will retire in the next 10 years. There are concerns within the business, academic, and technical communities about the United States being able to replace the retiring workforce. This retirement bubble, along with continued long-term growth in the wind industry and competition from the manufacturing, construction, and other energy sectors will exacerbate the existing shortage of workers in the U.S. wind industry.

---

[11] http://www.windpoweringamerica.gov/schools/education/education_training.asp (accessed September 13, 2012).
[12] http://www.awea2.org/ (accessed September 13, 2012).

3.18 Traditional sources of labor are not expected to be sufficient to make up the deficits caused by these factors, and nontraditional workers will be needed for the workforce.
3.19 Traditional science and engineering programs in the United States do not adequately address the needs of the wind power industry in content or size and they do not produce enough qualified workers.
3.20 There is an urgent need for an enhanced education pipeline to ensure that the demand for U.S. workers will be met.

Recommendations

The following recommendations should be initiated as quickly as possible. They are ordered and labeled in terms of when they would be expected to be operational. The recommended actions are expected to continue for the long term.

3.7 Industry, government, and educational and training institutions should work together to develop an interactive Wind Career Map such as the Solar Career Map to provide Web-based information about wind occupations. (Short Term)
3.8 Industry, government, and educational and training institutions also should work together to initiate an effort to accredit wind education programs and continuing education providers, and to certify master trainers and instructors for wind technicians. (Medium Term)

In addition to these recommendations, the Shared Recommendations (at the end of the chapter) also apply for the wind industry.

GEOTHERMAL ENERGY

Introduction

Geothermal resources are concentrations of heat that can be extracted and used economically. The Earth contains an immense amount of heat, but it is generally too diffuse or too deep to be used economically. Therefore, geothermal resources are sought in areas where geological processes have increased temperatures sufficiently near the surface that the heat can be used. A detailed treatment of the following introductory information is offered by Renner (2008).

There are two types of geothermal applications: electrical generation and direct use. Direct uses include heat for buildings, industrial processes, district heating systems, and the drying of crops and lumber. Direct use also includes geothermal heat pumps (GHPs) that heat and cool buildings and supply hot water (LtGovernors.com, 2012). Only heat concentrations associated with water in permeable rocks are now being exploited economically to produce electricity and for most direct uses. Researchers are developing methods to enhance permeability in hot rocks to allow economic production from currently uneconomical systems. Systems with adequate natural permeability are termed hydrothermal geothermal resources and systems that will require enhancement of the productivity are termed enhanced or engineered geothermal systems (EGSs).

Types of Geothermal Systems

All commercial production is now restricted to geothermal systems that are sufficiently hot for the intended use and contain a reservoir with sufficient water and productivity for economic development (hydrothermal systems). The U.S. Geological Survey (USGS) classifies hydrothermal resources as high temperature if they are hotter than 150°C, intermediate if they are 90-150°C, and low-temperature if they are less than 90°C (Muffler, 1979). Hydrothermal systems are used to generate electricity from high-temperature resources, but under some conditions, water at about 100°C can be economically used. Intermediate-temperature resources are most often applied for direct uses, and low-temperature resources are used by GHPs.

Estimates exist for the amount of energy associated with water coproduced during ongoing oil and gas production (Tester et al., 2006). Although these fluids are generally at temperatures below 150°C, they can be used to generate electricity. A small 250-kWe electrical plant is operating at the Teapot Dome oil field near Casper, Wyoming (Johnson and Walker, 2010), and other sites on the Gulf Coast and in North Dakota are being studied for development.

Enhanced geothermal systems are subsurface zones with low fluid productivity and little water. They are not now commercially viable in the United States; however, the resource base of hot rock is very large. Experts have estimated that “EGS could provide 100 GWe or more of cost-competitive generating capacity in the next 50 years” (Tester et al., 2006, pp. 1-3).

Methods for Electrical Generation

Most geothermal fields are liquid dominated—water at high temperature, but still in liquid form because of the high pressure, fills the fractured and porous reservoir rocks. With such systems, the wells produce a mixture of steam and water, and a separator is used to separate the two phases. The flashed steam powers a turbine to drive a generator, and afterward the water is injected back into the reservoir (Renner, 2008). Figure 3.13 depicts a flashed-steam power plant.

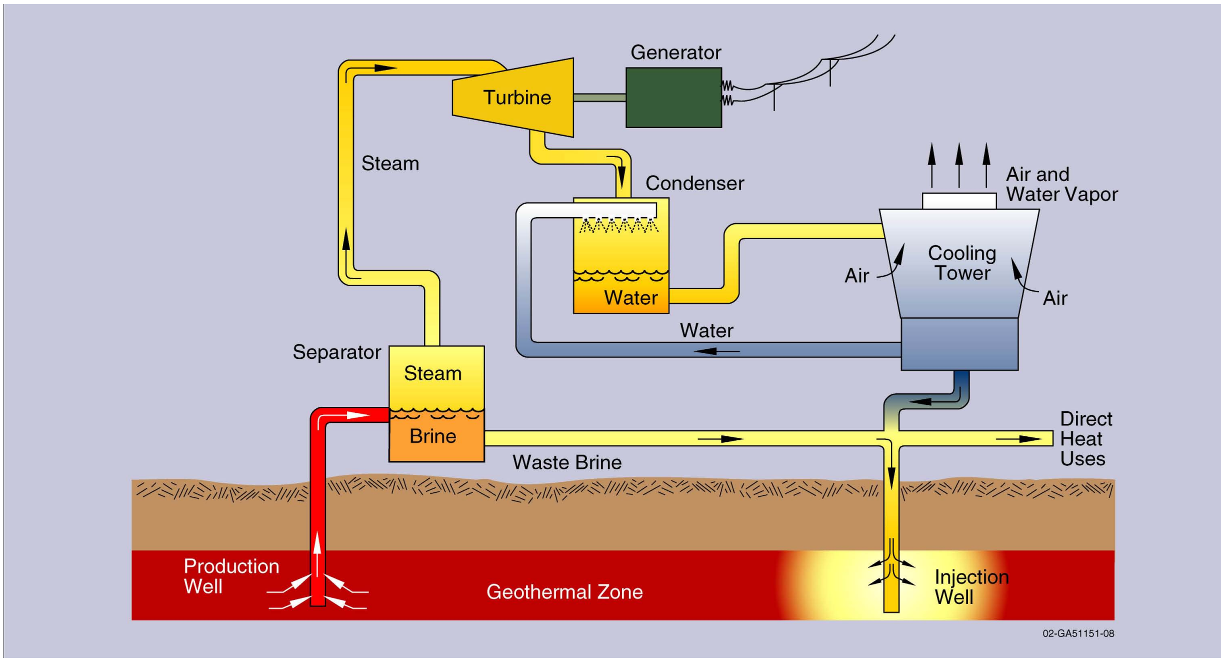


FIGURE 3.13 A flashed-steam power plant. SOURCE: Courtesy of Idaho National Laboratory.

In several geothermal fields, the wells produce only steam. In vapor-dominated systems, the separators and system for handling the separated water are not needed. These systems are more economical, but rare.

Pumping is used for many water-dominated reservoirs that are below 175°C, to prevent boiling of the water as it passes through heat exchangers, and a low-boiling-point secondary liquid is heated to power a turbine for generating electricity (see Figures 3.14 and 3.15). This technology is termed binary. Binary geothermal plants have minimal emissions because all of the geothermal water is injected back into the reservoir. There are many more identified intermediate-temperature geothermal systems than high-temperature fields, providing an economic incentive to develop more efficient binary plants. Binary technology also can be used for low-temperature resources by incorporating suitable low-boiling-point working fluids. Such resources will need to be shallow, have high well flow rates, and have favorable economics.

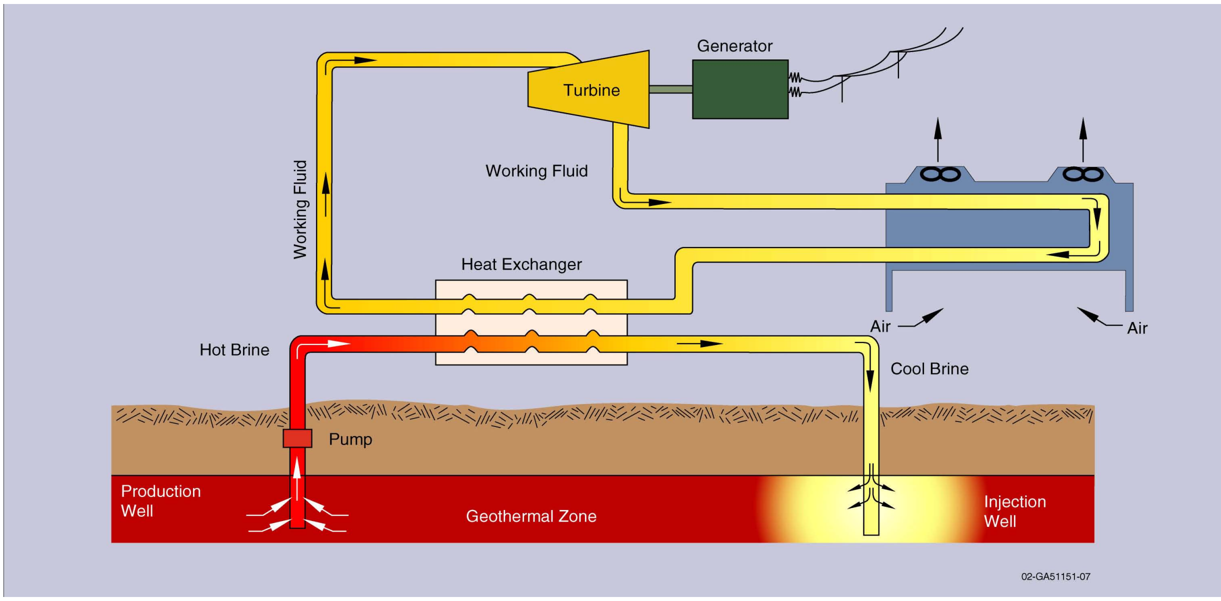


FIGURE 3.14 A binary power plant using an air-cooled condenser. When wet cooling is used, a cooling tower similar to one in a flash plant replaces the air cooler, requiring a source of water because all of the geothermal fluid is injected back into the reservoir. SOURCE: Courtesy of Idaho National Laboratory.

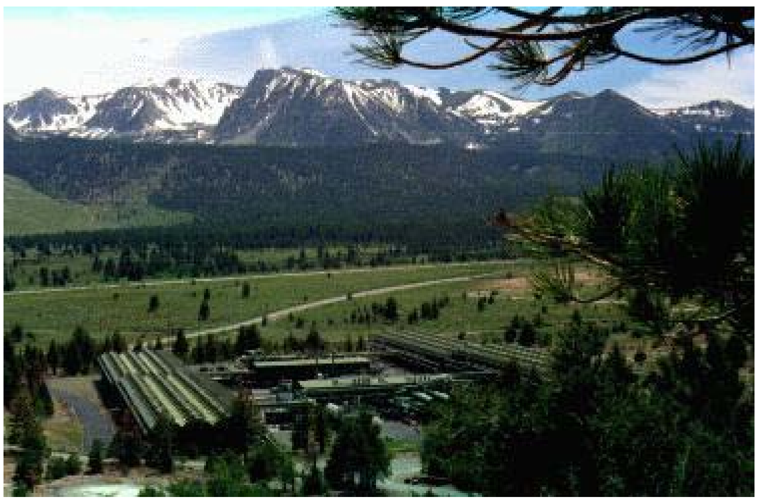


FIGURE 3.15 A typical geothermal power plant using air-cooled binary technology at the Casa Diablo field in California, with a generating capacity of about 30 MWe. SOURCE: Courtesy of J. L. Renner.

Direct Use of Geothermal Energy

Warm water (generally above 100°C) can be used directly to provide thermal energy for various applications. Swimming pools, space heating, and domestic hot water are the most common uses, but industrial processes and agricultural drying are increasing applications.

The most rapid increase in direct use is geothermal or ground-source heat pumps. GHPs use the ground rather than the air as the heat exchange medium, providing greater efficiencies. Depending on climate, advanced GHP use reduces energy consumption and power-plant emissions by 23-44 percent compared with advanced air-coupled heat pumps, and by 63-72 percent compared with electric-resistance heating and standard air conditioners. (L'Ecuyer et al. 1993, Renner, 2008). Strong growth in GHP use is expected to continue.

Geothermal Market Trends

U.S. Geothermal Development

Geothermal capacity and energy generation estimates come from three principal sources. Each year the EIA publishes data on electrical generation for the prior year, as well as the energy from GHPs (EIA, 2011c). The Geothermal Energy Association (GEA) publishes an annual report of geothermal electrical generation capacity and projects under development (Jennejohn, 2011; GEA, 2012). Data on geothermal direct use, as well as on electrical generation and GHP use, are summarized every 5 years in a comprehensive update of geothermal energy in the United States, prepared for the World Geothermal Congress (Lund et al., 2010).

Table 3.10 summarizes geothermal capacity and production in 2009. The total installed electrical capacity in 2009 was 3,048 MWe, producing 16,603 GWhe (gigawatt hour electric) from a running capacity of 2,024 MWe. Since the 2005 World Geothermal Congress, 514 MWe has been installed, representing a 20 percent increase or 3.7 percent annual increase over that period. Direct use (not including heat pumps) remained static for 2005-2009; however, GHPs were installed at a 13 percent annual growth rate, with about one million units in operation (Lund et al., 2010).

TABLE 3.10 Geothermal Capacity and Production as of 2009.

	Installed Capacity	Power Produced	Load Factor
Electricity	3,048 MWe	16,603 GWh/yr	0.94
	Installed Capacity	Energy Supplied	
Direct use[a]	611.5 MWt	9,151.8 TJ/yr	2,542 GWh/yr
Heat pumps	12,000 MWt	47,400 TJ/yr	13,167 GWh/yr

[a]Exclusive of heat pumps. Load factor is the ratio between the energy that a plant produces and the total energy that could be produced if the plant produced electricity at full capacity throughout the year.
SOURCE: Data from Lund et al. (2010).

Table 3.11 shows the annual consumption of geothermal energy for 2004-2010. It shows strong, steady growth in residential consumption (through increasing GHP use) and uneven growth in the generation of electricity.

TABLE 3.11 Geothermal Energy Consumption for 2004-2010 (Trillion Btu)

Sector	2004	2005	2006	2007	2008	2009	2010
Residential	14	16	18	22	26	33	37
Commercial	12	14	14	14	15	17	19
Industrial	4	4	4	5	5	4	4
Electric Power	148	147	145	145	146	146	153
Total	178	181	181	186	192	200	213

SOURCE: EIA (2011c, Tables 10.2a-c)..

Electrical Generation

Based on data from the EIA, GEA, and Lund, et al. (2010), geothermal electrical generation for 2004-2010 is shown in Table 3.12, indicating modest growth over the period.

TABLE 3.12 Net Geothermal Electrical Generation, 2004-2010 (GWh)

	2004	2005	2006	2007	2008	2009	2010
EIA	14,811	14,692	14,568	14,637	14,840	15,009	15,219
GEA				14,885			
Lund et al.				14,974		16,603	

SOURCES: GEA (2008), Lund et al. (2010), EIA (2012b, Table 1.1.A, p. 22).

The GEA estimates of electrical generation installed capacity and the EIA estimates of net summer capacity for 2004-2010 are shown in Table 3.13. In its latest report, the GEA notes an installed capacity of 3,187 MWe for the United States as of March 2012 (GEA, 2012). These data indicate a growth in capacity of around 12-13 percent through 2010, and continued growth since. Companies continue to explore and develop geothermal resources at more sites around the United States.

TABLE 3.13 Geothermal Electrical Generation Capacity for 2004-2010 (MWe)

	2004	2005	2006	2007	2008	2009	2010
Net Summer Capacity (EIA)[a]	2,152	2,285	2,274	2,214	2,229	2,382	2,405
Installed Capacity (GEA)	n/a	2,737	2,771	2,850	2,911	3,087	3,102

[a]EIA reports net winter capacity of 2,590 MWe in 2010.
SOURCES: EIA (2011d, Table 1.1B, p. 6), Jennejohn (2011).

Direct Use

The distribution of annual energy use for the various direct-use sectors is shown in Table 3.11, above. The EIA numbers are derived from records maintained at the Oregon Institute of Technology Geo-Heat Center. The EIA estimates that the numbers are underreported by 10 to 20 percent because of the small size of many direct-use applications, their isolated locations, and a lack of data. The growth of direct use over the past 5 years is due to the increased use of GHPs, because traditional direct-use development has remained flat, as shown in Figure 3.16.

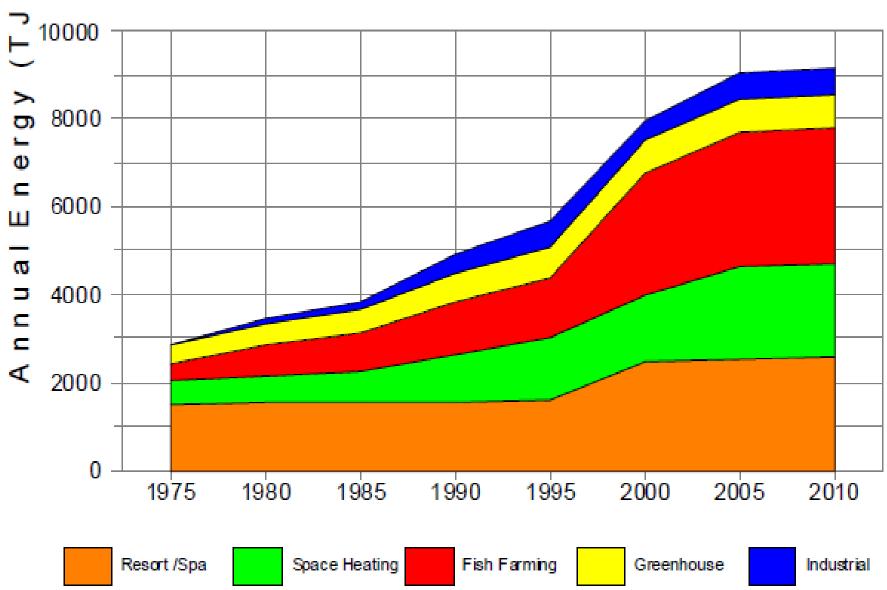


FIGURE 3.16 Direct-use growth in the United States without heat pumps. SOURCE: Tony Boyd, Geo-Heat Center.

For the past 15 years, installation of GHPs has increased at a steady rate. In 2009, an estimated 100,000 to 120,000 equivalent 12 kWt units were installed. As of 2010, estimates were that at least one million units had been installed, primarily in the midwestern and eastern United States. GHPs are located in all states and the number is increasing at a rate of 12-13 percent per year. The present installed capacity is reported to be about 12,000 MWt, and the annual energy use in the heating mode is reported to be 40,100 TJ/yr (or 11,147 GWh/yr) (Lund et al., 2010).

Projected Growth

Lund et al. (2010) report 132 confirmed geothermal electrical generation projects in the 2009 time frame, with an estimated potential generating capacity of 4,249-6,443 MWe. The GEA notes that the number of geothermal projects being developed and the geothermal prospects reported in 2011 increased by 12 percent over 2010, and in total, these projects were developing approximately 5,102-5,745 MW of geothermal resources (Jennejohn, 2011). The GEA also reports that the total number of confirmed projects and prospects has decreased slightly from what was reported in 2011, and the number of confirmed and unconfirmed projects represents 4,882-5,366 MW of geothermal resources in development (GEA, 2012). GEA (2012) provides a detailed breakdown of the projects in development by state. The EIA estimates for an increase in electrical generating capacity (see Table 3.15 below) suggest that level of production would not be accomplished until after 2025 (EIA, 2012b).

The confirmed projects are in 15 western states and smaller pilot projects are under early development in the states around the Gulf of Mexico. When considering the portion of the geothermal resources that developers believe to be viable for geothermal power plant production under existing economic conditions (the planned capacity addition, or PCA) in confirmed and unconfirmed projects, the range of power capacity in development is 1,961-2,023 MW. Of this amount, 949-956 MW is considered to be advanced-stage projects that are expected to be completed in the next 3-4 years. Considering the geothermal resources and planned capacity addition (PCA) in development together, an overall total of 5,317-5,836 MW is in development (GEA, 2012).

The growth to 2035 for residential GHPs and geothermal electrical generation projected by the EIA is shown in Tables 3.14 and 3.15. Geothermal capacity is expected to grow as a result of increased site availability, more favorable resource estimates, and lower costs for the construction of geothermal facilities.

TABLE 3.14 Projected Growth in Residential Geothermal Heat Pumps (quadrillion Btu per year)

2009	2010	2015	2020	2025	2030	2035	Annual Growth 2010-2035 (%)
0.00	0.01	0.01	0.02	0.02	0.02	0.03	6.4

SOURCE: EIA (2012a, Table A4, pp.139-140).

TABLE 3.15 Geothermal Energy Generating Capacity and Generation (EIA Reference Case)

	2009	2010	2015	2020	2025	2030	2035	Annual Growth 2010-2035 (%)
Electric power sector								
Net summer capacity[a] (GW)	2.37	2.37	2.86	3.57	4.45	5.48	6.30	4.0
Generation[b] (billion kWh)	15.01	15.67	18.68	24.41	31.53	39.89	46.54	4.5

[a]Net summer capacity is the steady hourly output that generating equipment is expected to supply to system load (exclusive of auxiliary power), as demonstrated by tests during summer peak demand.

[b]Includes both hydrothermal resources (hot water and steam) and near-field enhanced geothermal systems (EGSs). Near-field EGS potential occurs on known hydrothermal sites; however, this potential requires the addition of external fluids for electrical generation and will only be available after 2025. SOURCE: EIA (2012a, Table A16, pp. 162-163).

According to the Western Governors' Association (WGA), the western states share a capacity of almost 13,000 MWe of geothermal energy that is considered to be developable within a reasonable time frame. The WGA notes that 5,600 MW of this amount is considered to be viable for commercial development by the geothermal industry within 10 years of their report's publication (i.e., by about 2015). The levelized cost of energy of the 5,600 MWe would be about 5.3 to 7.9 cents per kWh (WGA, 2006).

In comparison with the latest GEA information given above, the 5,600 MW considered viable in the WGA report falls within the overall total range (5,317-5,836 MW) and is higher than the resource range (4,882-5,366 MW) noted by the GEA as being in development. It also is considerable higher than the PCA range (1,961-2,023 MW) given by the GEA. Tester et al.

(2006) note that 100 GWe or more of cost-competitive generation could be provided in the next 50 years with a reasonable EGS-related R&D investment.

Industry Overview and Profile

Structure and Location of the Industry

The structure of the U. S. geothermal industry includes three relatively separate sectors—generation of electricity, direct use, and GHPs. The electrical generation sector conducts exploration, performs developmental drilling, and builds and operates power plants. The direct-use sector (apart from GHPs) conducts exploration, drills production wells, and builds and operates facilities to use the energy from the produced geothermal fluids.

Although the electrical development and non-GHP, direct-use sectors both explore and drill, there are significant differences between them. Because of the higher value of the product, higher temperatures, and greater depth of the resource, electrical generation projects tend to spend more on exploration and drilling. Drilling for electrical-grade resources generally uses rigs from the oil and gas industry, and direct-use projects generally use water-well drilling rigs.

Installers are an important component of the GHP sector, but because of the large number of heat pumps installed annually, there also are a significant number of workers involved in manufacturing the units. The manufacturers are dominated by producers of air-sourced heat pumps and traditional air-conditioning units. The GHP sector has the largest marketing component of the geothermal industry.

Electricity is produced from geothermal resources in eight western states (Alaska, California, Hawaii, Idaho, Nevada, Oregon, Utah, and Wyoming), with the majority of the installed capacity in California (about 82 percent) and Nevada (about 15 percent). In addition, small power plants that will utilize coproduced water from oil and gas production are under development on the Gulf Coast and in North Dakota. Exploration and early resource development also are under way in Arizona, Colorado, New Mexico, and Washington (GEA, 2012). If the promise of EGSs is fulfilled, geothermal electrical generation will be possible throughout the United States.

The majority of direct use is concentrated in states west of the Rocky Mountains. However, geothermal resources are known to be used for space heating and spas in Arkansas, Georgia, New York, Virginia, and West Virginia. GHPs are used and continue to be installed in all states, with activity mainly in midwestern and eastern states, which require both heating and cooling (Lund et al., 2010). Companies developing geothermal projects in the western United States require the goods and services of vendors identified in 43 different states to support the development of the resources (GEA, 2012).

Size and Employment

The primary source of information on the number and types of geothermal jobs available is a series of reports published by the GEA. The GEA estimates that geothermal power plants employ 1.7 full-time positions per installed megawatt (Kagel, 2006). The report was based on a detailed survey of the geothermal industry, also conducted by the GEA (Hance, 2005). Another GEA report assumes 1.7 full-time positions (for power production and management) and 6.4

person-years (for associated manufacturing and construction jobs) per megawatt of installed geothermal power capacity (Jennejohn, 2010). Estimates by the GEA indicate that approximately 5,200 direct jobs associated with power production and management are supported by the geothermal industry, and that geothermal energy has a total direct, indirect, and induced impact that accounts for approximately 13,100 full-time jobs (Jennejohn, 2010).

Lund et al. (2010) summarize the professional personnel working in the geothermal industry in 2009 and estimate that about 0.5 person-years per MWe of installed capacity are for professional personnel. Table 3.16 gives the estimated allocation of professionals for 2005-2009.

TABLE 3.16 Allocation of Professional Personnel with University Degrees to Geothermal Activities (Professional Person-Years of Effort)

Year	Government	Public Utilities	Universities	Private Industry
2005	2	2	10	1,200
2006	2	2	10	1,200
2007	2	2	10	1,000
2008	2	2	10	1,000
2009	2	2	10	1,500
Total	10	10	50	5,900

SOURCE: Adapted from Lund et al. (2010, Table 7).

Challenges

The geothermal industry will be affected by the same workforce aging and big crew change as discussed for oil and gas in Chapter 2. The geothermal industry, particularly with respect to exploration professionals, has a similar bimodal age distribution. In addition, the geothermal industry has significant difficulty in recruiting and retaining professionals in light of the relatively attractive salaries and benefits offered by the petroleum and mining industries. Replacing retiring workers, expanding the geothermal workforce, particularly professionals, and slowing the attrition of professionals to related industries are crucial. Replacement of experienced explorers and technology development are needed to improve the rate of success in bringing greenfield exploration to successfully operating geothermal fields. Better training of geoscientists in the genesis of epithermal ore deposits and a better understanding of fluid pathways in the subsurface are, is important in the development of better conceptual models of geothermal systems.

Many geothermal reservoir engineers and drilling engineers are also nearing retirement age and their early replacement is required so that their experience, particularly in the “art” of geothermal drilling, can be passed on to the next generation of geothermal drillers. Hydrologists and engineers trained for the petroleum industry have much of the training required for geothermal operations; however, additional training for drillers is required in the control of lost circulation in geothermal environments, and operational differences in mud, and equipment needs at elevated temperatures.

Challenges to development of geothermal resources are influenced by the quality of the resource, high risk of exploration, cost of drilling wells, cost and efficiency of power conversion, and the selling price of electricity. Access to land for exploration and development is also an important challenge, because much of the resource is on federal land and the leasing and permitting processes may extend the period for development and limit access to good exploration targets.

The USGS has estimated the potential for electrical generation from conventional hydrothermal resources in the western United States (Alaska, Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming), identifying 241 moderate- and high-temperature geothermal systems. The mean power generation potential of these systems is 9,057 MWe, and there is a 95 percent probability of achieving 3,675 MWe and a 5 percent probability of achieving 16,457 MWe. For undiscovered resources, the mean estimated power production potential is 30,033 MWe, with a 95 percent probability of achieving 7,917 MWe and a 5 percent probability of achieving 73,286 MWe (Williams et al., 2008).

Geothermal exploration has not yet developed tools for exploration and development that have a sufficiently high rate of success to attract investors. The current state of the art is comparable to the days when oil and gas reservoirs were located by drilling in oil seeps. Exploration techniques are needed that can predict not only the presence of elevated subsurface temperature, but also the presence of a reservoir with adequate fluid production to permit economic development.

Small rigs utilized by the hydrology and mining sectors are often used for drilling temperature-gradient wells and small-diameter exploration wells. Wells for geothermal electrical development are generally large diameter (greater than 7 inches), deep (greater than 2,000 ft), and require drilling rigs similar to those used for oil and gas. Consequently, when oil and gas prices rise, the costs of drilling and geothermal development also rise. However, the cost of natural gas does not have as great an influence on increasing the value of electrical generation, and so that geothermal value does not increase as rapidly as drilling costs. Decreasing the cost of drilling is a major challenge to geothermal development.

The efficiency of converting geothermal energy into electricity is relatively low because of the low temperatures of even the best geothermal resources. This challenges the industry to develop more efficient energy conversion technology without adding too much to the cost of the generating equipment. The selling price of geothermal energy, the remote location of much of the resource, and access to transmission infrastructure are also challenges that the industry cannot directly influence by improved technology.

Development of technology to economically develop geothermal energy through the use of EGSs would create a step change in production of geothermal energy. Estimates by Tester et al. (2006) indicate that about 100,000 MWe or more of cost-competitive generating capacity could be developed in the next 50 years with a reasonable investment in R&D. Their estimates also indicate that 14×10^{24} Joules of energy are available between depths of 3 and 10 km in the United States. With a recovery factor of 2 percent, about 1,249,000 MWe for 30 years should be available between 3 and 10 km (Tester et al., 2006).

Public Policy and Regulatory Issues

Public policy and regulatory issues play an important role in the development of geothermal energy, particularly for electrical generation and GHPs. For example, RPSs in many of the western states with geothermal resources have made development of geothermal electrical generation products more attractive. Of the Gulf Coast states with the potential for moderate-temperature geothermal energy associated with oil and gas production or in geopressured resources, only Texas has an RPS.

Federal incentives and funding that aid in offsetting the associated high capital cost and risk have stimulated the development of geothermal projects. Geothermal power projects are eligible for the production tax credit (PTC) and the investment tax credit, 3. The American Recovery and Reinvestment Act of 2009 (ARRA; Public Law 111-5[1]) made projects that are eligible for the PTC also eligible for a cash grant in lieu of the credit from the Treasury Department. The grant is equal to a tax credit of 30 percent for the eligible parts of the capital investment. Projects that were under construction by the end of 2011 and in service by the end of 2013 may receive the cash grant (Jennejohn, 2011).

The DOE federal stimulus legislation funding (ARRA) is also having an important influence on the U.S. geothermal market through cost-shared projects with the geothermal industry in the development of innovative geothermal exploration technology, demonstrations of EGSs, and projects advancing the technology for using geothermal resources cooler than 150°C. The GEA also provides more information on government incentives for geothermal development (Jennejohn, 2011). Geothermal electricity will continue to compete with fossil-fuel-generated electricity and will require government support similar to that provided to the solar and wind industries if it is to compete in the marketplace.

Access to federal land is also an important issue, since much of the unexplored resource is believed to be beneath federal lands. Leasing and acquiring development permits on federal land are time-consuming and limit access to the land. Recently, the U. S. Bureau of Land Management (BLM) and the U. S. Forest Service (USFS) prepared the *Final Programmatic Environmental Impact Statement for Geothermal Leasing in the Western United States* (BLM/USFS, 2008). This environmental impact statement, coupled with changes in BLM leasing and regulatory practices, has decreased the time for accessing federal land for exploration and development. It is important that the BLM and other federal and state agencies involved in leasing and regulating geothermal development have adequately trained staff.

Geothermal Workforce Occupational Categories

The GEA notes the following about the types of jobs created in the geothermal industry.

> *The development of geothermal resources provides long-term income for people with a diversity of job skills. This includes welders; mechanics; pipe fitters; plumbers; machinists; electricians; carpenters; construction and drilling equipment operators; surveyors; architects and designers; geologists; hydrologists; electrical, mechanical, and structural engineers; HVAC technicians; food processing specialists; aquaculture and horticulture specialists; managers; attorneys; regulatory and environmental consultants; accountants; computer technicians; resort managers; spa developers; researchers; and government employees who all play an important role in bringing geothermal energy online.* (Jennejohn, 2010, p. 8)

[1] http://www.gpo.gov/fdsys/pkg/PLAW-111publ5/pdf/PLAW-111publ5.pdf.

The information gathered by the GEA for the analysis used in the report cited immediately above indicates that, over its development cycle, a typical 50-MW geothermal power plant can involve up to 860 people with a range of skills. These jobs will include on-site personnel at the power plant, possibly employees in nearby cities, and possibly employees in manufacturing plants far from the geothermal resource (Jennejohn, 2010).

The federal government also employs workers who spend all or a portion of their time on geothermal energy. For example, a Federal Interagency Geothermal Working Group has 13 representatives from various offices within 6 government agencies (Jennejohn, 2010).

A list of the jobs involved in the development of a typical geothermal electrical generation project and a list of the job types employed during the phases of a geothermal project are provided in Tables 3.17 and 3.18 respectively. Note that the GEA data do not specifically break out hydrologists and petroleum engineers used in environmental studies, field operations, and reservoir management.

TABLE 3.17 Jobs Involved in the Development of a 50-MWe Geothermal Electrical Plant

Stage of Development	No. of Jobs
Startup	10-13
Exploration	11-22
Drilling	91-116
Plant design and construction (EPC)	383-489
Operation and maintenance	10-25
Power plant system manufacturing	192-197
Total	**697-862**

NOTE: EPC = engineering, procurement, and construction. SOURCE: Jennejohn (2010, Table 2). With permission from the Geothermal Energy Association.

TABLE 3.18. Job Types Typically Employed During Exploration, Drilling, Power Plant Design and Construction, and Plant Operation.

Job Title	Educational Background	Number Employed
	A. Geothermal Exploration	
Geologist	Graduate level	1-2
Geophysicist	Graduate level	1-2
Crew to gather data	Undergraduate Level, Technical	2-5
Geochemist	Graduate Level	1
GIS specialist	Graduate Level, Technical	1
Exploration driller	Undergraduate-Graduate Level, Technical	3-7
Sample analyst	Graduate level	1-2
Consultants	Graduate level	1-2
Estimated total		**11-22**

Job Title	Description	Number Employed
	B. Geothermal Drilling	
Drilling Engineer	Support on-site well drilling	2-3
Rig hands or “drill men”	Operate geothermal drilling rig	15-20
Rig site manager	Manage drilling operations	1-2
Mud logger	Sample and analyze fluid and rock cuttings from the wellbore	2-4
Drilling fluids personnel	Ensure the continual flow of drilling fluids into and out of the well	2-4

Cementing personnel	Cement metal casings in place within the wellbore	6-10
Safety manager	Ensure the safe operation and management of both the drill rig and employees	1
Welder	Weld equipment at drill site	3
Estimated total		**32-47**

Job Title	Description	Number Employed
	C. Geothermal Drilling, Vendor Jobs Types	
Casing personnel	Installs metal casing in the geothermal wellbore after drilling is complete	4-5
Directional drilling personnel	Operates and oversees the directional drilling of a geothermal well	5-7
Well logging contractor	Operates downhole well logging equipment	2
Geologist	Utilizes geological techniques and expertise to help mitigate drilling risk	3-10
Rig transporter	Operates transportation needed to move the drill rig from one job site to the next	25
Fuel transporter	Operates transportation needed to deliver fuel to the drill site	20
Estimated total		**59 -69**

Job Title	Description	Number Employed
	D. EPC Phase (Plant Engineering and Design)	
Degreed engineer	Engineers of various backgrounds (electrical, civil, mechanical) prepare equipment specifications, schematics, drawings, and general plant design	10
Plant designer	Utilizes design software to prepare engineering designs for the geothermal power plant	30
Document controller	Manages documents pertinent to the design of the geothermal power plant	1-3
Design team supervisor	Supervises and manages the overall geothermal power plant design process	1- 3
Administrative support	Assists the project team in document control, customer service, and other aspects as needed	1-3
Estimated total		**43- 49**

Job Title	EPC Team or Contractor
E. EPC Phase (Plant Construction)	
Construction manager	EPC overhead staff
Project engineer	EPC overhead staff
Field engineer	EPC overhead staff
Project superintendent	EPC overhead Staff
Safety manager	EPC overhead staff
Document controller	EPC overhead staff
Administrative support	EPC overhead staff
Welder	Subcontractor or craftsperson

Assembly mechanic	Subcontractor or craftsperson
Inspection personnel	Subcontractor or craftsperson
Concrete construction operator	Subcontractor or craftsperson
Steel erector	Subcontractor or craftsperson
General construction personnel	Subcontractor or craftsperson
Estimated total	**340-440**

NOTE: EPC = engineering, procurement, and construction. SOURCE: Jennejohn (2010, Tables 3-7). Used with permission from the Geothermal Energy Association.

This GEA report on green jobs does not provide information on personnel required to operate geothermal plants. However, power plant managers, engineers, maintenance technicians, and site operators are employed at most geothermal sites. If hazardous gases such as hydrogen sulfide are emitted or hazardous solids are generated during production, chemical engineers and hazardous waste specialists, as well as pollution control device operations staff, are required.

Employer Needs and Challenges

Occupational Outlook

As described above, the GEA estimates that geothermal power plants employ 1.7 full-time positions for power production and management, and 6.4 person-years for associated manufacturing and construction jobs per installed megawatt of geothermal power capacity. The GEA estimates that up to 660 MW of geothermal projects that are under development will enter stages of steamfield (production and injection drilling) and/or power plant construction. The GEA estimates that the total direct, indirect, and induced impact of these advanced projects would account for up to 2,805 full-time jobs (Jennejohn, 2010).

Other, older estimates also exist. The WGA (2006) estimates that new geothermal power capacity of 5,600 MW is considered to be developable, and this could add nearly 10,000 jobs, and additionally provide about 36,000 person-years of business in construction and manufacturing (WGA, 2006). The WGA report based its numbers on a report by Hance (2005). These reports are limited to employment in the electrical generation sector. Employment numbers for direct use, including GHPs, are not available.

Table 3.19 provides estimates of the impact on future employment of geothermal industry growth, based on an analysis used by Hance (2005) and updated information from the EIA, the installed geothermal power capacity as of March 2012 from the GEA, and the factors of 1.7 full-time positions (operations and maintenance, or O&M jobs) per MWe of installed capacity and 6.4 person-years per MWe of installed capacity for associated temporary manufacturing and construction jobs noted above (Hance, 2005; Jennejohn, 2010; EIA, 2012b; GEA, 2012). Using the EIA’s 2010-2035 annual growth rate of 4.0 percent (Table 3.15) for the net summer capacity and the GEA estimate of 3,187 MWe for installed capacity, the new geothermal electric capacity installed was projected for each year for 2012 through 2035. The GEA multipliers were then applied to obtain the number of permanent (O&M) jobs and the number of person-years of temporary manufacturing and construction employment provided.

TABLE 3.19 Estimated employment impact of geothermal industry growth, based on the EIA's 2012 Reference case.

Year	Total Capacity (MWe)	New MWe Installed	Person-Years Manufacturing & Construction Jobs	New Permanent O&M jobs
2012	3,187	N/A	N/A	N/A
2013	3,314	127	816	217
2014	3,447	133	849	225
2015	3,585	138	882	234
2016	3,728	143	918	244
2017	3,877	149	954	254
2018	4,033	155	993	264
2019	4,194	161	1,032	274
2020	4,362	168	1,074	285
2021	4,536	174	1,117	297
2022	4,718	181	1,161	308
2023	4,906	189	1,208	321
2024	5,102	196	1,256	334
2025	5,307	204	1,306	347
2026	5,519	212	1,358	361
2027	5,740	221	1,413	375
2028	5,969	230	1,469	390
2029	6,208	239	1,528	406
2030	6,456	248	1,589	422
2031	6,715	258	1,653	439
2032	6,983	269	1,719	457
2033	7,262	279	1,788	475
2034	7,553	290	1,859	494
2035	7,855	302	1,934	514
	Total	**4,668**	**29,876**	**7,936**

SOURCE: NRC staff.

Table 3.19 suggests that, if the predicted 4.0-percent annual growth is achieved, the geothermal industry could create an estimated 7,936 new permanent O&M jobs and 29,876 person-years of temporary manufacturing and construction work from 2012 through 2035.

These numbers will be much larger if EGSs are developed to the extent envisioned by Tester et al. (2006). Many more scientists experienced in seismology induced by geothermal stimulation and operations as well as scientists and engineers with expertise in rock mechanics will be required. Experience in diverse geothermal geological settings, rock types, and stress regimes will be needed. Interdisciplinary training, as envisioned in Box 7.3, will be needed to meet this requirement.

Needs and Challenges

If estimates of geothermal power online in the future are accurate, a substantial number of professional, skilled technicians and support staff will be required by the geothermal industry. This is particularly true for the GHP and electrical generation segments of the industry.

Some professional earth scientists and engineers could be available from the mining and petroleum industries, if employment opportunities there return to past levels. However, as demonstrated in the sections on oil and gas and mining in Chapter 2, employment needs in these extractive industries are expected to increase in the foreseeable future. Therefore, the geothermal industry will need to provide incentives to professional geoscientists and engineers to entice them to join the geothermal industry. The positive side of this need is that geothermal exploration draws heavily on the same geological and geophysical techniques and skills used in the mining industry so that the geothermal industry can draw on trained mineral explorers. Traditionally trained petroleum engineers and hydrologists are not completely trained for the geothermal industry. Because neither environment is equivalent to a geothermal reservoir, some cross training is needed. Likewise, petroleum engineers and many hydrologists can easily transfer to geothermal drilling and reservoir engineering with only a minor amount of on-the-job training.

Geothermal resources are found in geological environments similar to many hydrothermal ore deposits. The principal difference between mineral and geothermal exploration is that, in the case of geothermal exploration, the “ore deposit” currently is being formed by the hydrothermal system. Hence, an appreciation of fluid flow in the subsurface is needed in addition to the usual tools of mineral exploration. Reservoir engineers, drilling engineers, and hydrologists also use the tools developed by the petroleum industry and hydrology sector, but differences in techniques and equipment are required because of the harder rocks and higher temperatures found in geothermal systems.

Power plant O&M professionals and skilled plant operators also will be needed as new geothermal power plants come online. As discussed below, curricula for power plant operators are under development and available through community and technical colleges.

Relatively slow growth is projected for direct-use development, aside from GHPs, , with the major challenges tending to be the production and marketing of the agricultural, industrial, or recreational products supported by geothermal development. However, better-trained drillers and geoscientists would aid the expansion of the direct-use sector. These professionals could be provided by using consulting groups that otherwise would be active in electrical development projects.

The rapidly growing GHP segment has, as its greatest need, trained heat pump installers, as well as technically trained staff to determine the heat transfer capability of the earth for proper sizing of the subsurface heat exchange system. The following section lists several organizations that have developed training to meet these needs.

Hiring and retaining trained geoscientist and engineers is difficult for the geothermal industry during periods of high demand for these professionals in the mining and petroleum industries. This is because the geothermal industry cannot effectively compete with salaries and benefits provided by the mining and petroleum industries.

If the projections of future growth are realized, employment opportunities across the spectrum of skills needed for the geothermal industry will be available.

Education and Training

Alison Holm (2011) provides a guide to geothermal education and training. Her report is the basis for the following discussion.

The U.S. educational system has had only limited coursework available that is related specifically to geothermal development until relatively recently. Most professionals and skilled workers received their academic training in allied fields, such as petroleum engineering, mineral or petroleum exploration, or power plant operation related to fossil-fuelled electrical generation.

Because geothermal electrical development should be handled as the combined production of geothermal fluid and electricity, the training of geothermal professionals in a systems approach to joint operation of the geothermal field and power production would be useful. Although little has been published on this aspect of geothermal operation, papers by Bloomfield and Mines (2000, 2002) suggest that combined operation of a resource and its geothermal power plant can mitigate resource decline and temperature breakthrough,[2] while also increasing plant revenue. Interdisciplinary Centers of Excellence in Earth Resources Engineering (as envisioned in Box 7.3) would be a logical environment for the interdisciplinary training required.

Long-standing geothermal educational opportunities have been available at Stanford University, providing master's and Ph.D. degrees specializing in geothermal reservoir engineering, and at the Southern Methodist University Geothermal Laboratory, training geoscientists in geothermal exploration. More recently, the University of Nevada at Reno has offered opportunities for geosciences research related to geothermal resources.

Because of increased geothermal activity and spurred by the private-sector and federal funding, a number of colleges, universities, and training institutions across the country recently have begun providing undergraduate, graduate, and certification programs related to geothermal development and operation.

Throughout her guide, Alison Holm provides an extensive listing of institutions that provide coursework, research opportunities, and degrees or certificates in technology needed by the geothermal industry. Two of the opportunities listed are briefly described below.

The National Geothermal Academy (NGA) at the University of Nevada, Reno, Redfield Campus offers an intensive 8-week summer program on all aspects of geothermal energy development and utilization. A consortium of geothermal schools administers the DOE-funded NGA. The NGA uses teachers from academia and the geothermal industry and it is located on the University of Nevada, Reno's Redfield campus.

Truckee Meadows Community College in Reno, Nevada, offers a Geothermal Plant Operators Program for training geothermal technicians (Box 3.2). The college offers a 2-year Associate of Applied Science degree or a 1-year certificate program. In addition, Imperial Valley College in Imperial, California, is working with Truckee Meadows Community College and San Diego State University to develop a geothermal program. They have more than 30 small geothermal plants being built at their location.

The GHP segment of the geothermal industry has led the way in developing technical training for design and installation of GHP systems. Alison Holm's compilation lists nine groups proving training related to GHP applications. However, the list is not comprehensive. Equipment manufacturers, trade associations, 4-year colleges, and technical or community colleges provide the training.

---

[2] Temperature or thermal breakthrough means that cooler water is moving into the geothermal reservoir and cooling it.

BOX 3.2
Truckee Meadows Community College

The Truckee Meadows Community College (TMCC) in Reno, Nevada, was awarded a grant by the U.S. Department of Energy in September 2010 to develop and implement a program to educate geothermal power plant operators. Industry was involved in all phases of the credit curriculum development and the results can be viewed at http://tmcc.edu/geothermal. The curriculum is very hands-on. TMCC has a geothermal lab, which is used for teaching and hands-on experiences. The geothermal industry has supplied TMCC with pumps, valves, turbines, and other materials for work in the lab. Industry advisor Ormat has a 100-MW geothermal plant approximately 1/4 mile from the TMCC lab. They conduct tours and are involved in the teaching. The plant is state of the art and well suited for training. The students receive classwork from the geothermal lab and also at the Advanced Industrial Technology Center, where they learn electricity, AC controls, instrumentation, electric motors and drives, and other topics. Graduates will receive a 34-unit Certificate of Achievement, preparing them for jobs in a rapidly growing field of geothermal power, both domestically and internationally. Articulation and transfer for the certificate and the proposed AAS degree program are being considered by the University of Nevada, Reno, as is program replication through National Science Foundation Advanced Technological Education project at Imperial Valley College in California, with transfer to San Diego State University.

SOURCE: tmcc.edu/geothermal.

Innovation

Improved technology for geophysical measurements that can indicate zones of fluid circulation in the subsurface are needed to improve the success of geothermal exploration. In addition, reduction in the cost of geothermal development and operation, and improvements in the efficiency of generating electricity from geothermal resources will provide incremental changes in the development of geothermal energy in the United States.

However, the game changer for geothermal energy will be the development of technology for EGSs. As noted by Tester at al. (2006), this technology would allow geothermal production from a much larger resource base than the currently utilized hydrothermal systems.

Technology improvements are required in the ability to: create increased productivity from wells; create artificial reservoirs (i.e., well interconnectivity and adequate heat transfer); dramatically decrease drilling costs; and increase the efficiency of energy conversion, coupled with steady or decreasing cost of conversion, in order to develop EGSs in lower-gradient areas.

Conclusions and Recommendations

Conclusions

3.21 The geothermal industry supports about 5,200 direct jobs related to power production and management, and the total direct, indirect, and induced impact of geothermal energy accounts for about 13,100 full-time jobs.

3.22 Both geothermal electrical generation and the number of residential geothermal heat pumps are expected to continue to grow at a healthy pace through 2035.

3.23 Federal government incentives and funding are important factors in geothermal energy development.

3.24 Geothermal electrical generation could substantially exceed the U.S. Energy Information Administration estimates if enhanced geothermal systems technology is developed and is economic. To be economic throughout large portions of the United States, significant advances in creating underground fracture systems at depths below 3 km will be necessary, along with dramatic decreases in the cost of drilling to such depths.

3.25 Geothermal electrical development requires exploration, well drilling, reservoir engineering, and plant construction and operation. The skills required for exploration, well drilling, and reservoir engineering are similar to those employed in the mining, petroleum, and hydrology industries. This alignment across industries allows in large measure for common educational and training pathways, and for easy workforce mobility between the industries.

3.26 Geothermal reservoir engineering and petroleum reservoir engineering have successfully relied on very similar techniques, and many engineers have worked in both technical areas with little need for additional training. Hence, reservoir engineering needs for geothermal can be met through traditional reservoir engineering education, coupled with on-the-job training. Hydrologists can also transfer their skills to the geothermal industry, particularly as related to direct-use applications. To be fully functional in the geothermal industry, many petroleum engineers and hydrologists will require additional training in nonisothermal systems, heat transfer, and multiphase fluid flow.

3.27 The geothermal industry has significant difficulty in competing with the petroleum and mining industries for geoscience and engineering professionals due to the relatively attractive salaries and benefits offered by these other industries. This competition will increase if the manpower projections for these industries are accurate.

3.28 Geothermal heat pumps are mechanically similar to air source heat pumps and require skills already available through the conventional HVAC industry, except for the design and installation of the geothermal heat exchanger. Additional trained installers with expertise in sizing and installing the ground heat exchanger will be needed to sustain the projected growth in geothermal heat pump installations.

3.29 Plant operators will be needed to operate and maintain geothermal power plants. Many of these skills are transferrable from gas- and coal-fired electrical generators, but the geothermal industry competes with these other plants for operators. Geothermal binary power plants require additional training. Geothermal plant operators also need a better understanding of the interaction between the geothermal reservoir and operation of the power plant.

3.30 To achieve the U.S. Energy Information Administration projected growth, it will be essential that earth scientists trained in exploration methods enter geothermal exploration.

3.31 The aging of the geothermal workforce, particularly experienced explorationists, is a crucial issue, as is slowing the attrition of professionals to related industries.

Recommendations

The recommendations are ordered and labelled in terms of when they would be expected to be operational. The recommended actions should be started as quickly as possible. They will become operational in the long term and will continue for the long term. However, the need for better exploration technology for hydrothermal resources is critical and needed immediately. If the industry cannot find the resource, then the other job categories will not need to be filled for hydrothermal systems. EGSs have a longer lead time, with a relatively small need at present and building as the technology is proven. There will be a relatively small EGS need for next 5 years, and then it will rapidly increase after that if the technology can be proven.

Community colleges are the most likely source of training for power plant operators. There is some current need for operators as new plants relatively slowly come online, and then the need will build if exploration and EGSs are successful. Next, in terms of need, will be drilling crews.

3.9 Community college instructors and guidance counselors should inform students that the skills delivered by the community college span across the oil and gas, geothermal, and mining industries. Such information could potentially provide greater opportunities and options to the graduates from these programs. (Long Term)

3.10 The staffing of geothermal exploration, drilling, and reservoir engineering includes the recommendations made by the committee for the oil and gas, and mining sectors, with some additional recommendations as follows:

A. Geothermal exploration primarily relies on the same exploration skill set as that needed for mineral exploration. However, the geothermal industry is increasingly relying on seismic techniques to site drilling locations, and so associated skills should be acquired. (Long Term)

B. Geothermal drilling is quite similar to that for oil and gas (many geothermal wells are drilled using oil and gas rigs and drilling crews). However, geothermal drilling generally requires more experience with control of lost circulation and handling higher temperatures than is usual in oil and gas drilling, and this experience should be acquired. (Long Term)

In addition to these recommendations, the Shared Recommendations (at the end of the chapter) also apply for the geothermal industry.

CARBON CAPTURE, USE, AND STORAGE

Introduction

Carbon capture and storage (CCS), or more recently renamed carbon capture, use, and storage (CCUS), began in earnest nearly two decades ago, with the pioneering Sleipner Saline Aquifer Storage (SACS) project in the North Sea. The primary purpose of the SACS project was to eliminate carbon dioxide (CO_2) emissions into the atmosphere in order to avoid paying a tax of about $50/tonne imposed by the Norwegian government on offshore CO_2 emissions. Previously, starting in the 1970s, motivated primarily by the desire to increase U.S. domestic oil production, the petroleum industry developed the process of CO_2-enhanced oil recovery (EOR) as a way of increasing production from mature oil fields. As the world leader in this technology, over 50 million tonnes of CO_2 are currently injected into U.S. oil reservoirs each year, leading to the incremental recovery of 281,000 barrels of domestic oil per day (bbl/day), or 6 percent of U.S. crude oil production (Kuuskraa, et al., 2011). The high cost of CO_2 capture and the desire to increase domestic oil production, combined with a lack of binding national CO_2 emission reduction goals, have motivated a renewed emphasis on combining the emission reduction potential of CCS with CO_2-EOR, into so-called Carbon Capture, Use, and Storage.

CCUS Technology Overview and Market Trends

CCUS is a suite of technologies designed to reduce CO_2 emissions and simultaneously increase oil recovery. CCUS is typically a four-stage process: CO_2 is first separated from a mixed-gas stream (emitted from an ethanol plant, coal- or gas-fired power plant, cement plant, refinery, or other industrial source); compressed into a liquid; transported through a pipeline; and then pumped deep underground for permanent sequestration, or in the case of CO_2-EOR, to increase oil production (see Figure 3.17). When pumped underground for CO_2-EOR, some fraction of the injected CO_2 returns to the surface with the produced oil. For CO_2-EOR to be considered as sequestration, the CO_2 pumped out of the oil reservoir with the produced oil must be recaptured and pumped back underground. The actual amount of CO_2 sequestered must be verified with monitoring. Except for the potential for increasing CO_2-EOR, the sole purpose of CCUS is to combat climate change caused by anthropogenic emissions of CO_2 into the atmosphere. Carbon dioxide capture and sequestration is unlikely to become a significant industry absent government policies, incentives, and regulations for large reductions in CO_2 emissions.

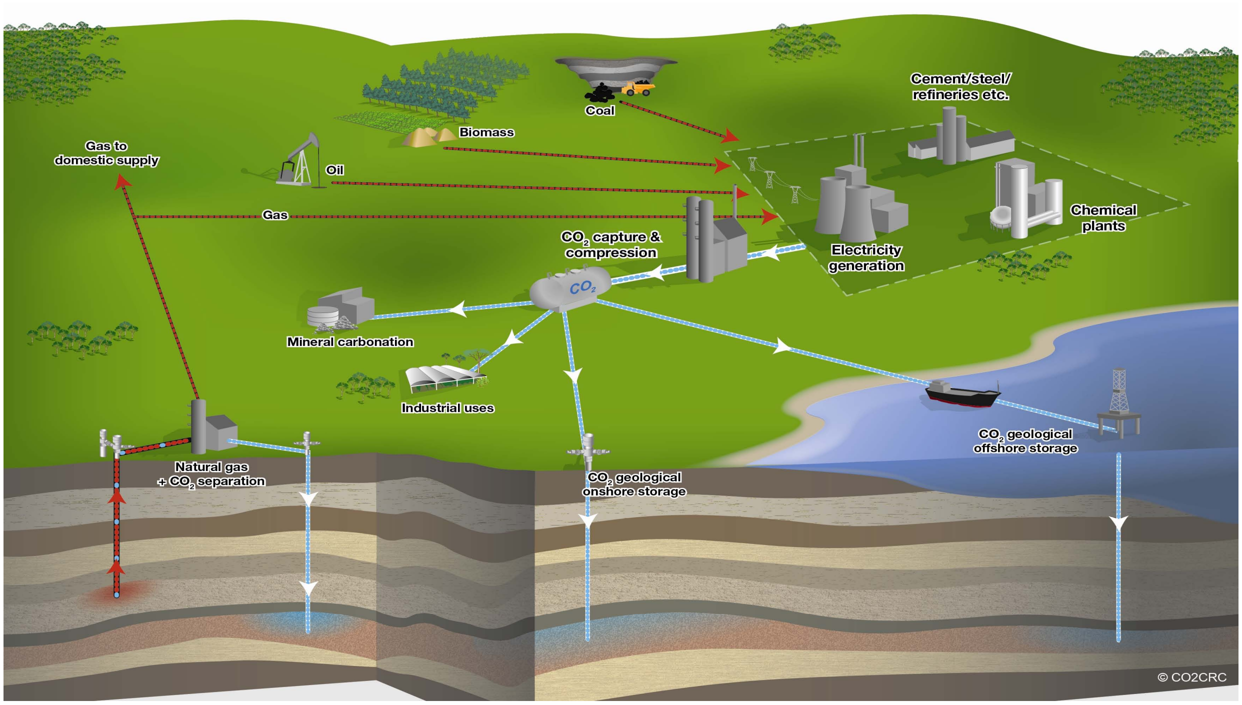


FIGURE 3.17 Schematic of the carbon dioxide capture and sequestration process.
SOURCE: Reprinted with permission from CO2CRC.

The production of oil and projects using CO_2-EOR have grown steadily since the 1970s and can be expected to continue to grow (see Figure 3.18), particularly if abundant and moderately priced CO_2 from anthropogenic sources becomes available. If moderate-cost supplies of captured anthropogenic CO_2 become available, and with appropriate policy incentives, the National Enhanced Oil Recovery Institute (NEORI) estimates that CCUS has the potential for:

> *"…production of an additional 9 billion barrels of American oil over 40 years, quadrupling CO_2-EOR production and displacing U.S. oil imports… At the same time, the proposed incentive would save the United States roughly $610 billion in expenditures on imported oil, while storing approximately 4 billion tons of CO_2 captured from industrial and power plant sources, thereby reducing total U.S. CO_2 emissions in the process."* (NEORI, 2012, p. 2)

Worldwide, eight projects are sequestering CO_2 in deep underground formations (see Table 3.20). Over the past decade, industry and governments worldwide have committed or invested $26 billion in pilot-scale and first-of-a-kind demonstration projects (GCCSI, 2011). The DOE, in partnership with industry and universities, has carried out over 20 small- to mid-scale pilot tests (< 1 Mt/year) demonstrating the feasibility of pumping CO_2 underground, monitoring where it is goes, and demonstrating that it can be effectively trapped underground in appropriate geological settings (see Figure 3.19).

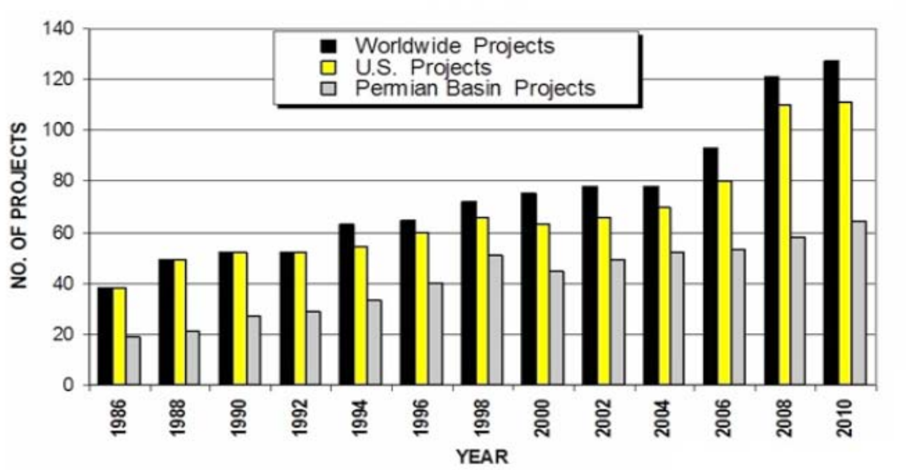


FIGURE 3.18 Number of projects using CO_2-EOR: worldwide, United States and the Permian Basin, West Texas. SOURCE: Melzer (2012, p. 4).

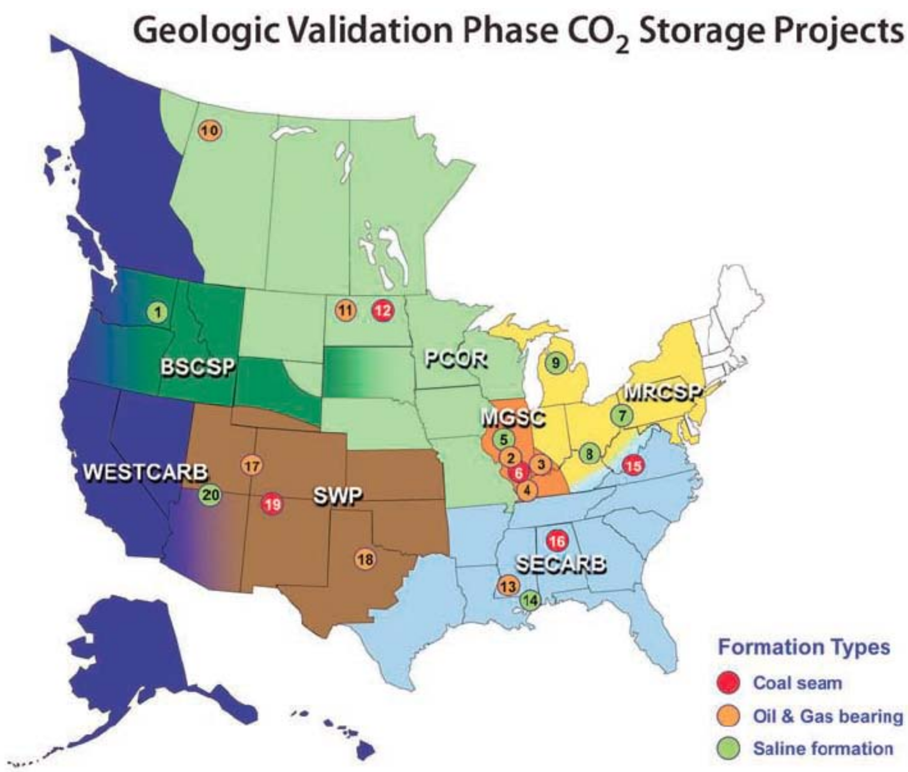


FIGURE 3.19 Location and sequestration formation type for small-scale pilot injection tests supported by the U.S. DOE Regional Sequestration Partnerships. SOURCE: DOE (2010a, p. 9).

TABLE 3.20 Global Carbon Capture and Storage Projects in 2012

Name	Location	Capture Type	Volume of CO_2 (MTPA)	Storage Type	Date of Operation
Shute Creek Gas Processing Facility	United States	Precombustion (gas processing)	7	EOR	1986
Sleipner CO_2 Injection	Norway	Precombustion (gas processing)	1	Deep saline formation	1996
Val Verde Natural Gas Plants	United States	Precombustion (gas processing)	1.3	EOR	1972
Great Plains Synfuels Plant and Weyburn-Midale Project	United States/Canada	Precombustion (synfuels)	3	EOR with MMV	2000
Enid Fertilizer Plant	United States	Precombustion (fertilizer)	0.7	EOR	1982
In Salah CO_2 Storage	Algeria	Precombustion (gas processing)	1	Deep saline formation	2004
Snøhvit CO_2 Injection	Norway	Precombustion (gas processing)	0.7	Deep saline formation	2008
Century Plant	United States	Precombustion (gas processing)	5 (and 3.5 from construction)	EOR	2010

NOTE: Four of these projects are located in the United States. All of the CCS projects are associated with gas processing or precombustion separation of CO_2, namely synfuel or fertilizer production. EOR = enhanced oil recovery; MMV = monitoring, mitigation, and verification; MTPA = million tons per annum.
SOURCE: Modified from GCCSI (2011, Table 1, p.11). Used with permission from the Global CCS Institute.

Eight development-scale projects are pumping from 0.7 to 5 million tonnes underground annually. In addition, the United States is the world leader in CO_2-EOR, with more than 70 projects using more than 50 Mt per year of CO_2, although most of this is from natural underground reservoirs. An extensive network of pipelines between CO_2 sources and sinks exists today.

Regulations motivated primarily for protecting drinking water resources have been developed for siting, monitoring, and closing geological storage projects (EPA, 2011). For projects that are purely for sequestration, one unresolved issue is how to deal with postclosure liability in the event that leakage occurs. Several legislative attempts to address this issue have been undertaken. Large-scale deployment of CCUS is unlikely until this issue is resolved. Again, CO_2-EOR remains the exception as project developers routinely hold liability for these projects.

Sequestration Technology Description

For this study, the focus is only on the utilization and sequestration components of CCUS technology, as the remainder of the workforce is not engaged in the geosciences.

Carbon dioxide can be sequestered in oil and gas reservoirs, coal beds, or salt-water saltwater-filled sedimentary rocks (see Figure. 3.20). Both sandstone and carbonate formations are suitable. In the future, it is also possible that other rock types, including basalt, could be used to sequester CO_2. Suitable formations are typically greater than 1 km deep and most importantly, are overlain by thick, low-permeability seals composed of shale, anhydrite, or low-permeability dolomite (IPCC, 2005). Selecting a suitable sequestration site requires extensive geological characterization and model development, typically by teams of sedimentary geologists, geophysicists, and modelers.

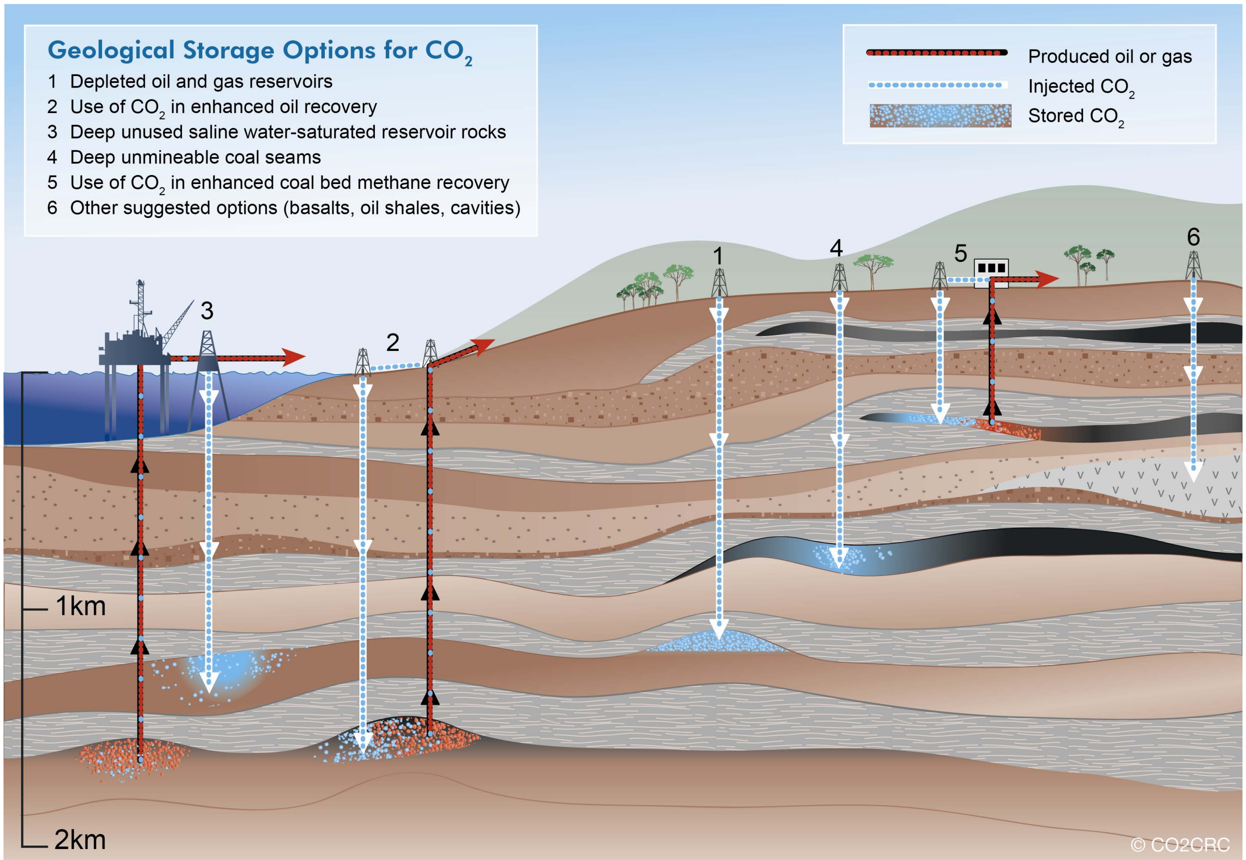
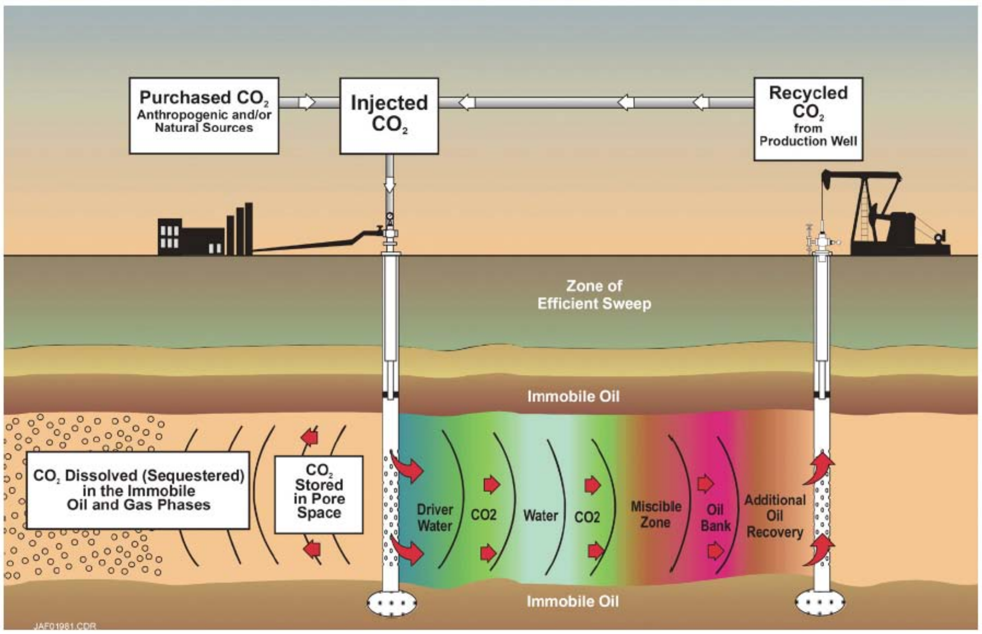


FIGURE 3.20 Current options for sequestering CO_2 in subsurface geological formations. SOURCE: Reprinted with permission from CO2CRC.

The technology for pumping CO_2 underground is well developed, based on over four decades of experience in the CO_2-EOR industry. Well drilling and completion technology, pumps, and surface equipment are all available. Rigs and rig crews used for oil and gas exploration and production are appropriate for drilling injection and monitoring wells for geological storage projects. The requirements for cementing injection wells for geological sequestration differ from a typical oil and gas well and special provisions must be made to meet the regulatory requirements to fully cement the well throughout its entire length.

CO_2-EOR, the largest utilization option, involves injecting supercritical CO_2 into an oil field. When mixed with oil, CO_2 lowers the viscosity and reduces the density of the oil, leading to improved recovery. For certain types of oil, at elevated pressures and temperatures, oil and water can become miscible, meaning they become a single fluid. Under these conditions, oil recovery can be improved dramatically. As shown in Figure 3.21, the bank of mobile oil is swept to the extraction well, sometimes involving the injection of water to further increase recovery through the so-called WAG (water-alternating-gas) process. Successful CO_2-EOR operations require sophisticated reservoir engineering calculations, advanced geological modeling, and well completion technologies.



Source: Advanced Resources International and Melzer Consulting, Optimization of CO_2 Storage in CO_2 Enhanced Oil Recovery Projects, prepared for UK Department of Energy & Climate Change, November 2010.

FIGURE 3.21 Schematic showing the processes of CO_2-enhanced oil recovery. SOURCE: ARI/Melzer (2010, Fig. 1, p. 3).

However, unlike oil and gas production, where monitoring tends to focus on injection and extraction rates and wellhead pressures, CO_2 sequestration requires tracking the location of the CO_2 plume, ensuring that it is not leaking back to the surface, and quantifying the amount of CO_2 sequestered. Monitoring techniques include seismic imaging, wellhead and formation pressure testing, well logging, groundwater monitoring, as well as a number of techniques for directly detecting and measuring leakage into the atmosphere (Benson, 2007). Seismic imaging and pressure monitoring are well-developed tools, but application for the purposes of a sequestration project requires specialized interpretation to comply with regulatory requirements.

Numerical simulations are routinely used to predict the performance of sequestration sites and CO_2-EOR projects, determine how many wells are needed for injection, assess the magnitude of the pressure buildup and determine how far it extends from the injection well, and maximize trapping of CO_2 in the sequestration formation. These are sophisticated mathematical tools that require specialized education, training, and experience to use them competently. Again, experience from the oil and gas industry is transferable, but numerical simulation for geological sequestration requires greater emphasis on thermodynamics, geochemical interactions, and geomechanical phenomena than is typically required in the oil and gas industry.

Protection of drinking water is the primary driver for existing CCUS regulations. Although geological sequestration formations will be much deeper than drinking water resources, protecting them will require developing a complete model of the geology, hydrogeology, geochemistry, and geomechanics, from the depth of the sequestration formation to the surface. Traditionally, subsurface scientists have focused on either shallow systems (e.g., vadose zone, drinking water aquifers), hydrocarbon resources (oil, gas, coal), or mineral resources. Successful sequestration will facilitate the development of a more holistic view of earth resources, which requires knowledge of a number of potentially interacting resources simultaneously.

The DOE has created seven CCS training centers to address workforce issues. The training centers (in Texas, Wyoming, Illinois, New Mexico, Oklahoma, Washington, and Georgia) provide sequestration-specific coursework for training and retraining workers for this industry. Training center activities include developing self-sustaining technology development programs, providing short- courses on CCS technologies, developing networks for outreach and community engagement, and coordinating regional training efforts.

Regional Distribution of Prospective CCUS Sites

Although it is difficult to forecast where and how quickly the CCUS industry will develop, prospective locations for CCUS can be determined by identifying regions where CO_2 sources and geological formations suitable for sequestration are colocated. Particularly promising areas for large-scale implementation of CCUS include the Gulf Coast states, portions of the Midwest, the Great Plains, and oil and gas fields throughout the United States (see Figure 3.22).

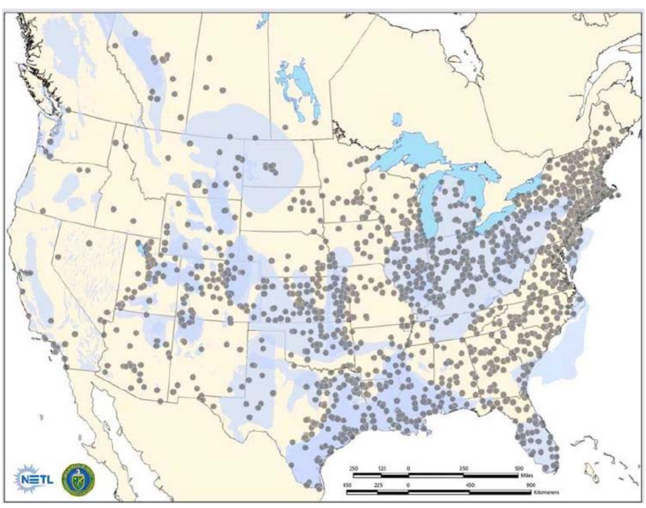


FIGURE 3.22. Location of existing sources of CO_2 and prospective sites for CO_2-EOR and geological sequestration. NOTE: Dots show the location of existing CO_2 emissions from large stationary sources and the shading shows the locations of favorable geological formations. SOURCE: DOE (2010b, p. 13).

CCUS Occupational Work Categories and Workforce Estimates

The CCUS occupational work categories can be divided into groups corresponding to the stages of a project, including: site screening, selection, and characterization; site design and approval; construction; operations; postinjection monitoring; and site closure (as illustrated in Figure 3.23). Specific workforce needs during each project stage are given in Table 3.21.

A rough estimate of the size of the workforce is in the range of 70-180 workers per million tonnes of CO_2 injected.[1] Consequently, if large-scale implementation of CO_2-EOR is realized, and the amount of CCUS quadruples from today's 50 Mt/yr to 200 Mt/yr by 2030, a workforce of 14,000 to 36,000 workers would be needed. This would correspond to about 3-8 percent of today's oil and gas workforce of about 434,600.[2] More accelerated estimates for the rate of increase suggest that the industry could scale up by a factor of 10 between now and 2030 (Kuuskraa et al., 2011). In this case, a workforce the size of anywhere from 35,000 to 90,000 (about 8 to 20 percent of the existing oil and gas workforce) would be needed. Another approach to estimating the 2030 workforce is based on the fraction of CO_2-EOR today. Assuming that the number of workers needed is proportional to the fraction of the oil produced using CO_2-EOR (6 percent of the workforce of 434,600), then, if we quadruple the amount of CO_2-EOR, a workforce of about 100,000 workers, or 23 percent, would be needed.

The size of the needed workforce relative to the size of the existing industry suggests that, although not insignificant, for the foreseeable future, the CCUS geosciences workforce will represent a modest fraction of the overall oil and gas workforce. These estimates are highly speculative and uncertain. However, the general conclusion that the CCUS workforce in 2030 will be a small fraction of today's existing oil and gas workforce is a reasonable assumption. On the other hand, if a U.S. climate policy restricting CO_2 emissions is enacted, workforce requirements could be greater than those described here.

[1] Employment statistics for a prospective CCUS industry are not available. These estimates are determined on the basis of a cost of \$10 to \$25 per tonne of CO_2 injected (Bajura, 2009). Additionally, it is assumed that 50 percent of this is labor cost and that the average salary in the industry is \$70,000 per year.
[2] 2010 employment for NAICS codes 211, 213111, and 213112. See Table 2.1 in Chapter 2.

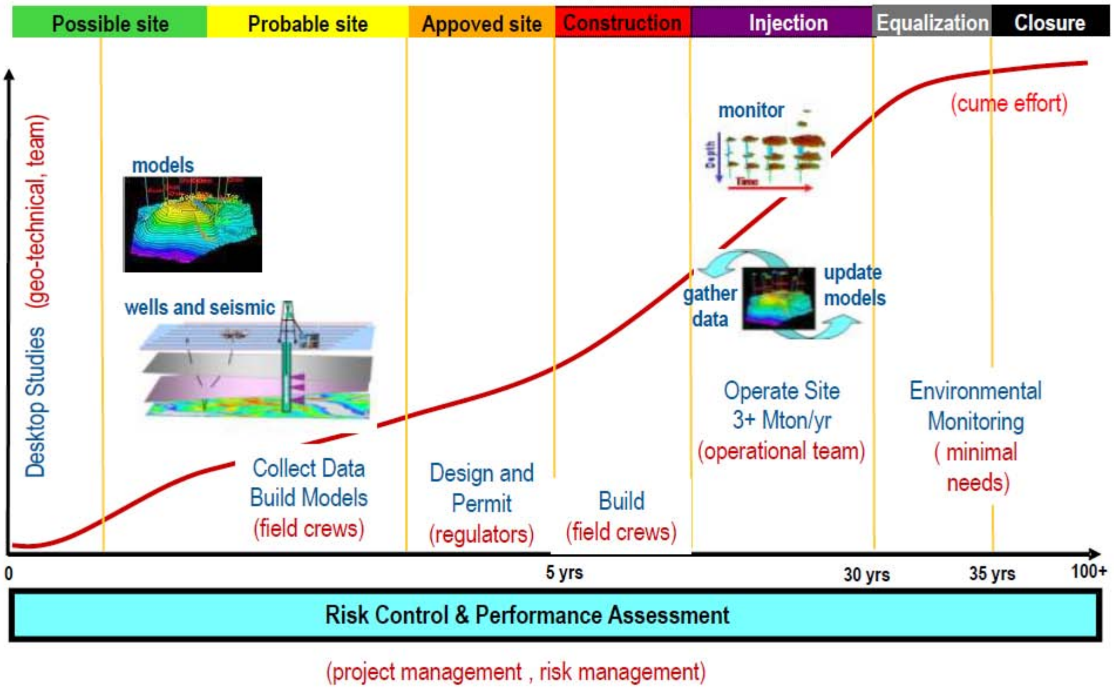


FIGURE 3.23 Stages of a CCUS project. The line is a conceptual representation of the cumulative level of effort for the work at each phase of the project. SOURCE: Courtesy of John Tombari, Schlumberger.

TABLE 3.21 Specific Workforce Needs During Each Stage of a CCUS Project

CCUS Project Stage	Workforce Needs
Site screening	Geologists; geophysicists; drillers; field crews for data acquisition; health, safety, and environmental professionals; project managers
Site selection and characterization	Geologists and petrophysicists; geomechanics; reservoir engineers/petroleum engineers; geochemists and chemical engineers; geophysicists and seismologists; hydrogeologists; geochemists; drillers and drill crews; field crews for data acquisition; economists; health, safety, and environmental professionals; project managers
Site design and approval	Well completion engineers; drilling engineers; reservoir engineers/petroleum engineers; geochemists and chemical engineers; geologists and petrophysicists; hydrogeologists; production/injection engineers; geophysicists and seismologists; health, safety, and environmental professionals; economists; project managers
Construction	Project managers; well drillers and rig crews; geologists and petrophysicists; pipeline construction crews; health, safety, and environmental professionals; well completion engineers; drilling engineers; reservoir engineers/petroleum engineers
Operations	Well-field operators and maintenance; reservoir/petroleum engineers; geochemists and chemical engineers; geophysicists; hydrogeologists; health, safety, and environmental professionals; project managers
Postinjection monitoring	Geophysicists; hydrogeologists; geochemists; reservoir/petroleum engineers; health, safety, and environmental professionals; project managers
Site closure	Completion engineers; workover crews; geophysicists; health, safety, and environmental professionals; project managers

SOURCE: Sally Benson.

Workforce Issues: A Good News and Bad News Story

The good news is that the geological sequestration workforce straddles two well-developed industry workforces—the environmental consulting industry[3] and the oil and gas industry. Consequently, with some retraining as discussed above, there is a well-developed and highly competent workforce able to jump-start this industry. Therefore, for the foreseeable future, unless the United States enacts a strong climate change policy, there is likely to be a sufficiently large workforce with the right skills, provided it can have the specialized training to augment their knowledge specific to sequestration.

The bad news is that over the long term, however, unless we can sustain a reversal in the decades-long decline in student recruitment into the geosciences, the lack of a strong geosciences workforce could limit implementation of CCS. Deployed at a scale where about 20 percent of U.S. CO_2 emissions reductions are provided by CCS, the scale of the CCS industry is expected to be about the same size as today's natural gas industry. Providing a workforce that can meet these needs, on top of an already stressed workforce for the oil and gas industry will be a formidable challenge unless more students enter the geosciences workforce.

One positive trend seen in universities across the United States is that students who normally would not be interested in working in the oil and gas industry are choosing to do their graduate studies in CCS. Motivated by contributing to solving the global warming problem, they enter a scientific discipline heretofore populated primarily by petroleum engineers. However, unless we are able to provide employment opportunities in this field, we will discourage those who have chosen this path. A clear and firm commitment of the government to solving these problems is crucial for having a workforce prepared to deal with these global challenges.

Concrete actions that are under way to address workforce issues in the short term include:

- More than a dozen universities are now providing sequestration classes as part of the upper division and graduate school curriculum;
- Universities are now matriculating dozens of M.S. and Ph.D. students whose research focuses on geological sequestration of CO_2;
- Major geosciences societies (e.g., Society of Petroleum Engineers, American Geophysical Union, American Chemical Society, American Association of Petroleum Geologists) have workshops or technical sessions at major international meetings focused on geological sequestration of CO_2;
- Joint-industry projects (JIPs) are sponsoring research and development, which provides training and retraining opportunities for reservoir engineers and geophysicists;
- Several CCS training programs (Research Experience in Carbon Sequestration[4] [RECS], International Energy Agency Greenhouse Gas Programme,[5] Australia) have been established to augment traditional graduate student geosciences curricula; and
- DOE has established CCS Regional Training Centers.

[3] The environmental consulting industry provides engineering, scientific, construction, and operations services to private-sector and industrial clients related to addressing issues of air pollution assessment and control, groundwater remediation, site restoration, mitigation of ecosystem impacts, and environmental impact assessments of new projects or for due diligence during acquisitions and mergers.
[4] http://recsco2.org/
[5] http://www.ieaghg.org/

Conclusions

3.33 Carbon capture and sequestration is unlikely to become a significant industry absent government policies, incentives, and regulations for large reductions in CO_2 emissions.

3.34 The production of oil and projects using CO_2-EOR can be expected to continue to grow.

3.35 Employment statistics for a prospective CCUS industry are not available. However, speculative estimates indicate that, if large-scale implementation of CO_2-EOR is realized and the amount of CCUS quadruples from today's levels by 2030, a workforce of 14,000 to 36,000 would be needed. More accelerated estimates suggest that 35,000 to 90,000 workers, or even 100,000 workers might be needed. A reasonable assumption is that the CCUS workforce in 2030 will be a small fraction of today's oil and gas workforce.

3.36 The geological sequestration workforce straddles the environmental consulting industry and the oil and gas industry. With some retraining, there is a workforce that can jump-start this industry. Therefore, for the foreseeable future, unless the United States enacts a strong climate change policy, there is likely to be a sufficient workforce with the right skills, provided it can have the specialized training specific to sequestration.

3.37 Unless student recruitment into the geosciences can be sustained, the lack of a strong geosciences workforce could limit CCUS implementation.

3.38 It is very important to sustain support for graduate school research in CCUS.

Recommendations

The following recommendations should be initiated as quickly as possible and some will take longer than others to become fully operational. The recommendations are ordered and labeled in terms of when they would be expected to be operational. All of the recommended actions are expected to continue for the long term.

3.11 The committee recommends that DOE, industry, institutions of higher education, and other involved organizations consider continuing support for DOE-initiated training programs for CCUS. (Short Term)

3.12. Industry, government, industrial and professional organizations, and educators should consider ways to encourage students to enter the geosciences, which provide a breadth of opportunities to not only provide the energy we need from fossil fuels, but to reduce their emissions through CCUS. (Medium Term)

3.13. The committee recommends that industry, government, industrial and professional organizations, and educational institutions consider providing research and educational support for the next generation of "earth resources engineers" who have a more holistic and integrated understanding of the interactions between the anthrosphere, atmosphere, biosphere, and near-surface and deep geological systems—and who are prepared to develop and manage the next generation of energy and mineral resources to support human well-being, while restoring and protecting the natural environment. (Medium Term)

In addition to these recommendations, the Shared Recommendations (below) also apply for CCUS.

SHARED RECOMMENDATIONS

Shared Recommendations for Chapter 2 and Chapter 3

As described in Chapter 2, the following Shared Recommendations 1-5 apply across the mature industries in that chapter, and they address a range of actions that are complementary. They also apply across the emerging industries in this chapter. Other industry-specific recommendations that are important for each of the emerging industries can be found in their respective sections of this chapter.

Shared Recommendations 1-5 should be initiated as soon as possible, and they are ordered and labeled in terms of when they would be expected to become fully operational. All are expected to continue for the long term. Short term is defined as 2 years or less, medium term as 2-5 years, and long term as more than 5 years.

Shared Recommendation 1: To address the growing demand for trained workers, industry, potentially with government support, should take an active part in developing the workforce of the future by working closely with educational institutions at all levels. Active involvement could include, but would not be limited to, developing a curriculum that trains individuals to be "job ready" upon completion of their certification or degree. This effort would benefit from being a national initiative and having a local/community focus. In pursuing this initiative, it would be important to consider, encourage, and emulate existing educational success stories, such as the programs supported by the National Science Foundation at community colleges, and the Truckee Meadows Community College program. The other educational success stories noted in Chapter 2 that are focusing on minority outreach also would be instructive for this broader initiative. (Short Term)

Shared Recommendation 2: To ensure that there are enough faculty now and in the pipeline, who are qualified to work and teach at the cutting edge of technology, the committee recommends that the government and industry consider entering into partnership to provide joint support for research programs at U.S. universities, with the goal of attracting and better preparing students and faculty, promoting innovation, and helping to ensure the relevance of university programs. (Short Term)

Shared Recommendation 3: The committee recommends that the industrial parties who are working with educational institutions on workforce education and training, along with the Department of Education, urge educators to encourage students to seek STEM disciplines, and to consider realigning education in the

K-12 curriculum to emphasize STEM education, with existing and future educators being better trained in STEM disciplines. (Short Term)

Shared Recommendation 4: To provide a needed enhancement of the workforce, the committee recommends that industry and educators pursue efforts to attract nontraditional workers (who predominantly are minorities and women) into the energy and mining fields. This initiative would benefit from being a broad, national initiative and having a local/community focus. In pursuing this initiative, it would be important to consider, encourage, and emulate existing educational success stories, such as those with a focus on minority outreach (noted in Chapter 2). (Medium Term)

Shared Recommendation 5: Industry and educators should also pursue efforts to attract more of the traditional workforce into the energy and mining fields. This initiative also would benefit from being a national initiative and having a local/community focus. Educational success stories, such as those highlighted in this report, could also offer insights for this initiative. (Medium Term)

Additional Shared Recommendation for Chapter 3

In addition, to Shared Recommendations 1-5 (above), the following Shared Recommendation 6 also applies across the emerging industries in this chapter. Shared Recommendation 6 also should be initiated as soon as possible. It is expected to become fully operational in the long term and to continue for the longer term.

Shared Recommendation 6: The Bureau of Labor Statistics should consider partnering with the renewable industries to effectively develop more granular and up-to-date data on their occupations. (Long Term)

4

The Electric Grid

TODAY'S ELECTRIC GRID

"The U.S. electrical grid is the largest interconnected machine on Earth: 200,000 miles of high-voltage transmission lines and 5.5 million miles of local distribution lines, linking thousands of generating plants to factories, homes and businesses" (Weeks, 2010). The National Academy of Engineering acclaims it the "supreme engineering achievement of the 20th Century" (Constable and Somerville, 2003).

The United States is the largest electric power producer, with about 1,100 GW of generating capacity, serving the largest economy in the world (EIA, 2011b). Private investors own most of the electric utilities, but some are owned by individuals (cooperative utilities) and municipalities. Public policy oversight of the industry is vested primarily in the states and the District of Columbia (Willrich, 2009). The Federal Energy Regulatory Commission sets interstate rates and commerce, including interstate transmission siting and approval. More than 3,200 entities within the electric power industry provide power to consumers (EIA, 2012i).

The electric power industry in the United States has annual revenues of more than $250 billion, and a base of assets of more than $800 billion. The distribution of these assets is as follows: 60 percent is power generation, 30 percent is distribution, and 10 percent is high-voltage transmission (Willrich, 2009).

The grid[1] consists of four components: generators, transmission lines, distribution systems, and consumer systems (MIT, 2011). Electricity is generated from a variety of sources, from fossil-fuel-fired plants to renewable-energy generation facilities. This electricity is moved from generating plants over long distances by transmissions systems, generally through high-voltage, high-capacity transmission lines. The high-voltage transmission system delivers its power to local distribution systems that transform the electricity into a lower voltage and send it to consumer systems. The distribution systems move the electricity through substations and transformers to the 144 million U.S. consumers, from residences to large industries (EIA, 2011b). Figure 4.1 provides a schematic of the electrical power system, from generation to final consumers.

[1] For a comprehensive description of the U.S. electricity grid, including its technical, managerial, and regulatory complexities, see: MIT (2011).

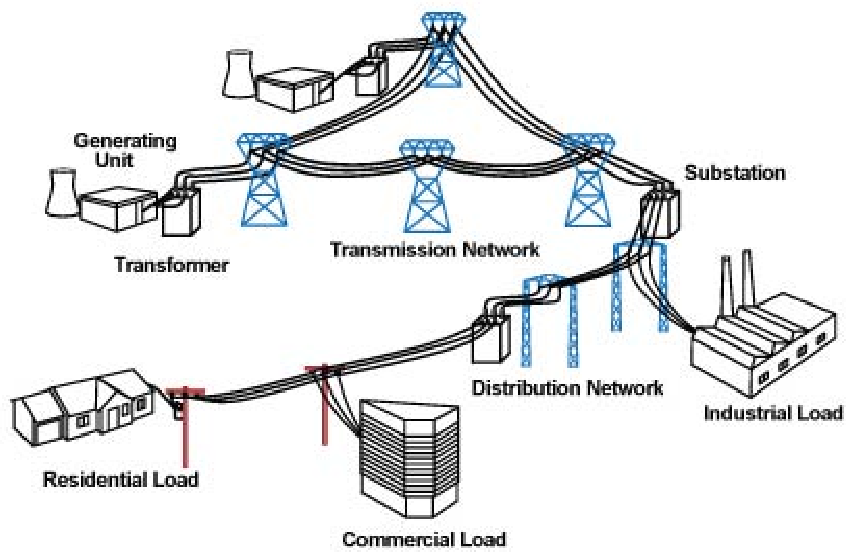


FIGURE 4.1 Structure of the electric power system. SOURCE: MIT (2011).

Transmission lines are owned by investor-owned utilities (73 percent), federally owned utilities (13 percent), and public utilities and cooperative utilities (14 percent (EIA, 2000). The national transmission and distribution system consists of three separate networks with limited interconnection: the Eastern Interconnect, the Western Interconnect, and the Texas Interconnect.[2] The Texas Interconnect is not actually interconnected with the other networks (the only connection is by certain direct- current lines), and the Eastern and Western Interconnects have limited interconnection (EIA, 2000). In essence, the continental United States consists of three independent systems that are further divisible among regional, state, and local distribution systems. Altogether, 3,233 organizations provide customers with electricity (EIA, 2012i). The Federal Energy Regulatory Commission regulates the investor-owned utilities to control and set rates.

Electric utilities own and operate any or all of the following: generation plants, transmission lines, distribution lines, and substations (which contain equipment to ensure safe and smooth current flow and regulate voltage). System operators (either independent or associated with a utility) manage and control electricity generation, transmission, and distribution. The effective functioning of the electricity industry is highly dependent on control systems. Operators must constantly balance power generation and consumption because electricity is generated and used almost at the same instant. For a long time, some parts of the electrical power network did not have sufficient technologies, for example, the means to enable system operators to know important information in order to measure how much electricity is flowing along distribution lines, to enable networks to more closely integrate parts of the grid with control centers, and to enable computerized control equipment to automate system management and recovery (GAO, 2011a).

In concept, the grid resembles the earliest days of power transmission and distribution with Thomas Edison's commercial power grid in Lower Manhattan in 1882 (Brady, 2009). The grid is a one-way system that is not very responsive to ever-changing energy needs and to alternative sources of nonbaseload power. Although the current U.S. grid is aging, the system

[2] A map of the national power grid is available at http://www.eia.gov/energy_in_brief/power_grid.cfm .

shows improvement in transmission and distribution losses. The performance of transmission and distribution systems is measured by the fraction of energy lost from heating of the lines and components. Losses have decreased from 10-13 percent in the 1950s to 7 percent today (MIT, 2011). Reliability, as measured by the number of outages and time without power, is comparable to other developed countries, but is highly variable depending on urban versus rural locations (Maitra, 2003). Utilities continue to invest in the transmission and distribution of electricity. Also, many projects are under way to move the grid to a smarter generation.

Several studies have been conducted to estimate the magnitude of the major investments needed—$1.5 to $2.0 trillion by 2030, with $880 billion for transmission and distribution to maintain present levels of electric service across the United States (Chupka et al., 2008), and $338 to $476 billion for Smart Grid investments until 2020 (EPRI, 2011).

Transmission Projects Under Way

The Edison Electric Institute (EEI) is the association of U.S. shareholder-owned electric companies and represents 70 percent of the U.S. electric power industry. The EEI published a report, *Transmission Projects: At a Glance*, (EEI, 2011) that lists 121 representative transmission projects that 37 of its members have planned for the next 10 years. It is not a comprehensive compilation of all projects that are being undertaken, but the sampling of projects captures a wide variety of project types that are under construction or planned. Investment of $61.2 billion is expected in more than 100 projects from 2010 to 2021, as reported by the EEI, to advance transmission.

The reported investment includes large-scale, interstate projects, renewable resource integration projects, and upgrade-for-reliability projects. The large-scale, interstate projects involve an investment of $41.1 billion and an addition of 8,300 miles of transmission lines. The renewable resource projects equate to the addition or upgrade of 11,400 miles of transmission lines and an influx of $39.5 billion. The reliability projects represent the addition or upgrade of 3,600 miles of transmission lines and an investment of $15.5 billion (EEI, 2011). While the information provided in the EEI report indicates the gross features of the included projects, the data granularity is insufficient to make specific estimates of human resource requirements. One impact of new transmission lines, however, will be more land use, and this, in turn, will likely mean that more industry and government expertise will be needed for environmental impact statements.

THE SMART GRID

Utilities have been working to update the transmission and distribution systems with new technologies and more information technology (IT) systems and networks. However, industry and government stakeholders are calling for a more expansive and integrated approach to changing the electrical power grid into an improved grid with enhanced performance, a grid that facilitates alternative types of electricity generation (including wind and solar) and one that provides instantaneous information about varying electricity costs to consumers (GAO, 2011a). This would involve making the current grid smarter by applying digital technology that ranges from meters on houses to transducers that monitor grid operation to advanced computer systems to evaluate data and more. The benefits of such an innovation include:

- Increased transmission efficiency;
- Quicker restoration after power disturbances;
- Reduced utility operations and management costs, and ultimately lowered consumer costs;
- Reduced peak demand;
- Increased integration of large-scale renewable energy systems;
- Better integration of customer-owner power generation systems, including renewable energy systems; and
- Improved security (DOE, 2012b).

Electrical supply and demand must be balanced in the electrical power system at every instant; therefore, the central consideration in modernization of the grid is continual data sharing among all of the system elements, such that the conditions within the grid are known and can be adjusted quickly as needed. To make this possible, multiple devices throughout the system must be interactive and computer controlled. Smart Grid design will involve incorporating into existing systems the sensors, controls, and wireless communication equipment that will enable the needed monitoring and control of grid activities (Fox-Penner, 2010; Weeks, 2010; Kowalenko, 2011; DOE, 2012b).

Conventional power plants have been energized by fossil fuels, by hydropower, or by nuclear power. In its current configuration, the grid has been developed to connect all of these to the users. However, the most favorable locations for large wind or solar sites are not usually within easy access to existing grid installations. Geographical dispersion of future grid connections for multiple wind and solar generators is important, not only for transport of generated electricity to potential user loads, but also to mitigate the power fluctuations that arise from the intermittency of wind and solar drivers.

For example, wind power is not used to provide baseload electricity because it is intermittent. (Baseload electric power is steady and continually produced, despite the varying demand.) Connecting multiple wind farms with a smart grid, however, would moderate their power variability, permitting a sizable portion of the wind farms to provide steady power (Alternative Power International, 2009). Interconnecting multiple wind farms could allow an average of 33 percent of yearly wind power to be used as baseload electric power, as long as minimum criteria are met for wind speed and turbine height (Archer and Jacobson, 2007).

Modernizing the grid to become a smart grid is an ongoing process that involves many steps at multiple levels of the system. Smart meters that communicate with the grid and hence the utility would continue to be installed for homes and commercial spaces. According to Federal Energy Regulatory Commission estimates, the use of advanced metering has increased from 0.7 percent in 2006 to 4.7 percent in 2008 (GAO, 2011b). In addition, Smart Grid initiatives have included new smart components to give system operators more data on transmission and distribution system conditions and the grid overall. Smart components include smart switches on the electricity distribution system—a smart switch can communicate with other smart switches to redirect electricity around problem areas when trouble arises. Smart components also include time-synchronized, high-resolution monitors on transmission systems. Future Smart Grid technology would also include storage capacity to allow storage when electricity is cheap to produce (GAO, 2011a).

With real-time information on all of the electrical flows on the grid, a little more variability is acceptable. In the Smart Grid, everything will be monitored at a very detailed level and ultrafast response will be possible, allowing operators to engage other plants if wind and solar generation drops, for example (Fox-Penner, 2010; Weeks, 2010).

According to a study by the Pacific Northwest National Laboratory, preparing a full-scale Smart Grid by 2030 could potentially reduce annual carbon emissions from the electric power sector by about 12 percent (about the output from 66 average coal-fired plants). The study attributes the reductions to nine sources, including the connection of more renewable power sources (Pratt et al. 2010; Weeks, 2010).

Challenges and Opportunities

Grid modernization is widely seen as an urgent need, requiring new technologies. Fortunately many of these technologies are now available or in advanced development. Modernization of the grid will require public policy reforms at the federal, state, and local levels, and cooperation between the industry and government. A large investment of resources will be required to achieve a new and smarter grid (Willrich, 2009).

Some Recent Smart Grid Projects

Through the Department of Energy Office of Electricity Delivery and Energy Reliability, the U.S. government in the American Recovery and Reinvestment Act of 2009 (Public Law 111-5), also known as the Stimulus Act, invested $4.5 billion to jump-start the Smart Grid. This was matched by $5.5 billion in private investment. Some recent Smart Grid projects are listed in Table 4.1.

TABLE 4.1 Federal Funds for Some Recent Smart Grid Projects (Millions of Dollars)

Smart Grid Investment Grant Program	$3,483
Smart Grid Demonstrations	$685
Interoperability Standards and Framework Development by National Institute of Standards and Technology	$12
Resource Assessment and Interconnection-Level Transmission Analysis and Planning	$80
State Electricity Regulators Assistance	$49
Enhancing State and Local Government Energy Assurance	$52
Workforce Development	$100

SOURCE: American Recovery and Reinvestment Act Overview. Adapted from Energy.gov, http://energy.gov/oe/information-center/recovery-act (accessed July 17, 2012).

In October 2009, nine federal entities signed a memorandum of understanding, increasing their coordination to expedite and simplify the building of transmission lines on federal lands. Following this, the Obama Administration formed the Rapid Response Team for Transmission

(RRTT),[3] composed of these agencies, which will accelerate deployment of seven pilot project transmission facilities beyond federal lands as follows:

- Oregon and Idaho, 300 miles of transmission lines (TL), creating about 500 jobs;
- Wyoming and Idaho, 1,150 miles of TL, creating 1,100 to 1,200 jobs;
- Minnesota and Wisconsin, 125 miles of TL and several substations, creating 1,650 jobs;
- Oregon, 210 miles of TL, creating 450 jobs;
- New Mexico and Arizona, 460 miles of TL, creating 3,480 jobs;
- Pennsylvania and New Jersey, 145 miles of TL, creating 2,000 jobs; and
- Wyoming, Utah, and Nevada, 700 miles of TL, creating 2,000 jobs.

Using just these limited data, it appears that these projects will create more than 11,000 new jobs; approximately one new direct job per mile of new transmission line (White House, 2012). On a smaller scale, the Obama Administration has announced a plan to provide approximately $250 million in loans to rural towns for replacement of aging infrastructure and to encourage development of renewable energy (White House, 2011).

WORKFORCE AND TRAINING REQUIRED TO IMPLEMENT GRID EXTENSIONS AND IMPROVEMENTS AND FOR THE SMART GRID

Replacing aging grid infrastructure, with its consequent pockets of unreliability, together with new goals for penetration of renewable generation and modernization to deal with growing electrification and climate change issues, dictate major investments in the grid over the next decade or two. Not only is the grid infrastructure aging, but so also is the electric power industry workforce.

As noted by several reports, the electric utility industry faces the problems of an aging workforce and likely skilled workforce shortfalls. After the North American Electric Reliability Corporation (NREC) raised the issue in 2006 (NERC, 2006), it reported in 2007 that: “Industry action is urgently needed to meet the expected 25 percent increase in demand for engineering professionals by 2015. Enhanced recruitment and outreach efforts through consortia, partnerships with local colleges, and increasing R&D support of university programs are vital for developing future industry talent (NERC, 2007, p. 8). In 2009, NREC further noted that: “In . . . 2007 . . . , NERC . . . confirmed industry concern on the qualified workforce gap, ranking the aging workforce high on both likely to occur and likely to have a consequence on the reliability of the bulk power system. Meanwhile, the demand for power workers to plan, maintain, and operate the bulk power system continued to increase . . .” (NERC, 2009, p. 64). Further, an MIT report notes: “Because of its aging workforce and the nature of emerging challenges, the electric utility industry faces a near term shortage of skilled workers, particularly power engineers. While this problem has been widely recognized, it remains to be seen whether efforts to deal with it will prove adequate (MIT, 2011, p. 18).

The Center for Energy Workforce Development found in its 2011 survey that 62 percent

[3] See http://www.whitehouse.gov/files/documents/ceq/Transmission%20Siting%20on%20Federal%20Lands%20MOU.pdf and http://trackingsystem.nisc-llc.com/etrans/utility/Search.seam.

of the electricity and natural gas utilities workforce has the ability to retire or leave for other reasons (CEWD, 2011a). Losses through attrition and retirement of technicians, nonnuclear plant operators, engineers, line workers, and pipefitters/pipe layers through 2015 could be 32-39 percent according to the 2011 survey (see Table 4.2). (The data in Table 4.2 do not consider the implementation of Smart Grid technologies.) Based on estimates from Heydt, et al. (2009, p. 5) and adjusting the estimated numbers of engineer replacements from Table 4.2 for power engineers, approximately 2,200 to 2,900 power engineers will be needed in the United States per year for 2010-2015 and approximately 850 to 1,150 per year for 2015-2020 simply to maintain the present levels. The loss of the knowledge and expertise of these workers is a challenge that will have to be addressed by improving the effectiveness of education at all levels, improving employability and retention, attracting potential employees at all levels, and successfully integrating culturally different workers into the industry.

TABLE 4.2 Center for Energy Workforce Development 2011 Survey: Potential Employee Losses Through 2020

	2010-2015		2015-2020	
Job Category	Potential Attrition & Retirements (%)	Estimated Number of Replacements	Potential Retirements (%)	Estimated Number of Replacements
Technicians	39	28,500	19	13,500
Plant operators	37	12,400	17	5,800
Engineers	38	10,600	15	4,100
Line workers	32	22,100	15	10,300

NOTE: Totals exclude nuclear. SOURCE: Adapted from CEWD (2011a, p. 3).

According to surveys by the CEWD (2009) and the National Commission on Energy Policy (NCEP, 2010), surveyed companies had difficulty finding qualified applicants to fill the skilled-craft positions. The CEWD found that 30-50 percent of the applicants that met the minimum requirements for a position were not able to pass the preemployment aptitude tests. Additional applicants were eliminated by background and drug screening so that 30 applicants had to be interviewed for every successful hire. Line workers were the hardest to find, with a hiring success rate of 1 in 50 applicants. However, by working with secondary and postsecondary institutions to create programs designed for the industry and aligned to industry skill requirements, companies have seen significant improvement in preemployment testing success (CEWD, 2009).

Hiring experienced engineers is a critical need and, while hiring has been slow in the electrical power industry (but less so than in other industrial sectors), filling engineering jobs with appropriately skilled applicants (e.g., with electrical engineering degrees), has been particularly difficult. About 23 percent of applying engineers did not have the appropriate education or experience. This may be partly because of a drop in students enrolled in electrical engineering degree programs and partly because median salaries for power engineers are the lowest among major electrical engineering fields. New hires with less than the required skills have been given company-sponsored training. In utilities, hiring of international students is not usual or is very limited.

For a number of reasons, utilities are more likely to hire graduate engineers at a B.S. level rather than at M.S. or Ph.D.MS/PhD levels. However, the strongest U.S. university programs in power engineering are those with substantial research and graduate programs, according to Heydt et al. (2009). Using their four criteria that an electrical engineering department must satisfy to be identified as having a strong power engineering program, the authors found fewer than five very strong power engineering programs in the United States. Some of the postbaccalaureate graduates of such programs are likely to become future faculty members at these or other institutions. They also are likely to teach important courses in power engineering at the undergraduate level in the 20 or more universities with substantial power engineering programs and the 100 or so other universities with some power engineering courses. All told, there are approximately 200 full-time equivalent power engineering faculty or instructors in U.S. universities. An estimated 40 percent will be eligible for retirement by 2013, and possibly one-half will do so (Heydt et al., 2009).

The number of graduating power engineering undergraduates is estimated at 1,500. This is roughly half to two-thirds of the number of utility replacements required each year, not taking into account the requirements for implementing new Smart Grid technologies. Enrollment in graduate power engineering programs is estimated at 550 in master's programs and 550 in doctoral programs. The number of graduating students at the master's level has been estimated at about 250 at the master's level and 100 at the doctoral level per year (Heydt et al., 2009). Many of these are of foreign origin and may return to careers in their home countries.

Implementing many aspects of the Smart Grid will require the traditional competencies, with some additional training to understand the new technologies, procedures, and protocols. This will be the case for line workers, power plant operators, relay and substation technicians, and other skilled-craft positions in the electric industry. Legacy power engineering educational programs are considered to be insufficient to accommodate the main elements of the Smart Grid, such as new designs and paradigms and new aspects of power system operation. These kinds of new technologies will have to be integrated into power engineering programs and their depth will have to be extended to the master's level (Heydt et al., 2009).

Beyond the workforce needs for operating, extending, and improving the existing grid, deployment and operation of the Smart Grid will require many workers. A 2008 study estimates the potential workforce impact of an accelerated deployment of Smart Grid technologies in the United States (KEMA, 2008). (It assumed a deployment period of 2009 to 2012.) Table 4.3 shows the study's estimates, projecting a net increase of approximately 55,900 direct utility jobs (the addition of new skills and transition of displaced workers) and contractor jobs, and an additional 25,700 new utility or energy service jobs during deployment. After the Smart Grid is deployed, KEMA projects that 32,000 utility jobs will be transitioned and there will be a net increase of about 27,200 jobs that will remain.

TABLE 4.3 Smart Grid Jobs Created and Transitioned

Jobs Category	Jobs in Deployment Period (2009-2012)	Jobs in Steady-State Period (2013-2018)
Direct utility Smart Grid	48,300	5,800
Transitioned utility jobs	−11,400	−32,000
Contractors	19,000	2,000
New utility or energy service company jobs	25,700	51,400
Total jobs created	**81,600**	**27,200**

SOURCE: Adapted from KEMA (2008, pp. 1-2).

Cybersecurity Considerations

The emergence of the Smart Grid will bring enhanced reliance on IT systems. As with all IT systems and networks, cybersecurity vulnerability and threats will emerge in relation to the new electricity grid. These potential vulnerabilities include an

- Increased number of access points and pathways for potential exploitation by adversaries and other malicious users,
- Interconnection of systems and networks providing wider access to exploitive and malicious users,
- Increased amount of customer information on systems raising concerns of monetary and private information theft by unauthorized users, and
- Increased risk from new and unknown vulnerabilities (GAO, 2011a).

Attacks have occurred on current smart systems. U.S. Government Accountability Office (GAO) testimony to Congress in 2012 (GAO, 2012) noted a number of issues. They include a lack of a coordinated approach to monitor industry compliance with voluntary standards, a lack of security in smart meters, a lack of information sharing in the electricity industry, and a lack of metrics to evaluate cybersecurity (GAO, 2012). The Central Intelligence Agency has reported successful attacks on the IT systems of electric power systems in multiple regions abroad (White House, 2009).

It is clear that the cybersecurity aspects of grid modernization efforts will require the employment of individuals with very specialized skills not customarily associated with the electric power industry workforce—IT specialists expert in the security of network systems, engineers capable of integrating new mixes of hardware and software systems, and managers with up-to-date technical knowledge not derivable from past experience and capable of instilling an appreciation and respect for the new standards that will have to be followed meticulously.

CONCLUSIONS

4.1 The Smart Grid would facilitate increased integration of wind and solar systems.

4.2 The electric utility industry has an aging workforce, with large numbers of retirements expected in the near term, and it faces a near-term shortage of skilled workers, particularly power engineers.

4.3 Approaches to addressing a shortfall in qualified workers include improving education at all levels, attracting employees at all levels, improving employability and retention, and integrating workers from different cultural backgrounds. Utility hiring of international students is not usual or is very limited.

4.4 Companies are having difficulty finding qualified workers to fill skilled-craft jobs. By working with secondary and postsecondary institutions to develop programs designed for the industry and aligned to industry skill requirements, companies have seen significant improvement in preemployment testing success.

4.5 Hiring experienced engineers is a critical need and it has been difficult to find workers with the appropriate skills (e.g., electrical engineering degrees).

4.6 One study found fewer than five very strong power engineering programs in U.S. universities. Some of the postbaccalaureate graduates of such programs are likely to become future faculty members.

4.7 The number of graduating power engineering undergraduates is roughly half to two-thirds of the number of utility replacements required each year, not taking into account the requirements for implementing new Smart Grid technologies.

4.8 Implementing many aspects of the Smart Grid will require traditional competencies, with some additional training to understand the new technologies, procedures, and protocols. Legacy power engineering educational programs are considered to be insufficient to accommodate the main elements of the Smart Grid. Such new technologies will have to be integrated into power engineering programs and their depth will have to be extended to the master's level.

4.9 An estimated 81,600 jobs could be created during Smart Grid deployment and 27,200 jobs following deployment.

5

Federal Energy and Extractive Industry Workforce Issues

THE WORKFORCE AND ITS ISSUES

Introduction

The federal government has a significant role to play in the domestic production and distribution of energy and raw materials. As stated in the Mining section of Chapter 2, the government role includes such areas as

- Permitting and regulating,
- Health and safety,
- Federal and state land administration, and
- Research and data compilation.

Federal employees are involved in all aspects of the energy and extractive industries, from initial access (through the permitting process), through production and the regulation of those activities, to closure and restoration during the reclamation process. If the government cannot find qualified workers, energy and extractive industries will be dramatically affected. For example, permits for exploration will not be processed, work sites will not be inspected, information accessible only to a comprehensive federal mandate will not be gathered or shared, and research into safer and healthier production will not be funded. Worker health and safety and the nation's economic health will suffer. Federal agencies require competent and motivated employees in order to carry out their congressionally mandated responsibilities, and thus are dealing with workforce issues that are very similar to those faced by the industry sectors.

This chapter focuses on the workforce issues faced by federal agencies that are involved with the energy and extractive industries and possible solutions to these important issues. The information in this chapter was obtained through discussions with representatives from a wide range of federal agencies involved with the energy and extractive sectors. Specifically, members of the study committee and staff met with federal employees on two occasions and had a telephone conversation with others on a third occasion to discuss their workforce issues.

On December 13, 2011, employees from a range of federal offices participated in a federal agency discussion meeting at the National Academies' Keck Center in Washington, DC. The federal employees attending this session were: Mary Cummings (National Nuclear Security Administration); Jeff Duncan (Mine Safety and Health Administration); Thomas Galassi (Occupational Safety and Health Administration); John Howard (National Institute for Occupational Safety and Health); Robert LaBelle (representing the Bureau of Safety and Environmental Enforcement and the Bureau of Ocean Energy Management); Brenda Pierce

(U.S. Geological Survey); and Steven Wells and Tim Spisak (Bureau of Land Management). Marilyn Suiter of the National Science Foundation was also in attendance and offered comments during the discussion.

On January 19, 2012, three study committee members (Elaine Cullen, Reginal Spiller, and Sterling Rideout) and staff met with employees of the DOE at DOE Headquarters in Washington, DC for a discussion of their workforce issues. The DOE employees participating in the meeting were: Guido DeHoratiis, Natenna Dobson, Shannon Gipson, Sharon Weaver, and Dawn Tolley (Office of Fossil Energy); Penny Boyce (Office of the Deputy Assistant Secretary for Human Capital and Corporate Services); Serena McIlwain (Office of the Chief Human Capital Officer); and Kathy Fear (Human Resources Division of the Office of Institutional Operations at the DOE's National Energy Technology Laboratory).

On January 9, 2012, two study committee members (Elaine Cullen and Reginal Spiller) and staff had a telephone discussion with employees of the DOE Office of Energy Efficiency and Renewable Energy about their workforce issues. The DOE employees participating in this discussion were: Michelle Fox, Linda Silverman, Christina Nichols, Jonathan Bartlett, and Joanna Maher.

Appendix B contains a detailed statistical and demographic view of the primary federal agencies responsible for management and oversight of energy and mining, based on data drawn primarily from FedScope[1] (an online tool from the U.S. Office of Personnel Management that provides information on the federal civilian workforce), with additional information drawn from the National Institute for Occupational Safety and Health (NIOSH) Web site. The data and discussion in Appendix B corroborate and further elaborate on trends and issues discussed in this chapter.

Overview of the Workforce and Its Issues

Federal agencies provide a range of services related to the energy and extractive industries. These include such things as

- Research (e.g., NIOSH, U.S. Geological Survey [USGS], Department of Energy/Energy Efficiency [DOE/EE], and DOE/Fossil Energy);
- Data gathering and management (e.g., USGS, Mine Safety and Health Administration [MSHA], U.S. Energy Information Administration [EIA], and Bureau of Labor Statistics [BLS]);
- Energy security (e.g., National Nuclear Security Administration [NNSA]);
- Permitting (e.g., Bureau of Land Management [BLM], U.S. Forest Service, and Bureau of Ocean Energy Management [BOEM]);
- Environmental oversight (e.g., Office of Surface Mining, Reclamation and Enforcement [OSM], BLM, and Environmental Protection Agency);
- Health and safety regulation (e.g., MSHA, Occupational Safety and Health Administration [OSHA], and Bureau of Safety and Environmental Enforcement [BSEE]); and
- Technical support (e.g., MSHA, OSHA, and BSEE).

[1] Available at www.fedscope.opm.gov/.

The formal education, training, and experience required for government employees vary widely and are dependent upon the duties of the individual agencies and their specific mission. Research agencies, for example, require their technical staff to hold 4-year degrees at a minimum, and terminal degrees are required for lead researchers in most cases. Regulatory agencies, by comparison, rely more strongly on industry experience and do not generally require employees to hold college degrees. There are many more agencies and programs within the federal system than these, and regardless of educational requirements, all of them rely on strong science, technology, engineering, and mathematics (STEM) skills among their workers in order to fulfill their charge. Federal agencies, however, are in direct competition with industry in trying to attract workers with these skills and often deal with regulatory restrictions that make federal service less than competitive. The number of professional scientists and engineers is shrinking, while demand for their expertise is growing. The projections for petroleum engineers, shown in Figure 2.5 in Chapter 2, are an example. Salaries for geosciences are further evidence of shortage, with increases in pay that averaged 7.9 percent in 2011 (see the Oil and Gas section of Chapter 2). Salaries for professionals in energy and extractive fields are high and increase with experience, as is shown in Table 5.1. With salary caps in place, and frequent freezes in promotions, the federal government cannot compete with industry for the scientists and professionals it needs.

TABLE 5.1 2010 Salary Survey for Petroleum Geologists

Years of Experience	High (USD)	Average (USD)	Low (USD)
0-2	110,800	93,000	60,000
3-5	122,900	102,300	90,000
6-9	180,000	127,800	100,000
10-14	195,000	139,100	109,000
15-19	215,000	151,100	120,000
20-24	270,000	191,000	135,000
25+	600,000	206,300	148,000

SOURCE: Nation (2011). Used with permission from AAPG Explorer.

Agencies from all departments are facing high rates of retirement. Many saw rapid growth in the 1970s, when passage of legislation such as the Occupational Safety and Health Act (1970) created both NIOSH to do occupational research and OSHA to regulate and inspect workplaces. The federal mining sector saw similar expansion with the passage of the 1969 and 1975 Mine Safety and Health legislation that created MSHA as an agency separate from its parent, the U.S. Bureau of Mines, and dramatically increased the size and funding for the Bureau of Mines to do health and safety research. Agencies that shared information for this study report that a significant percentage of their employees are now eligible for retirement, having served for more than 35 years in many cases. The following tables and charts show examples of workforce data for different government agencies.

Figure 5.1 shows the age breakdown for employees in the ocean science, technology, and operations workforce, which includes five agencies (National Oceanic and Atmospheric Administration/National Ocean Service [NOAA/NOS], NOAA/National Data Buoy Center, U.S. Navy/Naval Meteorology and Oceanography Command, National Aeronautics and Space Administration/Goddard Space Flight Center, and BOEM/BSEE.)

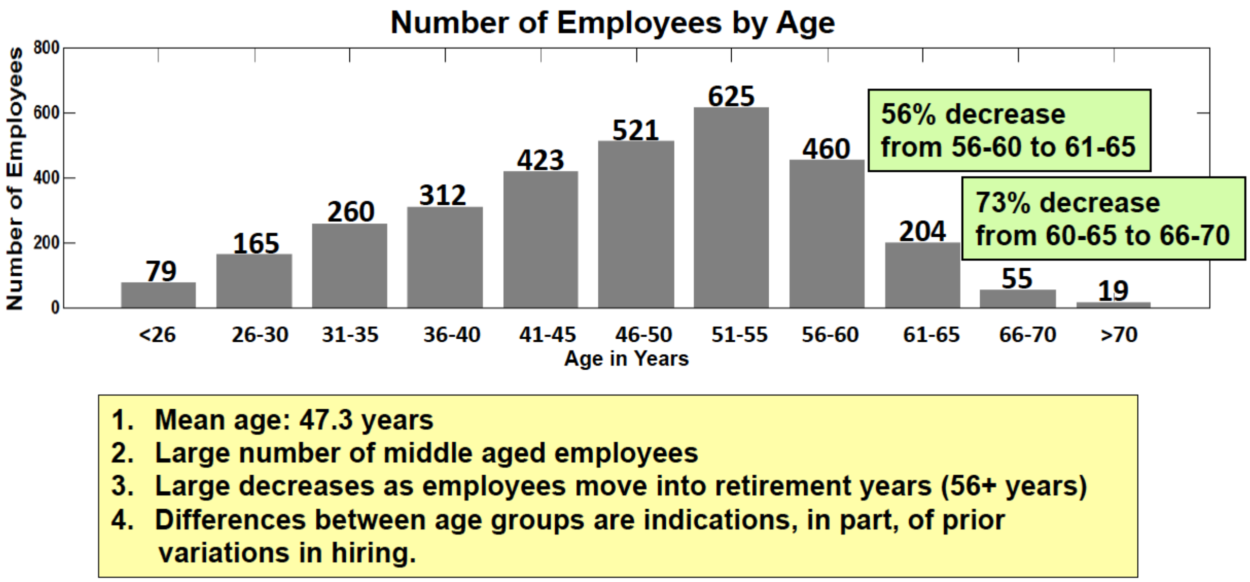
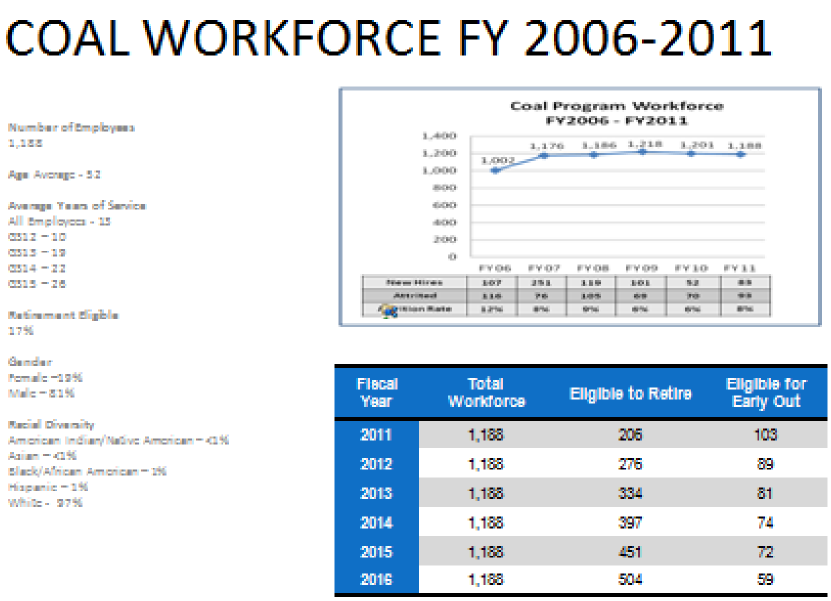


FIGURE 5.1 Ocean science, technology, and operations workforce by age. SOURCE: Sullivan et al. (2009, Slide 17). Used with permission from Tom Murphree.

The MSHA, which inspects and regulates the nation's mines, is facing a similar situation, despite having recently hired a significant number of new inspectors. Their projections show that, for the coal sector, 47 percent of the workforce will be eligible to retire within 5 years. The metal/nonmetal workforce for MSHA is roughly half the size of the coal group, and is expecting to lose 40 percent in the same period. Figures 5.2 and 5.3 show the 2006-2011 characteristics of the MSHA coal and metal/nonmetal workforces, respectively.



Fiscal Year	Total Workforce	Eligible to Retire	Eligible for Early Out
2011	1,188	206	103
2012	1,188	276	89
2013	1,188	334	81
2014	1,188	397	74
2015	1,188	451	72
2016	1,188	504	59

FIGURE 5.2. MSHA coal program workforce characteristics for fiscal years 2006-2011. SOURCE: Duncan (2011).

MNM WORKFORCE FY 2006-2011

Number of Employees
583

Age Average - 53

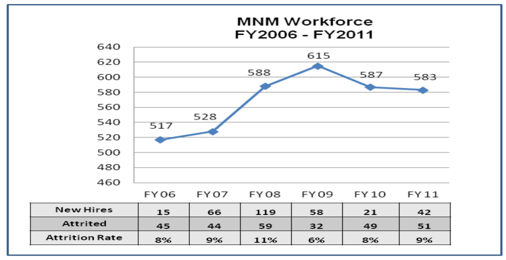
Average Years of Service
All Employees - 12
GS12 – 11
GS13 – 16
GS14 – 17
GS15 – 21

Retirement Eligible
15%

Gender
Female –18%
Male – 82%

Racial Diversity
American Indian/Native American – <1%
Asian – <1%
Black/African American – 5%
Hispanic – 6%
White - 87%

*Early Out: Minimum age 50 with 20 years of Service or any age with 25 years of service



Fiscal Year	Total Workforce	Eligible to Retire	*Eligible for Early Out
2011	583	86	45
2012	583	130	47
2013	583	158	46
2014	583	186	43
2015	583	218	42
2016	583	235	38

4

FIGURE 5.3 MSHA metal/nonmetal workforce characteristics for fiscal years 2006-2011. SOURCE: Duncan (2011).

The NNSA, charged with the security of the U.S. nuclear weapons and components, is facing a situation in which a majority of mission-critical employees are currently eligible or will be eligible for retirement in the next 4 years. Figure 5.4 shows the demographics of the NNSA workforce.

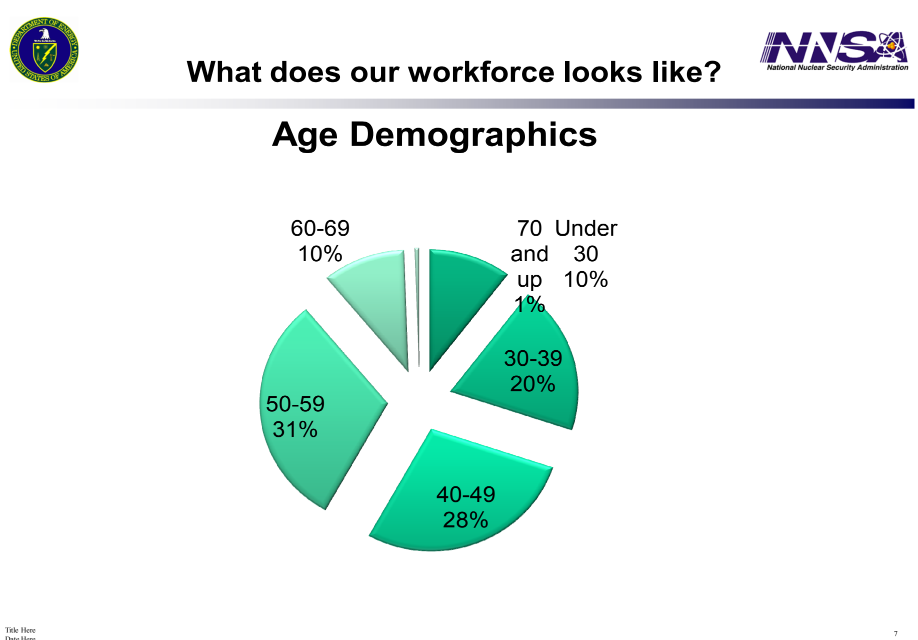


FIGURE 5.4 Age demographics of the NNSA. SOURCE: Cummings (2011).

NSSA reports that:

- 43 percent of engineers are eligible for retirement in the next 6 years.
- 52 percent of supervisors are eligible for retirement in the next 6 years. and
- Nearly half of senior managers are eligible to retire now.

These data show that critical positions may turn over very soon and there will be little or no time to train replacements.

Other agencies that provided information to the committee indicated similar circumstances. The OSM reported that 40-50 percent of current employees are eligible for retirement. In a January 2012 meeting with the U.S. DOE Fossil Energy Headquarters management team, the committee was told that a large portion of their technical staff is eligible for retirement.

As noted at the beginning of the chapter, study committee members and staff talked with federal employees on three occasions to discuss their workforce issues—meeting on December 13, 2011 at the National Academies' Keck Center in Washington, DC and on January 19, 2012 at DOE Headquarters in Washington, DC, and holding a telephone discussion on January 9, 2012. The federal participants in these discussions are also listed above. The following bulleted points came from these discussions.

Managers for agencies that deal with energy and extractive industries share common concerns about their future workforce. Because of the wide range in missions among these agencies, and variations in how managers are allowed by Congress to operate, managers are addressing these concerns in different ways. The concerns and ways of addressing them include the following:

- Capturing the wisdom and knowledge of key people before they leave is an issue for nearly every agency. OSHA is using a program called In-Teach that allows its retirees to develop training on information they would like to share with their colleagues. Many federal managers are frustrated with their inability to bring new employees into the system in a way that allows the employees the opportunity to overlap with existing experts and learn from them.
- Federal managers are having a hard time filling technical and mid-level management positions. The things that have historically been drivers for bringing people to the federal workforce—high salaries, good benefits, and job security—have been eroded by hiring freezes and caps on salary and benefits. Competition for people with strong STEM skills and experience is very high, and the government cannot match what industry is offering in terms of salary and benefits.
- Pay levels for nonscientific federal positions are comparatively low, which is causing turnover among lower-graded employees. Agencies such as OSHA and MSHA that employ their inspectors at GS-7/9/11 levels cannot pay relocation costs or match the salary levels that their people could earn if they went to work for industry. Many of the field offices for agencies such as BLM or MSHA are in geographic areas where there are limited numbers of potential employees, and those areas are not perceived as attractive to people from other parts of the country. Experience has shown that people tend to be "place-based," in that they prefer to stay in areas that they know and

understand. Incentives to relocate need to overcome this barrier, but federal jobs that don't offer high pay, permanent status, relocation bonuses, or moving allowances are simply not competitive.

- Federal managers find it increasingly difficult to post vacancies and fill these positions with qualified candidates. They view the internal human resources systems as cumbersome and not tolerant of innovation. Several agencies, however, are making use of alternate hiring authorities, such as Presidential Fellowships (OSHA) or hiring reemployed annuitants (USGS). Few agencies are able to make use of a strategy more common to industry and academia—hiring skilled foreign candidates. Restrictions on citizenship status, particularly in regulatory or security positions, make it impossible for most agencies to consider employing noncitizens. NIOSH, an agency under the Centers for Disease Control and Prevention, is an exception and has successfully employed senior research people from other countries, particularly in the health research field. NIOSH also has been successful in reemploying retirees as consultants to work on specific tasks or projects.
- Some agencies are able to use unpaid workers to fulfill their nonregulatory and non-oversight mission-critical duties. Vista Volunteers are used by OSM, for example, and USGS uses an Emeritus program to allow retirees access to an office and support staff in order to continue research or to publish their work.
- Many agencies are facing significant changes in the nature of the work they do, as work becomes more technical and more crosscutting. Finding and hiring people with a breadth of specialties, such as economic geologists (USGS) or GIS-competent marine resource managers (BOEM) is difficult, particularly when companies are also looking for these skills and are willing to pay a premium for them. Some agencies, such as the DOE/EE, are successfully using advanced technology to train new and existing employees. This mitigates, to some degree, the problems faced by agencies requiring training for their employees that takes the employees away from their families to a remote location for long periods of time, such as the 21 to 23 weeks of training at the National Mine Health and Safety Academy in Beckley, West Virginia, that MSHA requires of new inspectors. (Although this training is generally spread over an 18-month period, it is not considered a perquisite by new candidates.) Employee development opportunities are available in most agencies, because managers often find it easier to cross-train existing workers than to find new ones with the requisite skills. Some agencies, such as NIOSH, even offer "long-term training" that pays for terminal degrees in exchange for a guarantee that the employee will stay with the agency for a specified period of time.
- Nontraditional students are a recognized source for possible federal candidates. The OSM, for example, maintains partnerships with Historically Black Colleges and Universities in order to communicate career opportunities to students that may not know about federal jobs. The DOE has used the Mickey Leland Energy Fellowship program[2] (a 10-week summer internship program) to help develop interns. The National Science Foundation (NSF) is attempting to increase diversity in STEM programs (those considered most crucial to federal employers), by encouraging minority students and girls to participate in grade school science programs.

[2] http://fossil.energy.gov/education/lelandfellowships/

Recognizing the difficulty of relocating people to places that are unfamiliar, NSF recommends localizing training if possible, and relocating cohorts rather than individuals to diminish the anxiety these employees may feel about being outside of their familiar cultures.

- The DOE also is sponsoring the DOE Technical Career Internship Program,[3] which is intended to recruit excellent students from earth sciences and engineering universities as early as their sophomore year for internships in fossil energy programs. Penn State University is participating with DOE in this program.
- Returning military veterans are viewed as a possible source of candidates. Vets are given a hiring preference for work in government, as well as educational benefits, and are often more focused on careers than younger candidates may be.
- Agencies that deal with green energy are generally having less trouble attracting workers. The DOE/EE believes that there exists an "eco-consciousness" that makes work in renewable energy attractive. This trend is, perhaps, a mirror of what is seen in the solar and wind energy sectors. Employees seem to fall into a bimodal demographic distribution, with many under 30 years of age, and a significant group that is over 55 years of age. The generation in the middle is poorly represented. The DOE is using contractors to fill these gaps. Although these agencies also are struggling with the resistance to relocating common among the other agencies, they are compensating for this, to some degree, by allowing telecommuting and other high-tech off-site options.
- Federal managers are concerned about the low morale among their workers. Many, they believe, entered public service because they felt called to it, and are passionate about their work. Continued attacks on the federal workforce have a demoralizing effect.

The inability of the federal government to attract and retain enough qualified workers creates a situation that is concerning. If permits for exploration or extraction of minerals, oil, and gas are delayed by the lack of agency experts to process them, for example, the country is affected. Even more disturbing is the potential price in health and safety paid by workers in the energy and minerals industries.

In April 2010, Secretary of Labor Hilda Solis commissioned NIOSH to convene an expert panel to complete an independent assessment of the internal review conducted by MSHA on the Upper Big Branch Mine Disaster. Among their findings was the following: "if MSHA had engaged in timely enforcement of the Mine Act and applicable standards and regulations, it would have lessened the chances of—and possibly could have prevented—the UBB explosion" (Wade et al., 2012, p. ii). Inspectors, they found, did not identify or bring attention to two of the three likely causes of the explosion that killed 29 miners—the buildup of methane gas that was ignited by friction from the mining process, and the accumulation of float dust that propagated the ignition and exploded through the mine. The independent review panel made the following statement about the ability of MSHA to hire and train a cadre of inspectors that could prevent these types of disasters in the future:

> *No amount of additional training or revisions to manuals and handbooks can fully address this problem. Nor is an increase in the number of inspectors a viable long-term*

[3] http://www2011.energy.psu.edu/osd/doeintern.html

> *solution. . . . These structural problems are exacerbated by changes in the demographic composition of the MSHA inspectorate. Retirements have, and are continuing to decimate the ranks of mining faculty at universities, seasoned mining engineers, mine managers, miners, NIOSH mining researchers, and MSHA inspectors, among others. The pool of potential hires is insufficient to replace the numbers being lost through attrition, and with increasing frequency, the new hires are completely inexperienced in mining. The MSHA IR Report describes in detail a workforce that is unprepared to undertake the full scope and complexity of inspecting the mines and overseeing the enforcement process. The inexperience of the inspectorate was identified as a factor in MSHA's enforcement performance at UBB, and there is no reason to believe that District 4 has a disproportionate number of inexperienced inspectors. Given the paucity of candidates with even modest training or experience in mining-related fields, hiring a large cadre of new inspectors would not be sufficient to remedy MSHA's enforcement deficiencies. The shortage of qualified personnel, which is likely to persist for the foreseeable future, underscores the need for new solutions.* (Wade et al., 2012, p. 12)

POSSIBLE SOLUTIONS

Federal managers face many challenges. If the federal government is going to maintain its ability to provide essential services to the nation and its people, these challenges must be met. Attracting and keeping bright, talented employees with a passion for public service is paramount.

Recommendations

In discussions with federal managers involved with energy and extractive industries (on December 13, 2011 at the National Academies' Keck Center in Washington, DC, on January 19, 2012 at DOE Headquarters in Washington, DC, and on January 9, 2012 by telephone, as described above), some solutions to the workforce problem were suggested. Based on these suggestions, the following recommendations are made. They should be initiated as quickly as possible and some will take longer than others to become fully operational. The recommendations are ordered and labeled in terms of when they would be expected to be operational. All of the recommended actions are expected to continue for the long term. Short term is defined as 2 years or less, medium term as 2-5 years, and long term as more than 5 years.

5.1 Agencies should consider partnering more closely with elementary and secondary schools in order to share their employees' passion for science and technology, to assist with STEM education, and to communicate the many interesting career possibilities to students. (Short Term)

5.2 The federal government should consider using internships to create a stronger "farm system" that allows agencies to grow new talent and to give students considering federal careers interesting, practical, and meaningful work. The DOE Technical Career Internship Program could serve as a good example to emulate. (Short Term)

5.3 Agencies should develop a retention strategy for incoming workers. For example, after completing an agency-wide study of generational issues in their workforce, leaders at DOE developed a training program for managers in how to deal with different generations in the workforce, and how to recognize motivators for different generations. This program included a formal mentoring and coaching program, and the gathering of information on professional development needs for all employees. (Short Term)

5.4 Agencies should be positive, vocal advocates for federal employment. Young people will not choose careers with the government if they believe it to be a negative choice. (Short Term)

5.5 The federal government should empower the Office of Personnel Management to find the people the federal government needs and to offer them employment. Nontraditional students, employees with disabilities,[4] military veterans, and young STEM-competent students are all candidates for federal careers. The federal government should consider streamlining the hiring system to reduce the time it takes to fill vacancies, and to be more competitive for top-quality candidates. The delays that are common in hiring and promotion are not tolerated by younger workers, and are often identified as reasons they are leaving federal service. (Medium Term)

5.6 MSHA should consider developing innovative ways to attract new workers, including expanding the use of the Mine Health and Safety Academy in Beckley, West Virginia, to offer certificate and focused degree programs that will enable incoming employees to move more quickly into higher-paying jobs, making service to MSHA more attractive. This facility should also be considered as a safety and health academy to train employees for other agencies, including OSHA and state OSH organizations, as well as industry. (Medium Term)

[4] Americans with Disabilities Act (ADA) of 1990, including changes made by the ADA Amendments Act of 2008 (P.L. 110-325).

6

Safety and Health in Extractive Industries

Any discussion of workforce issues in high-risk industries such as those included in this study must include a look at the safety and health of both current and future workers. Because these industries include hazards not often encountered by other industries, it is paramount that all workers—those preparing to enter the workforce, those actively working in it, and those ready to retire from it—be protected by adequate safety and health practices. This chapter includes a discussion of data from two main industries, mining, and oil and gas extraction. It should not be inferred that the health and safety of workers in other industry segments are not important, but only that the data for mining and oil and gas extraction are more complete, are readily available, and can be used to illustrate trends that are common across the other industries as well. The nuclear industry is not addressed because it is unique and not really comparable with the other industries, since its workforce is very stable and receives initial and continuing training that is extremely specialized and rigorous, owing to the singular nature of this industry.

A LOOK AT DEMOGRAPHICS

Mining and oil and gas extraction and production are arguably the most "mature" industries included in this study. Mining has been an underpinning for civilization for thousands of years, but until relatively recently, the miners themselves have not been protected by safety regulations. In the early 1900s, an estimated 2,000-3,000 U.S. coal miners died every year. Metal/nonmetal miners, most of who worked in the mines in the West, were also killed at an appalling rate. Wallace (1976) reports that in the mines that made up the fabled Comstock Lode of Nevada, there were periods when a miner was killed every week, and others were severely injured every day. No accurate records were kept, however, and it was not until 1911 that the federal government even included metal/nonmetal mining in its fatality reports. The number of miners actually working in metal/nonmetal operations was not tracked until 1931. Figures 6.1 and 6.2 show coal and metal/nonmetal fatalities for 1900-2010, respectively.

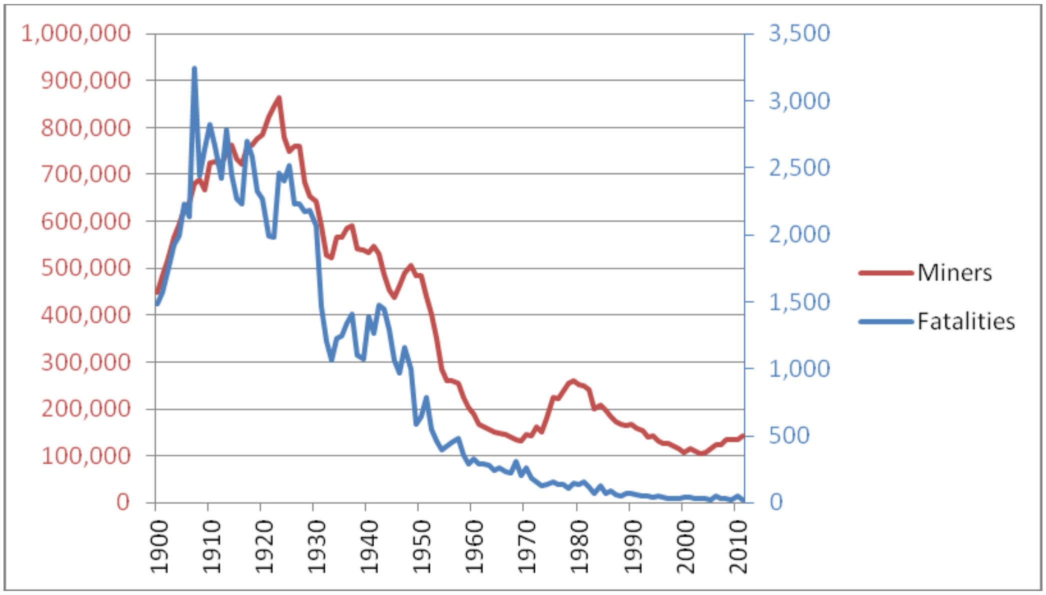


FIGURE 6.1 Coal fatalities for 1900 through 2010. NOTES: Total number of coal mining fatalities from 1900 through 2010 is 104,722, and office workers were included starting in 1973. SOURCE: Data from MSHA (2012b).

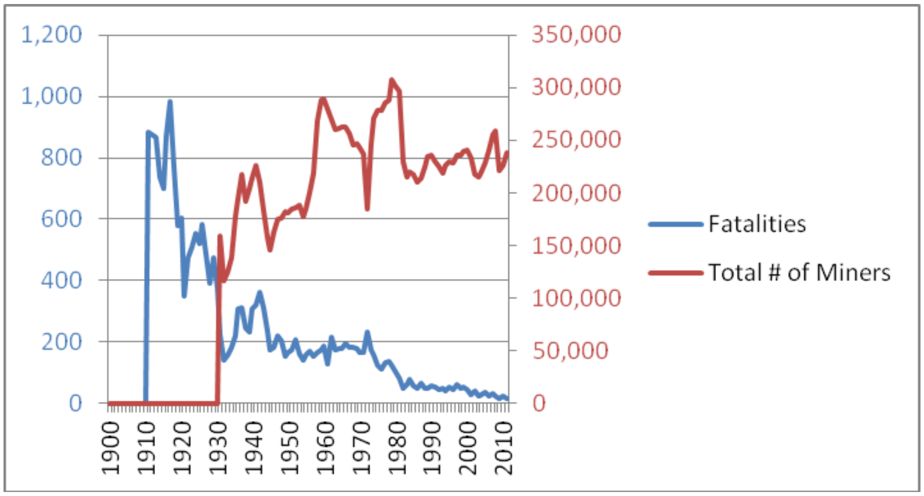


FIGURE 6.2 Metal/nonmetal fatalities for 1900 through 2010. NOTES: Total number of metal/nonmetal mining fatalities from 1900 through 2010 is 23,608. Metal/nonmetal operations include mills (metal, nonmetal, and stone), sand and gravel, surface (metal, nonmetal, and stone), underground (metal, nonmetal, and stone). Sand and gravel miners were included starting in 1958, and office workers at mine sites were included starting in 1973. SOURCE: Data from MSHA (2012c).

A particularly deadly year for coal miners was 1907, with 3,242 miners killed, mostly in mine fires and explosions (MSHA, 2012b). When the Monongha mine exploded and killed 362 men (the worst mine disaster in U.S. history in terms of lives lost), societal pressure convinced Congress to establish the U.S. Bureau of Mines in an attempt to make mining safer. Founded in 1910, the Bureau had no regulatory authority.

Rather, it was expected to investigate disasters and perform research on how to prevent such occurrences. One of the charges given to the Bureau was to keep statistics on the mining population. Consequently, there are specific employment and accident/injury data available for these sectors that are not available for other segments of the energy industry and that can be used to highlight concerns common to other industries that lack these detailed data. These databases are a wealth of information on industrial accidents and injuries. MSHA, which was separated from the Bureau of Mines and moved to the Department of Labor in 1975, maintains these data and makes them available through its Web site.[1]

Although the government has required mines to provide data since the mid-1970s on the number of person-hours worked (MSHA, 2012d)[2] and detailed information on every reportable accident or injury (noninjury incidents are reportable if they shut down a working area for more than 30 minutes regardless of whether any workers are involved), information on the worker population itself was not generally gathered. (Annual accident/injury data can be found online in MSHA's Accident/Injury database [MSHA, 2012d]). A large demographic study completed by the U.S. Bureau of Mines in 1986 provides an in depth look at the U.S. mining populations, as reported by Butani and Bartholomew (1988a,b). Coal mining and metal/nonmetal mining are discussed separately in the study because of the significant differences in practices. According to this study, the total estimated metal/nonmetal workforce in 1986 was around 179,800, while the coal workforce was around 152,800. These data exclude the category of office workers, which explains a discrepancy between the totals reported by the Bureau's study and by MSHA for the same years. The mean age for metal/nonmetal workers in 1986 was 40, while for coal miners it was 42 for anthracite and 39 for bituminous coal. These coal data were kept separately because of the significant disparities in how the two are mined, as well as the differences in worker populations. Anthracite miners numbered only around 2,600 in 1986, a small percentage of the total coal mining population, and the percentage is even smaller now. Today's miners are significantly older than other workers. BLS data, which include oil and gas extraction in the mining statistics, support this, showing that the U.S. mining population is consistently and significantly older than the general labor force. Figure 6.3 provides a comparison of age distributions for coal mining and all industries for the year 2003, and Figure 6.4 provides an historic comparison of the median ages for the U.S. and mining workforces by year.

---

[1] Available at www.msha.gov/.
[2] Available at available at http://www.msha.gov/stats/part50/p50y2k/aetable.htm.

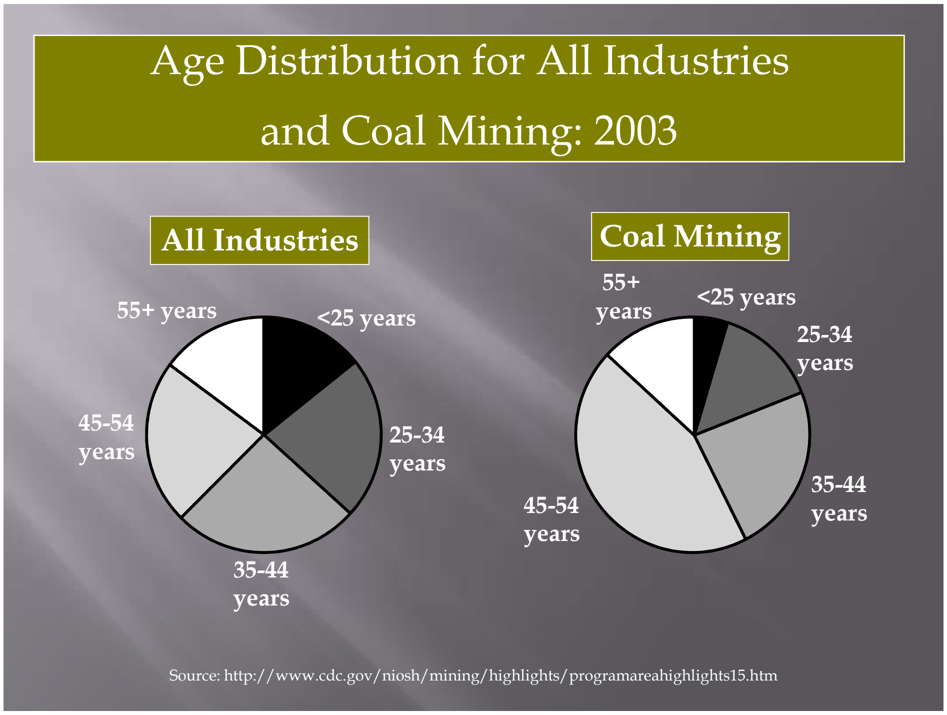


FIGURE 6.3 Age distribution for all industries and coal mining, 2003. SOURCE: NIOSH.

The oil and gas industries show similar trends. A study conducted in 2008 showed that nearly one-third of the global petrotechnical workforce is over the age of 50 (see Figure 2.6 in Chapter 2) and that the distribution of these workers is truly bimodal, with the larger groups under age 30 and over age 50. There is a gap between these age groups, which is often attributed to the economic downturns experienced in the 1990s. The gap corresponds to those in the 35- to 45- year age range that normally would be transitioning into management positions. As is stated in the section in Chapter 2 on the oil and gas sector, companies may have difficulty finding qualified, experienced managers and supervisors, which also will affect the safety and health of their employees.

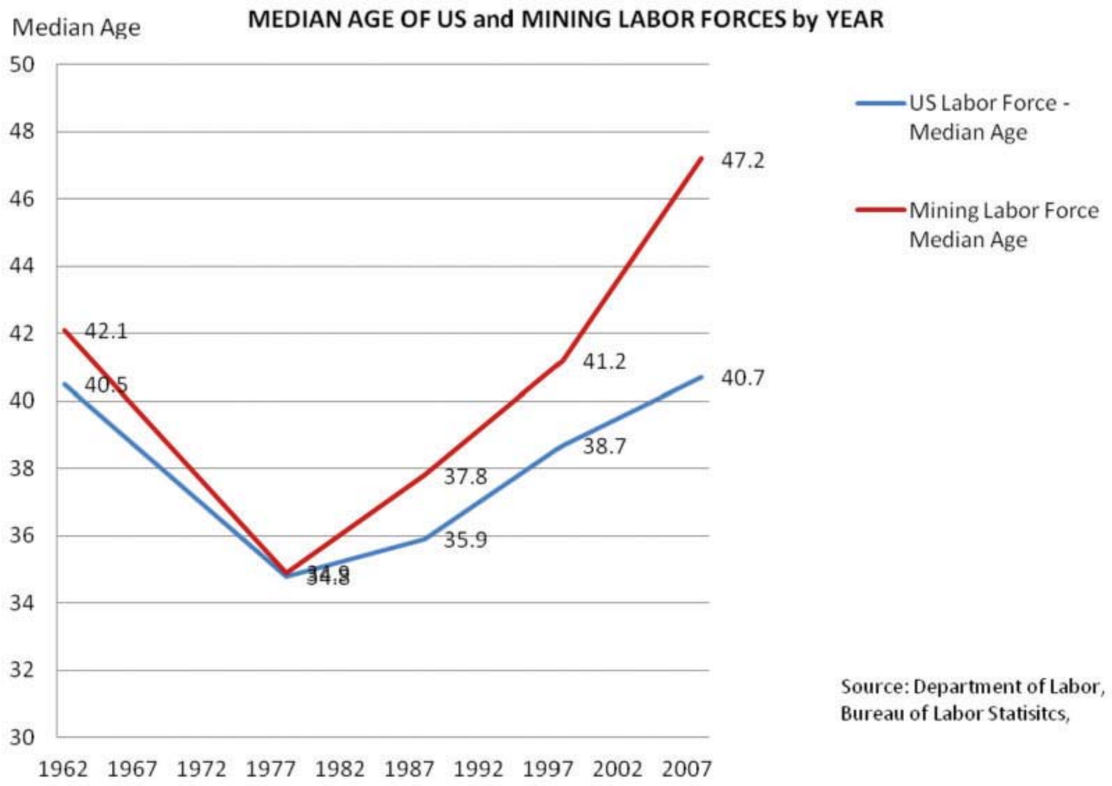


FIGURE 6.4 Median age of U.S. and mining labor forces by year. SOURCE: Data from U.S. Bureau of Labor Statistics in Brandon (2012, Fig. 9, p. 12).

National Mining Association data support these statistics, reporting in their 2010 coal miner profile that the median age of U.S. coal miners is 46, with 20 years of experience (NMA, 2011). Data from the BLS Current Population Survey on employed persons by detailed industry and age, given as 2011 annual averages (BLS, 2012b), showed that all of the sectors included under the mining category are reporting an aging workforce. Although the BLS does not gather this type of data for the emerging industries included in our study, such as solar and wind energy, discussions with industry representatives suggest that these sectors have attracted a much younger workforce. Although they may not have to deal with the challenges of an aging workforce, it is reasonable to assume that they will face the same concerns as the mining, oil, and gas sectors that have a large number of young, inexperienced workers coming in to replace retiring miners and oil and gas workers.

A SAFETY DILEMMA

Mining and oil and gas extraction, like most of the other industries included in this study, are physically demanding, particularly for entry-level workers who generally begin their careers as laborers. These are also occupations that rely upon on-the-job training rather than classroom education to train new hires. Workers learn the job from older, more experienced workers rather than from manuals or books. The construction industry, where many of the workers involved in solar and wind energy are found, is very similar to mining and oil and gas in how workers are trained, although more formal training or apprentice programs are offered in some areas by labor organizations. Inexperience is a significant factor in workplace injuries and fatalities among high-risk industries. MSHA released an Accident Prevention Alert recently that reported that of the 21 coal miners killed in 2011, ten of them had less than 1 year of experience at the task on which they were working (MSHA, 2012a).

Inexperience on the job is not solely related to age because older workers often change professions late in their careers and are attracted to the high wages paid by the mining industry (see Table 2.8 and 2.9 in the Mining section of Chapter 2). Even so, inexperience is most often a factor for new, young workers. Margolis (2010) reported that numerous studies have shown that younger workers are more likely to be injured on the job, and although this may be due to causes as diverse as temporary work assignments, lack of proper training, or inexperience, the fact remains that younger workers are at risk. Ismail and Haight (2010) analyzed metal/nonmetal mining fatalities between 2002 and 2006 and found that workers between the ages of 17 and 24 had the highest rate of fatalities (47.37 per 100,000 workers) among all age groups of miners who did similar tasks, with workers over the age of 55 rated second at 32.38 fatalities per 100,000 workers (see Figure 6.5). For a workforce that has been described as bimodal, with a large percentage of workers either younger than 25 or older than 50, these are grim statistics.

The trend holds true for oil and gas extraction workers as well. These data represent what is known as the “upstream” portion of the industry, excluding the midstream, or pipeline and transportation portion, and the downstream, or refineries. During the 6-year period from 2003 to 2008, 648 people died on the job, for a fatality incidence rate that, at 29.1 per 100,000 workers, was nearly 7.5 times higher than the 3.9 per 100,000 rate of all U.S. industries (NIOSH, 2013). Although length of service was reported for only 56 percent of these incidents, inexperienced workers, generally known in the industry as short service employees (SSEs), accounted for 55 percent of all fatalities where experience was reported (Retzer and Hill, 2011). Figure 6.6 shows the leading causes of fatality by company for U.S. oil and gas extraction workers for 2003-2008, and Figure 6.7 provides the number and percentage of fatalities by length of employment.

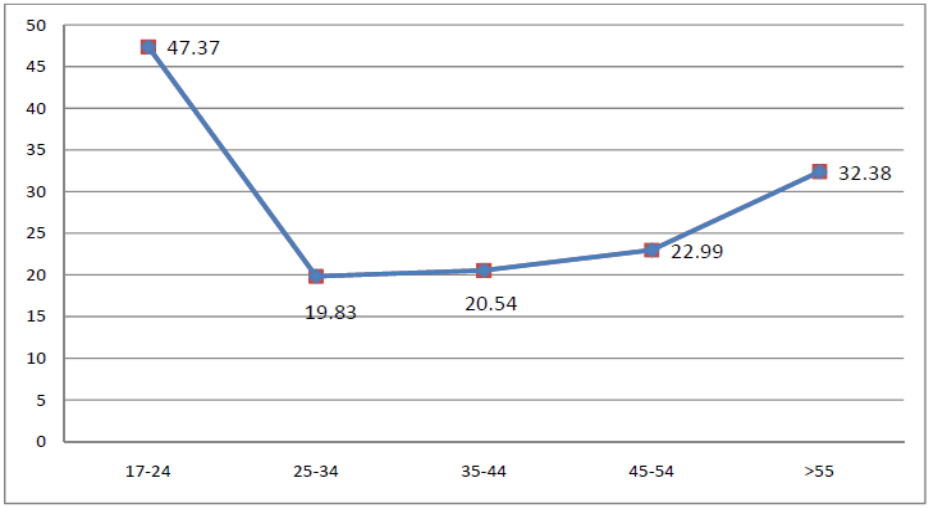


FIGURE 6.5 Fatalities per 100,000 workers based on age group in metal and nonmetal mines from 2002 to 2006. SOURCE: Ismail and Haight (2010).

Rank	Operator 121 (18%)	Drilling Contractor 198 (31%)	Well Servicing Company 329 (51%)	All Company Types 648
1	Highway Crash 29 (24%)	Struck by Object 52 (26%)	Highway Crash 120 (36%)	Highway Crash 190 (29%)
2	Struck by Object 19 (16%)	Highway Crash 41 (21%)	Struck by Object 60 (18%)	Struck by Object 131 (20%)
3	Aircraft 14 (12%)	Falls 28 (14%)	Explosion 34 (10%)	Explosion 53 (8%)
4	Fire 14 (12%)	Caught/compressed 17 (9%)	Caught/compressed 20 (6%)	Caught/Compressed 46 (7%)
5	Explosion 10 (8%)	Electrocution 13 (7%)	Fire 15 (5%)	Falls 45 (7%)
Other	35 (28%)	47 (23%)	80 (25%)	183 (29%)

FIGURE 6.6 Leading causes of fatality by company for U.S. oil and gas extraction workers (2003-2008). SOURCE: Retzer and Hill (2011).

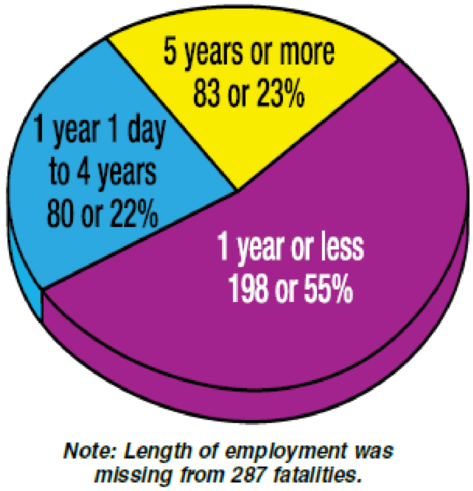


FIGURE 6.7 Number and percentage of fatalities by length of employment. NOTE: Length of employment was missing from 287 fatalities. SOURCE: Retzer and Hill (2011).

Data gathered by the Texas Oil and Gas Association corroborate this. Eighty-nine oil and gas workers died in Texas between 2001 and October 2010. Thirty-four percent of them had 3 months or less of experience, and 65 percent had a year or less of experience (see Figure 6.8). These data also provide information on workers who are seriously injured on the job. Considering fatal injuries plus catastrophic injuries (injuries costing more than $100,000), 31 percent occurred to workers with 3 months or less of experience and 66 percent occurred to workers with a year or less of experience (see Figure 6.9). It is clear that high-risk extractive industries can be particularly deadly for young or inexperienced workers (Stephens, 2011).

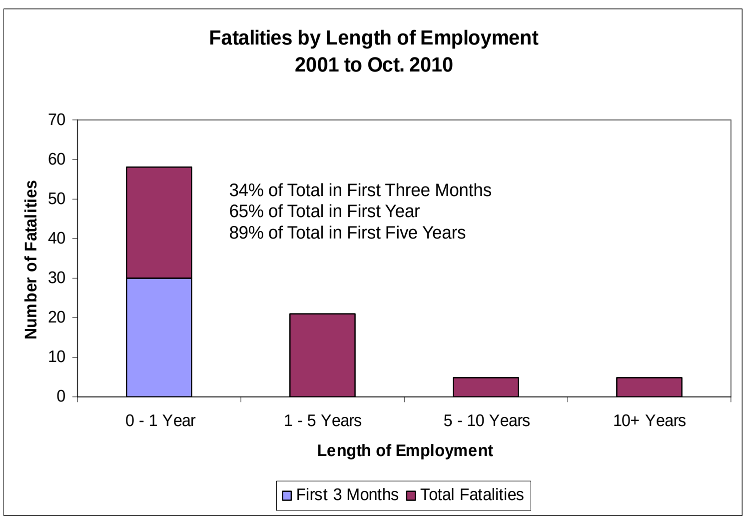


FIGURE 6.8 Fatalities by length of employment for Texas oil and gas workers (2001 to October 2010). SOURCE: Stephens (2011). Used with permission from Texas Mutual Insurance Company and the Texas Oil and Gas Association.

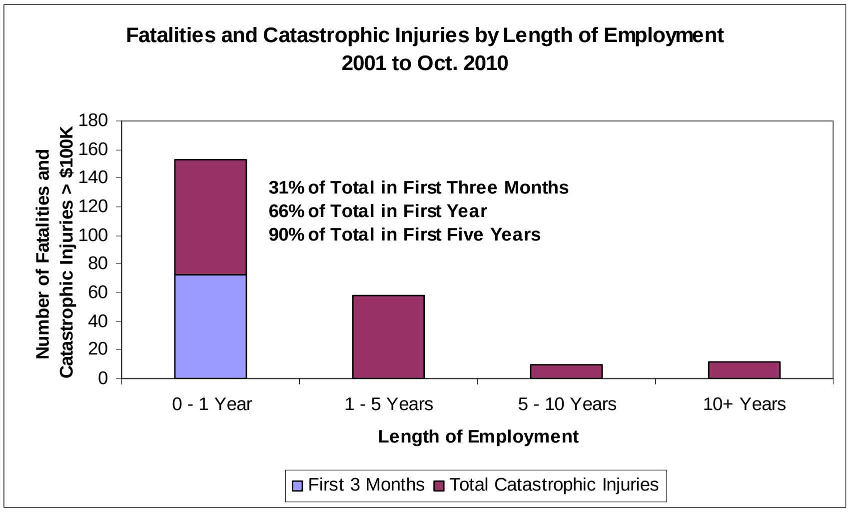


FIGURE 6.9 Fatalities and catastrophic injuries by length of employment for Texas oil and gas workers (2001 to October 2010). SOURCE: Stephens (2011). Used with permission from Texas Mutual Insurance Company and the Texas Oil and Gas Association.

A definition of "older workers" can be elusive. According to the Age Discrimination in Employment Act, workers over 40 must be protected. The Older Americans Act, however, defines older workers as those over 55 (Ismail and Haight, 2010). Others define the aging process as a loss of physical and mental abilities rather than chronologically. One fact that researchers can agree on, however, is that for high-risk industries, older workers (here defined as those 55 or older) have higher fatality rates than workers between 25 and 55, and when injured on the job, they have the highest median days lost. Figure 6.5, above, shows fatalities per 100,000 workers based on age group in metal and nonmetal mines from 2002 to 2006.

Fotta and Bockosh (2000) present findings that show that the mining work force is aging, and that older workers are much more likely to be found as supervisors, electricians, mechanics, or surface equipment operators than as laborers or underground equipment operators. These are people the industry looks to as expert miners and as mentors to an increasingly inexperienced workforce, and yet the percentage of these key people who are injured on the job or are impaired by work-related health issues has risen dramatically. Figure 6.10 shows this trend. When they are unable to work, who will provide the industrial wisdom needed to train a new generation of workers?

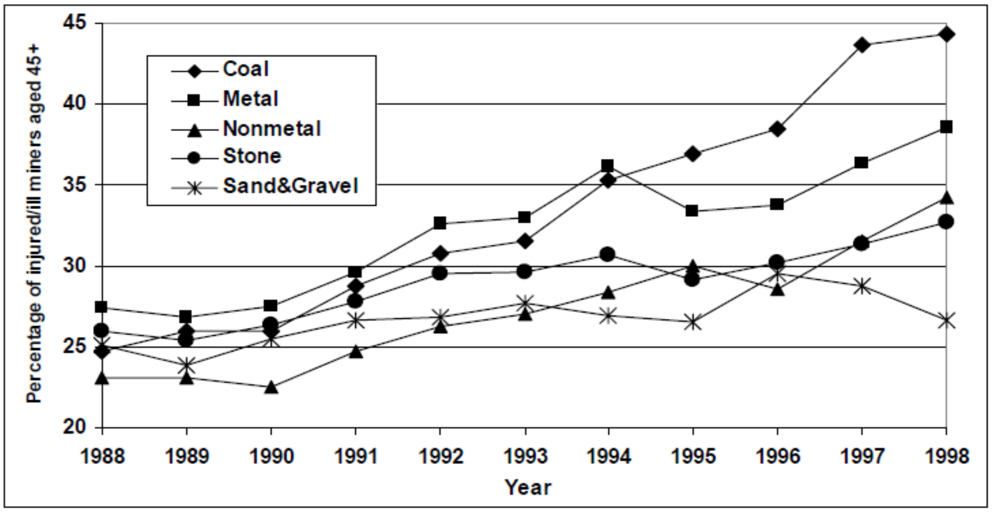


FIGURE 6.10 Percentage of injured or ill miners, age 45 years and over, by operator canvass class and year, MSHA, 1988-1998. SOURCE: Fotta and Bockosh (2000).

The International Labor Organization estimates that by the year 2025, 30 percent of the population of North America will be over 55 years of age (Ilmarinen, 2001). This situation impacts all industries, but is extremely acute for high-risk industries, where hazards are part of the daily work. In a recent talk, Dr. John Howard, Director of NIOSH, presented data from the U.S. Census Bureau that detail the percentage of growth for different age groups in the workforce (Howard, 2009; see also Figure 6.11). The figures are dramatic—all groups under 55 years of age show nominal growth, or in the case of 35- to 44-year-olds, a loss. The category between 55 and 64 is expected to grow by 73 percent and those over 65 by 54 percent. The issue of an aging workforce is a major concern to occupational safety and health.

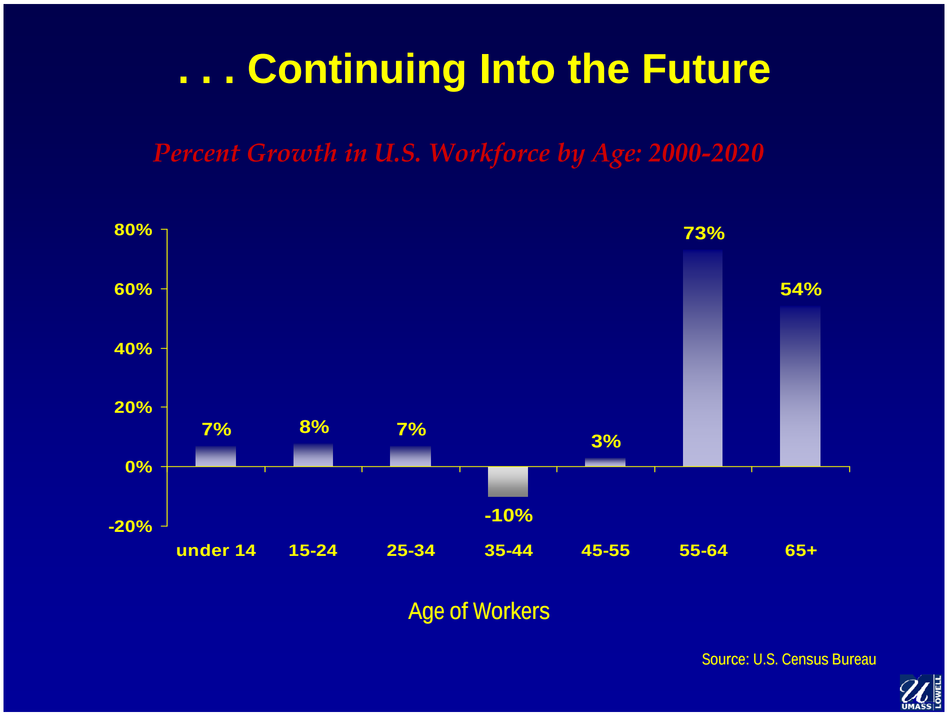


FIGURE 6.11 Percent growth in the U.S. workforce by age (2000-2020). SOURCE: Howard (2009).

The imminent retirement of a significant percentage of the mining and oil and gas workforces creates a looming crisis for extractive industries. To do the work, these industries require workers, and their workers are increasingly either aging with a high level of experience, or young with little or no experience. Discussions presented in previous chapters have shown that there is a significant time investment that is required before an inexperienced person can be turned into a knowledgeable, competent employee (see Figures 2.33 and 2.34 in the Mining section of Chapter 2). The safety and health problem is obvious: How do these industries protect both young and aging workers during the time it takes to develop the needed expertise? The NIOSH mining program states that this is a two-pronged dilemma: which includes “1) the ability to transfer the knowledge that older . . . workers have to younger workers, and 2) the need to maintain a healthy, age-diverse workforce despite the fact that many older workers may be experiencing normal physical and cognitive changes that accompany aging.” (NIOSH, 2012). Workers who are approaching retirement age must deal with the inherent hazards of the work at the same time they are experiencing the physical changes that accompany aging. Keeping them safe through the final years of their careers is a challenge that must be addressed by the energy and extractive industries.

The critical reality of losing the experienced workers is that they are not only the mentors to the inexperienced workforce, but they are also the keepers of the historical and corporate memory. They are the people who have first-hand experience about what has gone wrong in the past and what was done to address those situations. As was stated in Chapter 2 on the oil and gas industry, “Without experienced supervision and guidance the past mistakes will be made all over again and the past learning’s forgotten until new knowledge is acquired all over again." As our industries lose talent and experience, we, as a nation, not only lose capacity but also capability to perform the tasks at hand."

WORKFORCE CHALLENGES

All of the energy and extractive industries are projecting increased needs for workers for the foreseeable future (see figures from all of the chapters showing projections for workers). Our nation is not likely to decrease its need for raw materials and energy, and it is these industries that provide them (see Figure 2.26 in the Mining section of Chapter 2). Options for finding additional workers are limited, especially as other countries face the same shortages and attempt to attract U.S. workers with higher pay (see discussion on Global Competition in the Mining section of Chapter 2). Although a short-term strategy used by some companies is to offer a slightly higher wage in the hopes of luring workers from their competitors (known as "cannibalizing your neighbors" in some areas), this is not a long-term solution, for it does little to increase the available pool of workers. More viable options include:

- Hiring new, young, inexperienced people and finding a way to keep them safe until they have gained enough experience to do the work, which involves finding and using mentors and developing and providing effective training;
- Retaining older, experienced workers and either redesigning the work in order to compensate for their aging or transferring them into positions that do not require rigorous physical effort;
- Bringing workers in from other countries and designing multicultural training and communication programs in order to ensure that they have the basic understanding to be safe, productive workers despite language barriers;
- Attracting new workers at all levels from other disciplines (another form of cannibalism in the view of those disciplines); and
- Opening these fields to nontraditional workers not currently found in large numbers, such as women and minorities.

All of these options will likely be needed if the United States is to meet the demand for energy and raw materials in the future. Training and retention of workers will be overriding requisites of our workforce strategy.

In addressing the workforce challenges, proper training is critical. New workers are often exposed to environmental or occupational hazards for which they have no experience or even language to describe. Training is necessary for all new employees that describe common health and safety hazards and how to deal with them, as well as survival skills needed to respond to disasters such as the Upper Big Branch Fire or the explosion of the Deep Water Horizon oil rig.

It should be noted that this report does not include a detailed discussion of all that should be included in safety and health training for new workers because each industry has its own challenges and providing recommendations about what should be included in such training is beyond the scope of this study. It also is important to note that the majority of incidents in the industries covered by this report involve one worker, but workers should be prepared for disasters if they occur.

It is important that safety and health training, which is currently uneven across industries, meet a minimum standard for content and be provided by trainers who are not only industry knowledgeable but also trained in how to communicate effectively with a diverse workforce. Workers will represent different generations, different nationalities, different geographic areas, different genders, and different learning styles, and all must be provided the information they need to survive, and to prevent debilitating work-related illnesses.

As experienced workers leave the workplace and take with them the knowledge and wisdom they have gained over their careers, it is important that companies capture what they know and use it to train new generations. Research has shown that expert workers are much more credible to their young colleagues than "talking heads," and that training provided in industry-specific language is far more effective than that using highly technical or legal language. Stories told by the master workers are excellent sources of information and can be used to keep the interest of new trainees as they learn the language, the culture, and the skills needed in their work. Capturing these stories on video and creating a virtual "wisdom library" that can be used whenever needed would be an effective strategy.

Retaining older workers is a solid strategy. These people have a wealth of knowledge that can be used to develop younger workers. Experienced people can be used as mentors to teach people not only how to do the tasks, but why. They also understand how to do the work safely, as evidenced by their longevity, and they can provide an additional safety net for new hires as they gain the necessary experience. An added benefit is that young workers who may leave because they have become discouraged with their assignments would have access to coaches and mentors to help them learn and develop. Older workers may opt to continue in their current jobs, and can often continue to do the work they have done, if these tasks are not too physically demanding or are redesigned to accommodate them.

Attracting nontraditional employees is also a good strategy. Many of the sectors included in this study have not historically had a large percentage of nontraditional workers. (These may include employees with different national backgrounds, but the largest underrepresented group is women.) A recent report from the NIOSH Office of Mine Safety and Health Research provides details on the demographics of the mining worker population. According to the report, women make up around 7.5 percent of the current workforce, and minorities account for around 6.4 percent (McWilliams, et al., 2012). There are opportunities for industry to attract qualified workers from different demographic groups. There will be some cultural resistance to bringing women into what have been male-dominated fields, but with the increase in technology and automated operations, the traditional argument that women lack the physical strength to do the work is not always relevant.

It is apparent from discussions held with industry representatives, however, that many of the sectors face workforce shortages that are principally geographical in nature. Efforts to relocate workers from large cities with high unemployment rates to isolated areas where jobs are plentiful, for example, have not been successful in spite of the high wages offered. If this strategy is to be successful, these workers must be given much stronger social support than they have received in the past.

Many studies have shown that younger workers often expect a much better balance between work and life than their parents had. It is important that industry leaders understand this in order to attract and retain new employees.

What is becoming increasingly common is that the workforce of the future will not resemble that of the past. There are currently four recognized generations in the workforce, for example, and minorities and women are represented in increasing numbers. Supervisors and managers will need to be trained in how to lead such diversity, and this training will be quite different from what they have traditionally had. The "soft skills" not normally included in engineering and scientific degree programs should be provided to industry leaders if they are to be successful in leading diverse work teams. These skills include such things as effective communication, communicating across cultures, building multigenerational work teams, understanding adult learning styles,; and motivating diverse teams. Additionally, industries are turning to safety management systems and development of safety cultures as strategies to move beyond compliance-based safety, or measuring safety solely by counting injuries and fatalities. Supervisors and managers of the future will need to be trained in those techniques. For example, some companies have adopted a Target Zero program to promote a safety culture (the Southern Company is one example).

Training is critical for our workforce strategy. As has been consistently discussed in this report, our nation's educational system needs to provide a workforce that is competent in the STEM-related fields. These students, whether they choose to continue their education into professional fields or to enter their careers immediately following high school graduation, will face a work environment that is far more technological than in the past, requiring skills that were unheard of 30 years ago. Employers today are reporting that new hires often lack the basic skills required, and that retention is a major problem. This situation requires remediation. Unskilled workers are both incapable of the productivity needed by the energy and mining industry sectors, and they are at risk for occupational injury and illness.

The health and safety of the U.S. energy and extractive workforces are both a legal and an ethical imperative. Protecting workers as they begin their careers, or as they finish them, are two common challenges faced by these industries.

The safety and health of workers are not optional. The federal oversight of job safety is increasing, and managers and supervisors who are lax in providing a safe work environment and are not insisting that safety policies and regulations be followed, are being held legally, and in some cases, criminally accountable.[3] Energy and extractive industries must protect their workers from the hazards they face. The workforce of the future will be much more diverse in age, gender, background, and national origin. Supervisors and leaders must be prepared to deal with these challenges if our nation is to have the energy and minerals it needs for a vibrant economy.

[3] Mine Improvement and New Emergency Response Act of 2006, Public Law 109-236 (S 2803), June 15, 2006. Available at http://www.msha.gov/MinerAct/2006mineract.pdf.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

6.1 The U.S. dependence on raw materials and energy is expected to continue to grow.

6.2 The workers in energy and extractive industries are at much higher risk for fatal injury than are workers in other fields as a whole.

6.3 Studies have shown that workers who have less than 1 year of experience or are over 55 years of age are more likely to be victims of occupational injury and death than are other workers.

6.4 In the "mature" industries included in this study (coal mining, metal/nonmetal mining, oil, and gas), the worker population is increasingly bimodal, with a significant number of workers in the two high-risk groups—those who are very young or aging. Injury and fatality rates in these industries are likely to increase as a result.

6.5 Those industries included in the study that are categorized as "emerging" (solar, wind, and geothermal) report a significant number of younger people in their workforce. This has been shown to be a high-risk group.

6.6 Mining and oil and gas, particularly, are facing significant numbers of workforce retirements, which creates the dilemma of leaving a significant gap between new hires and the experienced workers that traditionally mentor them and teach them how to do the work. Research has shown that it takes a significant number of years before a new employee can be considered as experienced or competent.

6.7 Options for maintaining an adequate number of workers in the coming years include opening these fields to nontraditional workers and foreign workers, as well as retaining older workers to both draw on their institutional and occupational wisdom and expertise and to train new workers.

6.8 Energy and extractive industries of the future will be more technologically driven than they have been historically, requiring a workforce with skills they do not currently have. A STEM-capable workforce is essential if these industries are to be viable in the next decades, and unskilled workers are at greater risk for occupational injury and illness.

Recommendations

The following recommendations should be initiated as quickly as possible and some will take longer than others to become fully operational. The recommendations are ordered and labeled in terms of when they would be expected to be operational. All of the recommended actions are expected to continue for the long term.

6.1 Safety and health training, which is currently uneven across industries, is best if it meets a minimum standard for content and it is provided by trainers who are not only industry knowledgeable but also trained in how to communicate effectively with a diverse workforce. Where not required by mandate, companies should consider providing training to all new employees, describing common hazards and how to deal with them. (Short Term)

6.2 Undergraduate engineering programs preparing future leaders for all of these industries should include safety and health training as part of the required curriculum. (Short Term)

6.3 Companies should capture what experienced workers know before they leave the workforce, and use it to train new generations. Capturing these stories on video and creating a virtual "wisdom library" that can be used whenever needed would be an effective strategy. (Short Term)

6.4 Retaining older workers is a solid strategy for keeping knowledge and experience in the workplace, and companies could strive to retain valued older workers, who can serve as trainers and mentors to younger workers. (Short Term)

6.5 Companies should reach out to attract and retain nontraditional workers. (Short Term)

6.6 To make the strategy of relocating workers to work sites successful, companies should consider giving these workers much stronger social support than they have received in the past. It is important that industry leaders understand this in order to attract and retain new employees. (Short Term)

6.7 Companies should train supervisors and managers in how to lead a diverse workforce, and this training would be quite different from what they have traditionally received. To help ensure that industry leaders will be successful in leading diverse work teams, this training would be best if the "soft skills" not normally included in engineering and scientific degree programs were provided. These skills would include such things as effective communication, communicating across cultures, building multigenerational work teams, understanding adult learning styles, and motivating diverse teams. Leadership training should also include topics such as risk management, development of safety cultures, and disaster management. (Short Term)

7

Educating and Training the Energy and Mining Workforce

INTRODUCTION: ON OUR PRESENT COURSE, DEMAND WILL SOON OUTSTRIP SUPPLY

There is a clear need for an increasing supply of energy and mining professionals and technicians, as discussed in the previous chapters. For both of these energy and mining workforce components, a strong foundation in science, technology, engineering, and math (STEM) skills is required. The discussion in this report differentiates these components by referring to the technical workforce as the STEM technical workforce, and the engineers and scientists as the STEM professionals. The demand for both components is growing due to the expected retirement of baby-boom employees and growth in the energy and mining industries. Moreover, skilled energy and mining jobs at all levels increasingly require STEM capabilities.

According to the Bureau of Labor Statistics (BLS) Education and Training Classification System, a majority of jobs across the full spectrum of industries in the 21st century economy requires some education beyond high school, but not necessarily a 4-year college degree. The same holds true for the energy and mining industries.

For this reason, this study has focused in large part on identifying promising practices in developing the current and future energy and mining STEM technical workforce and also barriers impeding that development. A highlight of the study's findings is the identified industry–education partnerships, particularly at community colleges or in the first 2 years of higher education, that have emerged as critical to the nation's energy and mining future. These partnerships are designed to create competency-based educational pathways to careers in these industries. Successful models now exist in manufacturing—closely aligned to the energy industry—and in several energy sectors, specifically nuclear power, electrical transmission, and most recently, renewable energy. There is great potential for extending this model of workforce education into all of the energy and mining industries.

Energy and manufacturing are inexorably linked. While manufacturers produce the equipment and materials to fuel energy discovery, production, and distribution, manufacturing also is the largest consumer of energy products. The success of both industries is fundamental to U.S. economic and national security. Recognizing this fact, the third annual index of the public's perception of manufacturing (Giffi and DeRocco, 2011) identified (1) a manufacturing facility, and (2) an energy production facility, as the public's preferences when asked what industry they would prefer to create 1,000 new jobs in their community.

Remarkable parallels exist between the workforce profiles, requirements, and challenges of these key industries. Innovation is critical to their business success, and the scientists and engineers in their workforces drive the research and development (R&D) that fuels their capacity for innovation. The infusion of technology into virtually all business processes in these two sectors is integral to their success and it has had a dramatic impact on their workforces. This trend, known as "skill-based technological change," means that technological development and organizational changes translate into the need for workers with more education to handle more complex tasks and activities (Carnevale et al., 2010). Both industries' workforces are grounded in the skilled crafts and trades. However, largely because of the imperative of innovation and the infusion of technology into the energy, mining, and manufacturing enterprises, the application of STEM principles in the workplace has increased the skill and competency requirements of the workforce. Thus, the energy and mining workforce is discussed in terms of two key components directly related to STEM knowledge and skills—STEM professionals and the STEM technical workforce.

Much research has been done by many esteemed organizations, for example, the National Academy of Sciences' Committee on Prospering in the Global Economy of the 21st Century (NAS/NAE/IOM, 2007), that have focused on improving the production of STEM professionals. Among their foci and recommendations have been actions to increase the nation's talent pool by vastly improving K-12 science and mathematics education and to make the U.S. the most attractive place for research so that the nation can develop, recruit, and retain the best students, scientists, and engineers from inside and outside of the United States. The committee accepts those recommendations and to supplement and strengthen the nation's resolve to develop the energy and mining workforce, focuses most of its recommendations and strategies on developing the STEM technical workforce. Without the technical capacity to produce energy and extract minerals, production will most assuredly leave our shores, followed by R&D.

The energy and mining industries face several major demographic challenges. The first is shared by virtually all U.S. industries—the aging of the baby boom generation. The more mature energy and mining sectors (oil and gas, coal, and nonfuel minerals) have the most significant challenge in terms of workforce replacement requirements. In addition to the number of needed replacements, these industries will face the need for replacements with higher levels of education and different skills than their predecessors. Across the entire economy, by 2018, 33 million replacement jobs will have to be filled, and 63 percent will require workers with at least some college education (Carnevale et al., 2010). These energy and mining industries also have the traditional challenges of a 20th century workforce—predominantly male, Caucasian, and older—that is misaligned with the profile of the 21st century workforce.

Immigration policy of the United States and most of its international competitors has an impact on workforce availability. The current workforce-related immigration programs, that is, the H-1B visa program targeted at high-skill professionals and the H-2a and H-2b programs for temporary workers (primarily in the agricultural sector and for low-skill jobs) are misaligned with the nation's need to increase the STEM professionals and STEM technical workforce. In comparison, for example, Canada has a points-based program aimed at fulfilling policy objectives for immigration, particularly in relation to labor market needs.

Although reformed immigration policies could be helpful, it is most important to focus on strategies to "grow" our own talent. The United States has models currently at work that should be brought to scale to accomplish this goal. This action calls for a lasting commitment to the public–private partnerships that will define and support educational pathways for all students and workers to build the competencies and skills required for the U.S. energy and mining workforce.

BUILDING THE PIPELINE: ACADEMIC AND WORKFORCE PREPARATION BEGINS IN K-12

The pronounced need for a STEM technical workforce and the inadequate pipeline of qualified workers is not unique to the U.S. energy and mining industries. In fact, the decline in preparedness for a qualified STEM technical workforce is an impediment to overall U.S. economic growth. This was cited by the National Academies in its *Rising Above a Gathering Storm* reports (NAS/NAE/IOM, 2007, 2010). All four major recommendations in the first report pertain to factors crucial to meeting the energy and mining workforce demands of the future, but the two relating to improving K-12 STEM education and increasing the number of people pursuing STEM education most directly affect the energy and mining workforce educational needs.

Key Indicators of Our K-12 Challenges

Lack of Preparation Among U.S. Students

A recent ACT report (based on the 1.6 million graduating seniors taking the ACT exam) corroborates the previous work of the *Rising Above the Gathering Storm* committee as it pertains to the poor educational preparation of high school students (ACT, 2011) Some of the most compelling statistics include the following:

- Only 25 percent of these graduating seniors met or surpassed the four College Readiness Benchmarks in the areas of science, math, reading, and English;
- 15 percent met the benchmark in only one subject; and
- 28 percent did not meet the benchmark in any of the four subjects (ACT, 2011).

The College Board, which administers the other major college entrance examination in the United States (the SAT), released similarly troubling statistics showing declines in critical reading skills, mathematics, and writing. The College Board explained the decline partially by stating, “as we reach more students who have less resources, scores will tend to drop” (W. Camara, The College Board, personal communication, 2011, as cited in Rivera, 2011). They suggested that education officials at all levels “look to the rigor of school curriculum” (Rivera, 2011).

ACT reported that 70 percent of the increase in postsecondary requirements is due to upgrades in skills demanded by occupations that previously did not require higher education. Also, their energy gap analysis indicated that the portion of examinees able to meet or exceed the criteria for energy education demands breaks down as shown in Table 7.1 (Scaglione, 2011).

TABLE 7.1 Examinees That Met or Exceeded Energy Skill Requirements

Occupations	Examinees That Met or Exceeded Energy Skill Requirements (%)		
	Applied Mathematics	Reading for Information	Locating Information
High-education occupations (typically require attainment of bachelor's degree or higher level of education)	12	59	2
Middle-education occupations (typically require work experience in related occupation, a postsecondary vocational award, or attainment of an associate's degree)	62	70	27
Low-education occupations (typically require short-, medium-, or long-term on-the-job training)	52	55	72

SOURCE: Adapted from Scaglione (2011).

Student Disengagement and High Dropout Rates

Recent statistics show that about 7,000 students drop out of high school every school day in the United States, and about 1.3 million students do not graduate each year. Also, a lack of student engagement is indicated by research to be predictive of a student dropping out (Alliance for Excellent Education, 2010). Other data indicate that more than half of high school dropouts under 25 years of age were unemployed on average for 2008 (Sum et al., 2009).

Figure 7.1 indicates the lack of educational preparedness in 2011 shown by ACT-tested high school graduates for each of the 2018 projected five fastest-growing career fields. It gives the percentage of these 2011 graduates who indicated a career interest in each of these fields that met each of the four ACT College Readiness Benchmarks. For none of these career fields did at least 50 percent of the 2011 graduates meet all four of the benchmarks.

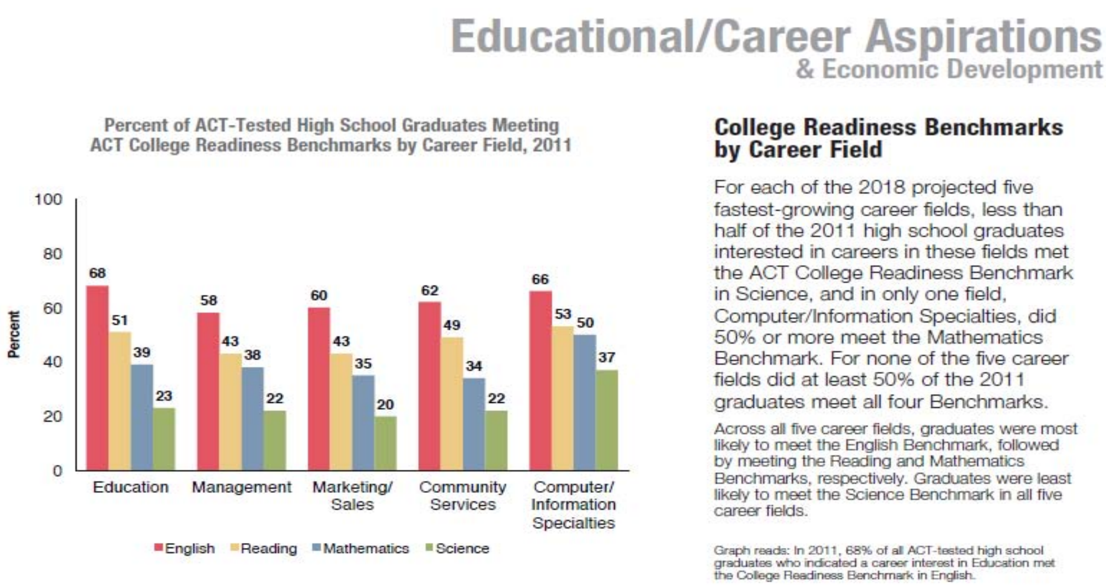


FIGURE 7.1 ACT data on educational/career aspirations and economic development. SOURCE: ACT (2011, p. 11).

Figure 7.2 shows the skill requirements for U.S. energy occupations.[1] In the analysis, occupations were grouped into the categories of low, middle, and high education (based on the BLS's Most Significant Source of Education/Training by SOC Code). Figure 7.2 shows an upward trend in the level of skills needed for jobs requiring higher levels of education, and it indicates how the skills requirements for the low- and middle-education occupations actually require middle and high skill levels, respectively.

U.S. ENERGY SKILL REQUIREMENTS
January 2006–December 2010

EDUCATION GROUP	APPLIED MATHEMATICS (RANGE: 3–7)	READING FOR INFORMATION (RANGE: 3–7)	LOCATING INFORMATION (RANGE: 3–6)
SKILL LEVEL REQUIRED FOR 85% OF OCCUPATIONS			
HIGH EDUCATION OCCUPATIONS	7	6	6
MIDDLE EDUCATION OCCUPATIONS	5	5	5
LOW EDUCATION OCCUPATIONS	5	5	4

FIGURE 7.2 ACT data on U.S. energy skill requirements (January 2006 – December 2010). SOURCE: Scaglione (2011).

Some Reasons for the K-12 Failures

Lack of a High Standard Core High School Curriculum

Both the ACT and SAT identify one area as a key indicator of student performance—for the SAT, those students who completed a core high school curriculum (4+ English, 3 math, 3 natural science, 3 social science/history) scored 143 points higher on average. The 2011 ACT data show that not only were the graduates who were taking the same defined core curriculum more likely to meet the corresponding ACT College Readiness Benchmark in 2011, but also that the largest curriculum-based difference in benchmark attainment was in mathematics.

Too Few Pathways to High School Graduation

Another factor contributing to the K-12 failures is that there are too few alternative pathways to high school graduation. Such alternatives would include career and technical education pathways that integrate academic and project-based learning.

[1] Energy occupations are defined as those that are specific to an energy industry (i.e., occupations for which at least 10 percent of the overall employment is represented by that industry).

Needed Improvement in K-12 STEM Teacher Preparation

The two highest priority actions for the nation, according to the *Gathering Storm* report (NAS/NAE/IOM, 2010), are to provide teachers in every classroom that are qualified to teach the subject they teach, and to double the federal investment in research (to be competitively awarded and largely performed by research universities as opposed to government facilities).

A program that has had significant impact in educating K-12 teachers who can improve student STEM achievement is the Robert Noyce Teacher Scholarship Program, a grant program administered by the National Science Foundation (NSF). It gives funding to higher-education institutions to give scholarships, stipends, and programmatic support for engaging and preparing gifted STEM majors and professionals to become K-12 teachers. For each year of support received, the stipend and scholarship recipients must finish 2 years of teaching in a high-need school district, with the ultimate goal being to provide more STEM-qualified K-12 teachers in high-need school districts.

The program also provides support for recruiting and developing NSF Teaching Fellows, who receive salary supplements while they satisfy a 4-year teaching requirement. It also provides support for developing NSF Master Teaching Fellows by offering professional development and salary supplements as they teach for 5 years in a high-need school district. The goal is to recruit people with good STEM backgrounds that might not otherwise consider being a K-12 teacher.

The University of Texas' UTeach program is a rigorous, comprehensive, and proven approach to inquiry-based curriculum, internship, and mentorship that has been emulated and replicated by universities across the United States. Public–private partnerships have supported the continuation and replication of the model, and the NSF Noyce program funds scholarships for students at many of the sites.

Disproportionate Access to Quality Instruction

Although success in science and engineering fields requires high-quality instruction, math and science teachers are distributed unequally, both geographically and in quality. In 2007, 80 percent of eighth graders were taught math and science by teachers with degrees in the field, while the percentage of students taught by instructors with general education preparation fell to 9 percent. Encouragingly, more than 82 percent of public school fifth and eighth graders had teachers who had worked in that level of education for 3 or more years (NSB, 2010).

Socioeconomic factors contribute to disproportional access to quality instruction. In 2004, black and Hispanic fifth graders were less likely than white students to receive instruction in math from teachers with a graduate degree. Also, in 2007, eighth graders whose mothers lacked a high -school diploma or its equivalent were far less likely to be taught science by an instructor holding a graduate degree, a regular or advanced teaching certificate, a degree or certificate in science, and more than 3 years of experience teaching the subject (NSB, 2010).

Impacts of K-12 Failures on Our Ability to Build an Adequate Pipeline of Qualified Students into Postsecondary Programs Aligned to Energy and Mining Careers

Overwhelming Requirements for Developmental Math

Developmental math can act as a critical gatekeeper for student pathways into energy and mining careers. It also is very important to student retention, and it impacts attrition rates once students are in community colleges. Student must overcome the current culture of math phobia to be successful in any postsecondary STEM program. The key to passing it may lie in innovative strategies in math delivery, including contextualization, compression and paired courses, STEMway, Statway, and Quantway; academic and nonacademic student support; and online technologies.

Remediation Requirements Shift Costs to Higher Education and Affect College Completion

Because of the lack of student preparation in K-12, about one-third of students entering higher education need remedial courses. Such remediation consumes higher education resources, and there is a high cost to both students and the nation. Nationally, for the 2007-2008 school year, remediation in public institutions costs an estimated $3.6 billion. Also, students who take remedial courses are more likely to drop out of college, resulting in an estimated $2 billion in lost lifetime wages (Alliance for Excellent Education, 2011).

Complete College America offers statistics on college graduation rates in 33 states. Its report gives data on students whose progress has been difficult to track, including those enrolled part-time, pursuing certificates, or taking remedial courses, as well as older and transfer students. Analyzing completion rates for these students yields a more complete understanding of student chances at college success. The report notes: “Time is the enemy of college completion. . . . The longer it takes, the more life gets in the way of success (Complete College America, 2011, p. 3).

With increasingly limited budgets for public higher education, community colleges and state universities must choose between offering developmental courses or other degree program courses. Students also find their time to degree completion longer and more frustrating.

These economic pressures on curriculum demands are unhelpful because community colleges are proving to be the best vehicle for delivering the quality technician-level, skills-based education that the energy and mining industries need for a STEM technical workforce. They are capable of rapid turnaround in delivering new and adapted curricula and offer low-cost accessibility for the broad and diverse student base needed for the energy and mining economy.

BRIDGE FROM SECONDARY TO POSTSECONDARY AND FIRST 2 YEARS OF HIGHER EDUCATION

Organizations across the country are building strategic partnerships in which industry representatives are advising educators on industry’s skill needs, and educational institutions are working to align education and workforce development programs directly to the industry needs. This work is primarily focused in postsecondary education, with particular applicability in the community college system. This is appropriate, based on the best information available regarding levels of education and skills requirements in demand. The following points are noted:

- By 2018, 63 percent of the 46.8 million openings (new and replacement jobs) across the economy will require workers with at least some college education (Carnevale et al., 2010);
- Of these, 30 percent will require some college or a 2-year associate's degree and 33 percent will require at least a bachelor's degree (Carnevale et al., 2010);
- Community colleges provide a continuum of postsecondary education from 1-year certificates through associate's degrees, and are often the first 2 years of higher education leading to bachelor's and higher degrees in 4-year colleges and universities;
- There are 1,200 community and technical colleges providing higher education that is more accessible to many and less costly than 4-year colleges and universities;
- Community colleges are more flexible and adaptable in aligning their programs of study to industry needs; and
- Community colleges are more flexible in their educational service delivery by adapting class schedules to working learners and transitioning workers with jobs.

This system of community and technical colleges has become an important economic development asset for the communities and states in which they reside. By specifically working with energy and mining companies choosing to locate within the college footprint, the college can tailor its curriculum for the needs of the company located or locating in the community.

The Petroleum Engineering Technology program at Houston Community College and its HCC-NE Energy Institute are an example of industry–education cooperation in the petroleum sector (see the Oil and Gas section in Chapter 2). This is an example of how curricula previously reserved for university levels can be taught at the technician level in order to meet industry needs for a flexible and skilled workforce. This program is designed to prepare individuals to work as petroleum engineering technicians in the oil and gas and related industries.

Many of these arrangements have been specifically designed to meet energy company and sector needs, identified between the college and the companies whom they directly serve. Although these can be incredibly successful partnerships (as long as the company/sector are present and hiring), they have not driven the systemic reform of the nation's public and private postsecondary education system necessary to ensure a STEM technical workforce for the energy and mining industries, broadly or for all sectors.

In a move to broader impact, the NSF has funded Advanced Technological Education (ATE) projects and centers at selected community colleges, with a mission to focus on particular industries or sectors, conduct industry-educator analyses of the skills and competencies required within the sectors, and provide expertise to other colleges on the development of curriculum aligned to the skills requirements. Examples include the ATE California Regional Consortium for Engineering Advances in Technological Education (CREATE) Renewable Energy Regional Center in Southern California, the Advanced Technology Environmental and Energy Center (ATEEC) National Environmental and Energy Resource Center in Iowa, the ATE Regional Center for Nuclear Education and Training (RCNET) in Florida, and the new ATE BEST Center for Commercial Energy Management in Northern California.

Each of these partnership arrangements has made progress in better aligning postsecondary education programs to the needs of the energy and mining industries broadly, and the sectors specifically. However, the United States still is not producing the STEM technical workforce needed for success in supporting the nation's diversified energy portfolio. The national solution being deployed to address the parallel challenges confronting the U.S. manufacturing industry today could be an important strategy for the energy and mining industries to pursue, in partnership with education and government.

The Solution for Manufacturing with Applicability to the Energy and Mining Workforce

The nexus of the solution is its reliance on industry-based skills certifications to drive the alignment of educational programs with the skills needed by advanced manufacturers. Individual manufacturing skills certification programs (in particular occupations or sectors) have been field tested for years, demonstrating that industry-designed and -implemented skills certifications and associated credentials can be translated to secondary and postsecondary learning standards and content in curriculum. For manufacturing, the Manufacturing Institute, a national, nonprofit, nonpartisan affiliate to the National Association of Manufacturers (NAM), organized selected individual certification programs into a system that identifies the basic skills requirements across all sectors in the manufacturing economy.

Key to understanding this solution is the fact that the core or basic skills in manufacturing (or energy)—including personal effectiveness skills, foundational academic skills, general workplace skills, and basic industry technical skills—are building blocks to virtually all careers in the industry, across virtually all occupations and sectors. Also, these basic skills can be learned in a secondary or postsecondary (community college) program, resulting in both high school and/or college credit and degrees, *and* industry-granted skills certifications.

The credentials gained in certification programs increase a worker's ability to be mobile in the workforce and compete for higher-level jobs. Skills certifications can be mapped to career pathways throughout many sectors and to educational pathways to help students who need to pick the right courses, transitioning workers who need to add new skills for new jobs, and current workers who need to upgrade skills in order to adapt to new technologies or business processes.

Certification of individuals is an important tool for developing and maintaining the nation's technical workforce, as are postsecondary programs that teach to industry-identified skills. Also, certification programs yield credentials with direct value in the marketplace. Skills certifications cut across all professions and have been in common use for many years in certain manufacturing and industrial sectors. Well-designed certifications help validate that workers have the required knowledge and skills, and they allow workers to be productive on "day 1."

In 2005-2006, manufacturing industry executives, in partnership with the Department of Labor, identified the basic or core personal effectiveness skills, academic competencies, general workplace skills, and crosscutting manufacturing skills necessary for workers to succeed in virtually all entry-level jobs across all sectors in advanced manufacturing, including in the energy sector. The industry representatives attested that individuals possessing these core skills were basically prepared for the technical workforce essential to the success of their industry.

These core skills were organized into a competency model, using the knowledge, skills, and abilities research in the Occupational Information Network (O*NET) database. The result was the Advanced Manufacturing Competency Model—a pyramid of knowledge and skills that align to those needed by workers throughout the industry. Higher-level or advanced skills identified by industry build on these core skills and provide career pathways and advancement opportunities in specific sectors or in specific occupations in regional economies, responding to local labor market needs.

The core skills can be gained in secondary and early postsecondary education programs, primarily in community colleges, in associate degree programs that integrate industry-recognized skills certification programs. Educational pathways to higher-level skills can be mapped to college or university baccalaureate- and graduate-degree programs, online programs, work-based learning, and/or apprenticeship programs to the journeyman and master levels. In other words, successful attainment of the core skills in community colleges positions workers for entry-level employment success as well as for career advancement in the industry.

The skills sets in the Manufacturing Skills Certification System (with applicability across all energy and mining industry sectors) are largely the applied STEM skills required in both sectors. Thus, integration of these industry-recognized skills credentials into secondary and postsecondary programs of study creates alternative STEM pathways to high school graduation and postsecondary degrees, creating the nation's technical workforce in a new, 21st century approach to career and technical education.

Because a system of nationally portable, industry-recognized credentials aligns learning standards, content, and skills certifications to educational and career pathways, benefits are immediately realized. Education and training become more engaging and meaningful to students who may therefore stay in school rather than leave because of nonengagement with traditional programs. Achieving industry-recognized credentials requires mastery and proficiency, leading to competency-based educational pathways of applied learning (offering an alternative to purely theory-based instruction and success measured by "seat time" and credit hours). Achieving skills certification leads to employment; this educational credential has value in the labor market. Also, this solution increases the number of skilled technical workers for American industries.

The Process Used by the Advanced Manufacturing Industry Sector

In 2009, the Manufacturing Institute launched the NAM-Endorsed Manufacturing Skills Certification System. By deploying this system of industry-recognized skills certifications through the nation's education and workforce development systems, manufacturers intended to use these publicly -funded systems to produce the skilled workforce critical to the strength and vitality of the manufacturing economy. The industry's purpose in developing and deploying this system is to provide industry expertise in helping secondary and postsecondary educational institutions design competency-based education and training for the manufacturing workforce.

The evolution of this certification system began with development of the Advanced Manufacturing Competency Model (Figure 7.3). Developed by a strong public–private partnership engaging the Department of Labor and industry, this model is essentially a roadmap of the skills needed by workers entering and advancing in careers in the manufacturing economy.

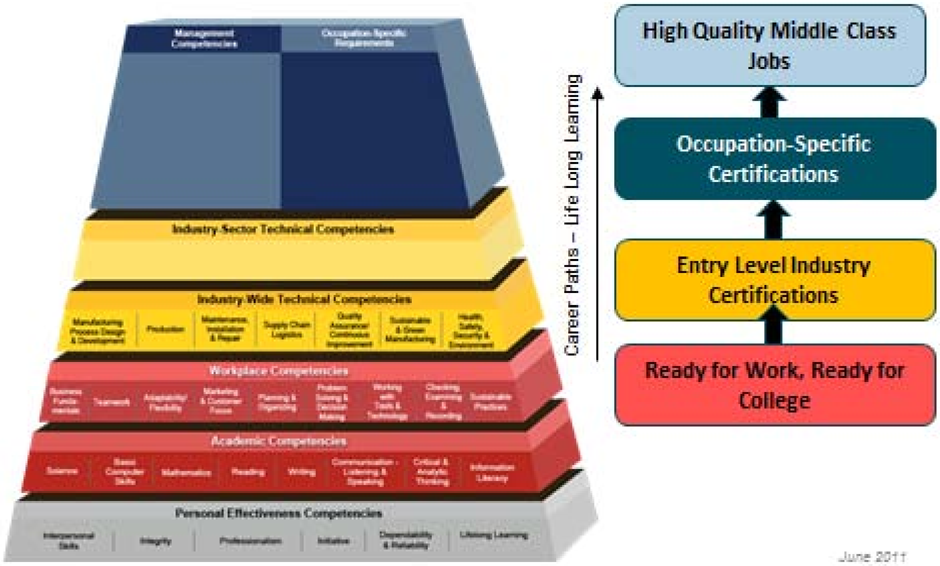


FIGURE 7.3 Advanced Manufacturing Competency Model. SOURCE: Adapted from U.S. Department of Labor (2010) in Manufacturing Institute (2011). Used with permission from the Manufacturing Institute.

The Manufacturing Institute and national trade association members focused initially on the core skills in the first four tiers of the competency model, recognizing that these foundational skills cut across all manufacturing sectors and are also applicable in related industries such as energy and construction. These core skills include personal effectiveness skills, basic academic requirements, general workplace competencies, and industrywide technical skills. The Institute then evaluated the marketplace for existing certifications that could meet the following national criteria: learning standards and content were directly aligned to the competency model; the certifications had achieved national portability, were third-party validated (ISO/ANSI preferred), and were industry-driven; and there was data-based evidence that supported the certifications' alignment to industry needs.

This collaborative effort yielded an organization of the certification programs and the credentials they offer, into a system of stackable credentials that can be earned in secondary and postsecondary education. The Skills Certification System and the career pathways it supports align to education pathways in secondary and postsecondary education. Tying the skills certifications into education pathways promotes their being part of degree programs allowing a worker to pursue stackable credentials and accumulate credits for multiple degrees.

These upwardly-moving pathways show how learning is a continuum for workers as more competencies are obtained and verified with recognized credentials. Credentials earned in the Skills Certification System improve a person's ability move in the workforce, strive for higher-level jobs, and move to valued careers by (1) bestowing skills and competencies that are recognized throughout the industry and (2) providing career pathways that are mapped to educational pathways linked with credentials of value to employers in multiple sectors.

The first four tiers of skills and competencies needed for entry-level workers are relevant across all sectors in manufacturing and the related energy and construction industries. From a workforce development perspective, it is important to note that the first three tiers are needed across all sectors of the U.S. economy. This supports the growing use by employers of the ACT National Career Readiness credential, and its associated WorkKeys® assessments, to validate an individual's readiness for employment and ability to learn technical skills. (The National Career Readiness Certificate [NCRC] and NCRC Plus are highlighted in Box 7.1.)

As the Manufacturing Skills Certification System's learning standards, content, and credentials are being implemented in high schools and community colleges across the nation, education pathways are being aligned to stackable certification pathways, which in turn are aligned to career pathways and jobs, salaries, and benefits that can be earned. No other industry has yet so clearly charted the education and career courses for students, educators, and workers. Figure 7.4 shows an example of aligning education, certification, and career pathways (Industrial Systems Technology at Forsyth Technical Community College). Another good example is the Engineering Technology Associate in Science degree program at the Florida Advanced Technological Education Center (FLATE, 2012).[2]

BOX 7.1
The National Career Readiness Certificate

The National Career Readiness Certificate (NCRC™) is an industry-recognized, portable, evidence-based credential that certifies essential workplace skills and it is a reliable predictor of workplace success. This credential applies in all parts of the economy and confirms foundational cognitive skills in

- Critical thinking;
- Problem solving;
- Reading and using work-related text;
- Applying information from workplace documents to solve problems;
- Applying mathematical reasoning to work-related problems;
- Setting up and performing work-related mathematical calculations;
- Locating, synthesizing, and applying information presented graphically; and
- Comparing, summarizing, and analyzing information given in multiple, related graphics.

A person can earn the NCRC by taking the following three WorkKeys® assessments:

- Applied Mathematics,
- Locating Information,
- Reading for Information,

WorkKeys® assessments measure skills from the real world that employers think are essential for job success. Test questions are drawn from situations in the daily work world.[a]

NCRC Plus

Foundational knowledge and skills that are related to job tasks are the best indicators of work performance. Combining measures of cognitive skills and those of work-related soft skills provides increased accuracy in predicting a person's success with work or training. Along with the foundational cognitive skills noted previously, the NCRC Plus ranks individuals in the soft skills categories of

- **Work Discipline**: Productivity and dependability;
- **Teamwork**: Tolerance, communication, and attitude;
- **Customer Service Orientation**: Interpersonal skills and perseverance;
- **Managerial Potential**: Persuasion, enthusiasm, and problem solving.

The NCRC Plus can be earned by taking the WorkKeys® *Talent* assessment.

---

[2] http://fl-ate.org/projects/ET_frameworks/2012/ET%20Curriculum%20Reform%20Summary%202012.pdf.

The foundational cognitive and soft skills measured by the NCRC and the NCRC Plus are known to be essential for workplace success and career advancement by many employers.

Visit nationalcareerreadiness.org to learn more about the power of the NCRC and NCRC Plus to help:

- **Career Seekers**: Provide employers with verifiable evidence of their job skills;
- **Employers**: Screen applicants and find the right workers for jobs at all levels, as well as make decisions about training and advancement of current employees;
- **Educators**: Ensure that their students are ready for meaningful careers;
- **Industry Associations**: Adopt the NCRC as the foundational credential of their skills certification systems
- **Workforce Developers**: Help to supply employers with workers possessing the necessary skills to meet demand; and
- **Economic Developers**: Inform businesses' decisions about where to locate or expand by demonstrating the skill level of regional labor sheds

[a]National Readiness Certificate, http://dlr.sd.gov/workforce_training/ncrc.aspx.

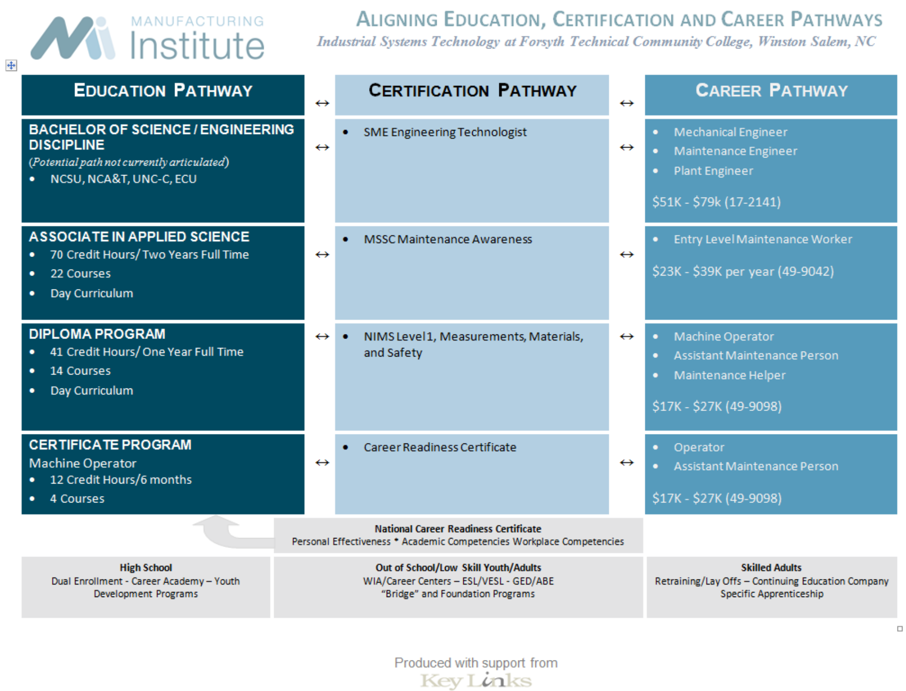


FIGURE 7.4 Aligning education, certification, and career pathways: example of Industrial Systems Technology at Forsyth Technical Community College. SOURCE: Manufacturing Institute (2011). Used with permission from the Manufacturing Institute.

MOVING THE MODEL INTO ENERGY

Replication of this model as a solution to address the energy industry's workforce development challenges has already begun.

As noted in the Nuclear Power section, the Nuclear Energy Institute has worked with the Center for Energy Workforce Development (CEWD) to create an Energy Competency Model for the energy generation, transmission, and distribution industry that is aligned with the entry-level needs of the nuclear power industry. The NEI also has developed an industry-recognized standard curriculum, as well as a partnership that recognizes the educational institutions providing this curriculum, which is aligned to the competency model and to the current or expected demand of the nuclear power sector.

The Nuclear Uniform Curriculum Program (NUCP) is an excellent model of industry–education collaboration. It has produced an industry guideline for an associate's degree program that clearly defines the competencies required, and has developed a curriculum that ensures consistency among educational institution programs. Forty-three community colleges across the United States are participating in the program. Several have had graduating classes that have included a quick transition from curriculum completion and industry internships into nuclear industry jobs.[3]

The CEWD Energy Competency Model offers a consistent definition of the competencies needed for work in the energy industry (see Figure 7.5). It aligns with the NUCP and builds from basic skills to more industry- and career-specific competencies (CEWD, 2010). Using the model, educational programs will provide industry-accepted, stackable, transferable credentials. Also, the CEWD has developed the Energy Industry Fundamentals Certificate Program that matches with Tiers 4 and 5 of the model; its courses are offered through an Approved Course Provider system (including high schools, community colleges, and other institutions; CEWD, 2012a).

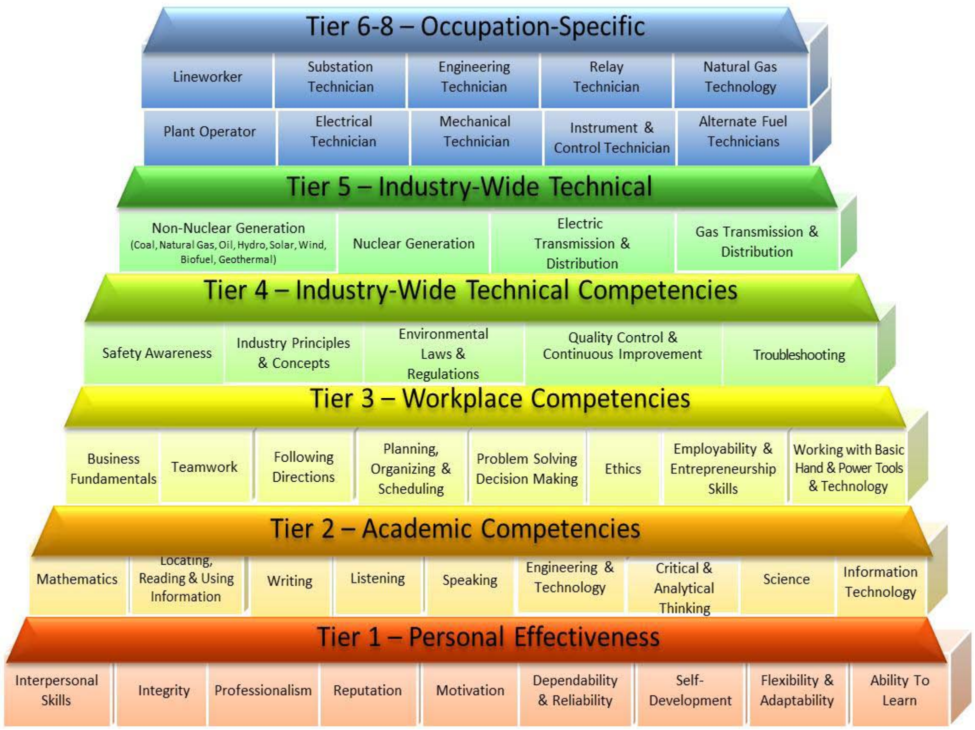


FIGURE 7.5 Energy Competency Model: Generation, transmission, and distribution. SOURCE: CEWD (2010, p. 2).

The CEWD, supported by the electric utilities and nuclear sector, has focused its primary efforts on in-demand skills and jobs in the occupations of line workers, natural gas technicians

[3] Additional information on nuclear education programs is available at: http://www.nei.org/careersandeducation/educationandresources/education.

and service technicians, transmission and distribution technicians, and nonnuclear power plant technicians and operators (CEWD, 2012b). Their development and deployment of education pathways, aligned to industry skills requirements and available jobs, are industry-driven and advanced by state teams impacting secondary and postsecondary education.

The Employment and Training Administration (ETA), a division of the Department of Labor, worked with subject matter experts from the DOE, Office of Energy Efficiency and Renewable Energy, NREL, NSF, educational institutions, and industry groups (such as NABCEP and IREC) to develop a competency model for renewable energy. The Renewable Energy Competency Model[4] was launched to the Competency Model Clearinghouse[5] in September 2012.

The only other energy sector that has effectively researched and designed its competency model to allow for alignment of educational programming to industry requirements is the solar sector. Substantial work in this sector is discussed in the Solar Energy section of Chapter 3.

SPECIAL CONSIDERATIONS FOR ENERGY- AND MINING-RELATED BACHELOR'S- AND MASTER'S-LEVEL ENGINEERING AND SCIENCE EDUCATION

While many of the energy workforce needs can be fulfilled with education at the community college level, there is still a strong need for specialized higher-education programs at the bachelor's and master's levels, especially in the areas of mining, petroleum engineering, and geosciences. These programs currently reside in traditional bachelor's engineering and science programs at specialized universities, such as the Colorado School of Mines, and new emerging programs, such as Professional Science Master's programs (see Box 7.2).

BOX 7.2
The Professional Science Master's Degree

The Professional Science Master's (PSM) is a 2-year graduate degree that is designed to combine intensive high-level education in science, engineering, or mathematics fields with business skills, such as financial and project management, communication, statistics, ethics, intellectual property, and regulatory affairs. The design of these programs draws upon advice from employers, with the goal of preparing students for a wide variety of career options that meet the needs of nonacademic employers, including industry, government, and the nonprofit sector. The PSM has been strongly supported by numerous employers and universities, and its rapid expansion around the country in recent years means there are now 244 PSM degree programs at 114 campuses.

In a recent report on the PSM (BHEF, 2011) the Business Higher Education Forum (BHEF) described the PSM as "a truly significant development" that creates "a new and much needed bridge between employers and potential employees who have both advanced education in critical disciplinary areas and training in management, communication, and related skills that will enable them to readily apply that knowledge effectively in business settings." It continues:

"…Every corporation seeking to recruit STEM talent should develop a strategy that integrates students from these professional programs to fill its needs for skills in the workplace. Corporations should support their employees' participation in PSM programs through tuition assistance or reimbursements. Businesses should incorporate programs leading to these new professional degrees in their research collaborations with universities. They should

[4] The Renewable Energy Competency Model is available at http://www.careeronestop.org/CompetencyModel/pyramid.aspx?RE=Y.
[5] http://www.careeronestop.org/CompetencyModel/.

retool their recruiting practices to ensure that they draw from the advanced talent and training that professional graduate-level programs produce."

Details on the more than 200 PSM degree programs around the country are readily available at www.sciencemasters.com.

An adequate supply of capable and creative scientists and engineers from universities is an essential component of any strategy to ensure that the United States remains an international leader in technology. Scientists and engineers provide much of the innovation from which high-quality products and jobs can develop to keep the U.S. competitive in the global marketplace.

Currently, the United States is failing to meet this challenge. The National Academy of Engineering recently noted that only 4.5 percent of university graduates obtain degrees in engineering, compared with 21 percent in Asia (Vest, 2011). Also, the 2010 update to the now classic *Gathering Storm* study, concluded that the nation's competitive outlook has worsened since 2005, when *Gathering Storm* issued its call to strengthen K-12 education and double the federal basic-research budget (NAS/NAE/IOM, 2007, 2010). The update report also notes that, in 2009, 51 percent of U.S. patents were awarded to non-U.S. companies. China has replaced the United States as the world's number one high-technology exporter and is now second in the world in publication of biomedical research articles (NAS/NAE/IOM, 2010).

The update report further notes that, historically, and especially since the end of World War II, the United States has relied on enhancing the pool of U.S. scientists and engineers with colleagues from other countries, many of whom came as graduate students and stayed, either in industry or as faculty at U.S. universities and colleges. Most became U.S. citizens and many have risen to leadership positions.[6] This pool is drying up, due primarily to two changes over the last decade:

1. More restrictive H1-B visa procedures that prevent U.S.-based companies from hiring foreign citizens have been introduced. Intended to provide greater opportunities for U.S. scientists and engineers, these procedures are actually counterproductive. Facing a shortage of qualified U.S. citizens, companies resort to creating branches overseas, and maintaining communications via the internet (with periodic visits and exchanges with the overseas offices) in order to develop a single global corporate community. The only negative effect is that fewer of the supporting staff are U.S. citizens. The restrictive visa regulations are self-defeating.
2. The rapid development of economies in Asia and South America is attracting scientists and engineers, many educated in the United States, to return to their native lands. In past decades, many from these regions opted to stay in the United States, and they have contributed substantially to U.S. international leadership in many areas of science and engineering.

The National Academy of Engineering is making vigorous efforts to stimulate greater public awareness of the role of engineering, and to develop stronger STEM courses in the K-12 curriculum, in order to increase the supply of U.S. scientists and engineers. Particular attention is being given to increasing participation by currently underrepresented minorities and women. Increasing scholarship support is critically important to offset rapidly rising tuition costs, especially for students from lower-income families.

[6] More than 25 percent of the members of the U.S. National Academy of Engineering were not born in the U.S.

Mining Engineering

The preceding discussion focused on science and engineering education in general. Mining engineering has several additional issues that warrant special consideration.

Most of the public is unaware of the fundamental dependence of the U.S. economy on minerals (discussed in the Mining section of Chapter 2). The 2009 decision by China to restrict exports of rare earth minerals, of which it is currently the sole producer, provided a dramatic example when it was realized that these minerals are essential to much of the high-technology industry[7] (see Box 2.7). Also, in contrast to hydrocarbon energy resources, there are essentially no alternatives to minerals.[8]

The public perception of mining in the United States is that of a mature and environmentally damaging industry that requires intensive regulation and control (to prevent problems such as pollution, noise, environmental degradation, and health issues, for example). One result of this image has been a decline in university enrollments in mining engineering. As illustrated by Figure 2.29 and the related discussion, approximately 70 percent of the industry's technical leaders will reach retirement age within 10 to 15 years, with few experienced engineers available to replace them. University programs in mining engineering are also small, and almost all faculty will need to be replaced within the next decade or less. Several leading universities have eliminated mining engineering.[9] Enrollments in South America, Asia, and Eastern Europe have not followed this trend, and these regions have an adequate supply of mining engineers.

The erosion of technological leadership has serious implications for the United States. Minerals are essential to the economy, yet many critical minerals must be imported. How can the United States retain a significant influence to ensure an adequate supply of minerals? Reducing obstacles to development of domestic sources may be a possibility for some minerals, but others are either unavailable or cannot be mined economically in the United States.

One possible option is for U.S. universities to develop graduate research programs with a goal of establishing technological leadership in mining. In contrast to petroleum companies, the mining industry[10] has been dominated by relatively small enterprises, and has not had a strong industrial R&D tradition. This is changing rapidly as the industry consolidates and several major international mining groups emerge. Mining projects are becoming larger and technically more challenging, extending well beyond current technology. Industrial R&D is needed. Mining companies will need to establish in-house R&D groups, composed of research teams incorporating a variety of science and engineering disciplines.

The research will require input from a broad range of disciplines. In 2006, the National Academy of Engineering introduced the name "Earth Resources Engineering" in recognition of

---

[7] *"Prized for their magnetism, luminescence and strength, rare earths are used by manufacturers of everything from smart phones to hybrid cars and wind turbines, but the elements occur together in the earth in different proportions and the separation process is complex and expensive."* (Prentice, 2011).

[8] Substitution of one mineral for another is sometimes possible (e.g., plastics—derived from hydrocarbon minerals—can replace some metallic minerals) and others can be recycled, but the demand for minerals worldwide is growing as populations expand.

[9] A similar trend has been followed in Australia, Canada, and Western Europe over the same period.

[10] There are industrial research laboratories in mineral processing. The Mining Research Laboratory of the South African Chamber of Mines, an international leader in mining research for several decades, has scaled back its research program substantially over the past decade. Innovation in mining equipment has been achieved by suppliers. Government mining research laboratories in Western Europe and the United States made important advances in the second half of the last century, but all are now closed.

the fact that the technologies traditionally associated with the classical extractive industries (petroleum, mining, and geological engineering) are now finding application to an increasing variety of "subsurface engineering" activities. The umbrella term was introduced to cover this broader activity (see Box 7.3).

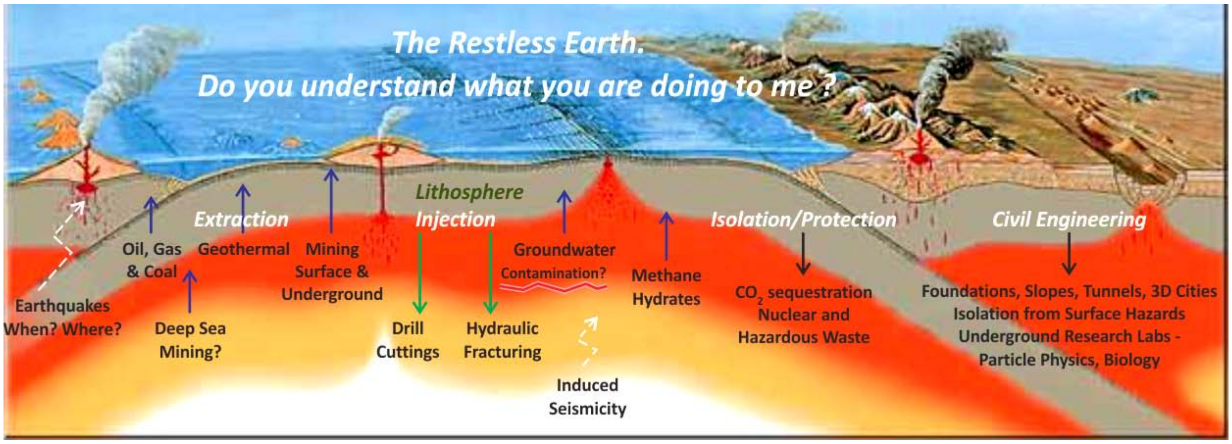
These developments suggest some steps that could begin to correct this serious decline in U.S. mining technological capability, and apply the best technologies available to the entire spectrum of current earth resources engineering activities. It is imperative that all engineering development of the subsurface protect the environment and public health and safety. Establishment of a federally funded 21st century version of the U.S. Bureau of Mines could serve this role, and contribute to the advance of technology.

Establishment of several interdisciplinary graduate Centers of Excellence in Earth Resources Engineering at leading U.S. research universities could help focus attention on the exciting science and engineering challenges presented by these industries and develop the professional expertise that will be needed by industry. These centers would complement the more classical programs of the U.S. schools of mines—some of which may establish such Centers of Excellence, either alone or with other universities. By establishing such centers now, the United States could become a technological leader in mining engineering, and thereby help ensure that it continues to play a leadership role in international mining.

Universities or schools of mines with the appropriate faculty expertise could develop intensive 1-year master's programs, designed to prepare graduates from other engineering disciplines for a career in the mineral industries. This could provide qualified personnel more rapidly than attempts to expand enrollments into undergraduate mining degree programs.

BOX 7.3
Earth Resources Engineering

"*Engineering applied to the discovery, development and environmentally responsible production of subsurface earth resources*"[a]



SOURCE: Fairhurst (2010).

Earth Resource Engineering activities are confined to a very shallow part of the 40- to 700-km-thick lithosphere (Earth's solid crust). Deepest borehole, ~12 km; deepest mine, ~4 km.

Rock pressure increase: Vertical, $\sigma_v \sim 27$ MPa/km; lateral, $\sigma_h \sim (0.5 - 3.0)\, \sigma_v$.

Pore water pressure, ~10 MPa/km. Rock temperature increase, ~25°C/km depth.

A New Research Frontier

Much of the expertise in subsurface engineering' resides in the three traditional disciplines of petroleum, mining, and geological engineering, but it is now being applied to a widening variety of engineering uses of the subsurface, as illustrated in the diagram above. Combined with the constant imperative to protect the environment and develop safe, lower-cost methods of extraction, this broad set of applications define the field of Earth Resources Engineering.

Rock in situ is arguably the most complex material encountered in any field of engineering. "Preloaded" by tectonic and gravitational forces, over many, many millions of years, it is deformed and traversed by weakening fractures and other planar discontinuities. Pressures and temperatures increase with depth, presenting severe engineering challenges, especially for development of deep petroleum, geothermal, and mineral resources. Scales, both spatial and temporal, have a major influence on rock mass deformability and strength. Dramatic advances in computer power now allow study of such complexities, but verification of the computer predictions can only be accomplished in the field. The field is the laboratory! Close liaison between researchers and field projects is essential.

As noted elsewhere in this report, growth in world population and demands for higher living standards require minerals—and innovative, less-costly technologies to extract them from greater depths. And, the United States is already heavily dependent on imports for the minerals essential to maintain the economy.

These challenges come at a time when more than 60 percent of the senior technological leadership in the extractive industries of Australia, Canada, Western Europe, and the United States is about to retire—with few replacements available. International competition for the few graduates is intensifying. The situation for faculty in U.S. universities is similar. A recent statement by the U.S. Department of Energy notes:

Chronic underinvestment in federal R&D in these subsurface disciplines has eroded the nation's capacity to educate and train the next generation workforce necessary for industry, academia, and government. As a result, the U.S. faces the prospect of ceding its historic leadership role in these disciplines, and thereby undermining its resource security. (U.S. Department of Energy, 2009, sec. 63, Subtitle E, p. 4)."[b]

The establishment of 5-10 interdisciplinary Centers of Excellence in Earth Resources Engineering[b] at leading U.S. research universities would be an excellent (and perhaps the only realistic) way for the United States to begin to reverse this trend and establish itself as a leader in subsurface engineering. These universities have an exceptional tradition of interdisciplinary research in science and engineering.[d]

With each center focused on some aspect of the spectrum of topics requiring study, they would serve as incubators, jump-starting the development of a robust industry that could solve an array of Earth's most complex engineering problems, with major benefits to both public and private interests.[e]

---

[a] This title was adopted by the U.S. National Academy of Engineering in 2006 to replace the former title, *Petroleum, Mining, and Geological Engineering,* in recognition of the widening scope of 'subsurface engineering' technologies.

[b] U.S. Department of Energy. Energy Innovation and Workforce Development (Document END09412): Strengthening Education and Training in the Subsurface Geosciences and Engineering for Energy Development, Section 63, Subtitle E, p. 4, 2009. Available at http://www.energy.senate.gov/public/index.cfm/files/serve?File_id=445ef86d-0ac5-33f1-17f3-7256a980ad8f (accessed June 26, 2012).

[c] University Centers of Excellence require funding of around $5 million/year for an initial period of 5 years with a possibility of a further 5-year extension. Funding may be by federal agencies or industry or a combination.

[d] Opinion of the committee.

[e] Opinion of the committee.

Stimulated by the report, *Grand Challenges in Engineering*[11] (NAE, 2010), the Earth Resources Engineering section of the NAE in 2010 defined several grand challenges in earth resource engineering. They are examples of the topics that could be studied at these centers. They are making the Earth transparent, quantifying subsurface processes, achieving minimally invasive extraction, and protecting people and the environment. The first challenge involves the ability to "see" several meters or more into rock in real time.[12] The second is for better understanding the thermo–hydro–mechanical–chemical reactions and interactions that occur when fluids circulate through hot rock at depth. This is key to effective extraction of geothermal energy, to extracting minerals via boreholes at depth (part of the third challenge), and to understanding the origin of ore deposits. The fourth challenge recognizes that minerals production must be consistent with environmental protection. These are a few examples among many.[13] The report *Evolutionary and Revolutionary Technologies for Mining* (NRC, 2002) provides additional examples.

ISSUES AND CHALLENGES RELATING TO SUCCESS

Recruitment of Students/Workers

As industry and educators will attest, recruitment into educational pathways leading to energy and mining careers is not a matter of "building them and they will come." Even if educational issues are addressed, other barriers such as cultural and geographic barriers remain.

Addressing the Image Issue

Many career opportunities in industrial sector jobs are not attracting students and transitioning workers because there is not enough career information and educational "navigation-to-the-jobs" information available. Engagement and recruitment strategies that address this and mitigate negative images of the industries are needed.

This is clearly true for the manufacturing and energy/mining sectors. The manufacturing industry recognized that the availability of educational pathways to careers is not the whole answer; engaging people in those pathways requires addressing the image of manufacturing. Therefore, the industry is pursuing the "Dream It! Do It!" career recruitment campaign as the public-facing message about high-tech, high-wage careers in the industry (Manufacturing Institute, 2012). The program's intent is to inform, excite, educate, and employ talent from the next generation.

[11] NAE President Charles Vest defined a "Grand Challenge" as one that is "visionary, but doable with the right influx of work and resources over the next few decades"—a challenge that, if met, would be "game-changing" and have a "transformative" effect on technology.

[12] Lockheed-Martin has introduced a system for communicating through rock (two-way text and voice communications to a depth of 1,550 ft and two-way text communications in excess of 1,550 feet [http://www.lockheedmartin.com/us/mst/features/110721-emergency-mining-communication-system-approved-.html]).The Canadian National Physics Laboratory TRIUMF has used cosmic ray muons to identify ore bodies (http://www.aapsinc.com/technologies/detector-and-imaging-technology/geophysical-exploration/).

[13] Application of the impressive advances in directional drilling of deep boreholes for petroleum extraction to certain other subsurface engineering applications must address the very challenging problems of drilling in hard rock.

Dream It! Do It! is a national brand and strategy, deployed locally for programs and marketing to be tailored to the needs of local industry. These local programs are grouped into a library of national resources that documents and shares tools and best practices for other Dream It! Do It! teams to be able to repeat proven initiatives in their communities. These programs include social networking and career navigation games. The Dream It! Do It! networks also engage with leading national youth development organizations to align proven concepts and initiatives.

Energy Sector Campaigns

Similarly, there are several excellent career pathways initiatives that are either state- or industry-specific that could be replicated nationally. For example, the State of Oregon has a user-friendly career pathway Web site that clearly takes students from interest to alignment with appropriate statewide solar and renewable energy programs.[14]

Targeted Campaigns to Separating Military Personnel

The CEWD is the first partnership among utilities and their associations, contractors, and unions to focus primarily on the need to build a skilled workforce pipeline that meets future industry needs. Troops to Energy Jobs is a new CEWD initiative that is designed to speed up the training of veterans for energy jobs (CEWD, 2011b). Many veterans have the skills and knowledge needed for energy careers thanks to the training and experience they received in military service, but they need a path to jobs and career advancement. Troops to Energy Jobs provides a way for veterans to enter the industry smoothly, regardless of their geographic location or targeted company. The program is in the pilot stage, and it will involve selected utilities, considered as top military employers and operating in states with strong state energy workforce consortia. The intent is to grow the program to include the entire energy industry.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

7.1 A high percentage of energy and mining jobs require some education beyond high school, but the majority do not require a 4-year degree. Therefore, the need for higher education, especially at the community college level, is growing.

7.2 A strong foundation in STEM skills is needed for many energy and mining jobs, and the need is increasing as STEM principles are increasingly applied in the workplace.

7.3 The current pipeline of STEM-capable students and workers is inadequate to meet projected future energy and mining workforce demands.

7.4 Many of the solutions needed to address the educational demands of the increasingly technical energy and mining jobs will go beyond the current educational structures.

7.5 Innovative curricula delivered in nontraditional formats and pedagogies (e.g., nonlinear or just-in-time) that embed STEM concepts in contextualized examples (e.g., technology-enabled, skills-based competency delivery) that are rigorous and

[14] http://oregongreenpathways.org/1347/solar-renewable-energy-statewide.

industry-recognized would enhance the mobility of students into the workforce and enhance industries' ability to compete globally.

7.6 There also is a strong need for specialized higher education programs at the bachelor's and master's levels, especially in the areas of mining, petroleum engineering, and geology.

7.7 An adequate supply of skilled scientists and engineers from universities is also essential to ensure that the United States remains an international leader in technology. Reliance on workers from other countries to fill the ranks is decreasingly an option.

Recommendations

The following recommendations should be initiated as soon as possible and some will take longer than others to become fully operational. The recommendations are ordered and labeled in terms of when they would be expected to be operational. The recommended actions are expected to continue for the long term.

7.1 Industry, educational leaders, and federal agencies should support the creation of alternative pathways to high school graduation that recognize that many students need project-based learning in order to understand STEM academic principles.

A. These alternative pathways should integrate academic and competency-based learning methodologies and prepare students for both postsecondary education and the world of work.

B. Because a high percentage of energy and mining jobs require some higher education but the majority do not require a 4-year degree, these educational pathways that integrate academic and technical learning standards and content should extend from high school, through community college programs of study, and into 4-year college and university degree programs.

C. The competency-based learning in these integrated pathways should incorporate the learning content and assessments of nationally portable, industry-recognized credentials.

D. Competencies and career pathways should be developed that cross-map energy and nonenergy skill sets into career lattices to improve student career prospects and improve adoption by community colleges. (Short Term)

7.2 The committee recommends that multiple energy sectors and the mining industry, through their national industry organizations, consider developing their workforces' competency models and developing and implementing the nationally portable, industry-recognized credentialing (learning standards, learning content/skills certifications) that will guide educators in creating educational pathways to prepare the energy and mining workforce. (Short Term)

7.3 Federal investments in workforce development and career and technical education should give priority to funding programs of study that result in nationally portable, industry-recognized credentials. (Short Term)

7.4 In order to attract students to the educational pathways and workforce development programs that will develop the energy and mining workforce with appropriate skills levels, the committee recommends that the energy and mining industries consider coalescing with government and education leaders in support of a major campaign to engage students and transitioning workers in the educational pathways that lead to energy and mining careers, and consider developing and implementing recruitment and retention strategies to support the energy and mining industries. (Short Term)

7.5 Special efforts should be made to attract separating military men and women whose military occupational specialty aligns closely to civilian skills requirements in the energy and mining industries. (Short Term)

7.6 Industry–education partnerships throughout the education continuum should be made stronger and more comprehensive. These partnerships should, for example, provide direct industry input to education and workforce development programs of study and curricula; offer more opportunities for work-based learning in internships, particularly earlier internships in the first 2 years of higher education; and expand mentorships. (Short Term)

7.7 The Bureau of Labor Statistics (BLS) should consider partnering more effectively with industry to more quickly and accurately reflect the rapid change of job and occupation characteristics and titles as well as the levels of education and training required in 21st century jobs. The BLS also should consider working with industry and the Departments of Education and Labor to better define the STEM technical workforce needed to support STEM professionals in our economy. (Medium Term)

7.8 It is important that the insights provided by the report, *Successful K-12 STEM Education*, that "“…effective instruction capitalizes on students' early interest and experiences, identifies and builds on what they know, and provides them with experiences to engage them in the practices of science and sustain their interest" (NRC, 2011, p. 18), be implemented in STEM programs of study. Key elements (also noted in that report) of such implementation should (a) have a coherent set of standards and curriculum, (b) reference current work on the Common Core State Standards for mathematics and science, (c) have teachers with a high capacity to teach in their discipline; (d) have a supportive system of assessment and accountability; (e) allow adequate instructional time; and (f) provide equal access to high-quality STEM learning opportunities.

Since the pipeline of STEM-capable students entering energy and mining programs and applying for energy and mining jobs is inadequate to meet projected future workforce demands, the committee recommends the following:

A. That the National Science Foundation and the Departments of Labor, Education, and Energy consider collaborating to facilitate strong partnerships between industry and community colleges that create and support technician-level education;
B. Improved K-12 mathematics preparation, including incentives for 4 years of mathematics in secondary schools, and
C. Mandatory STEM teaching credentials for STEM high school teachers, such as those advanced by UTeach and the NSF Robert Noyce Teaching Scholars. (Medium Term)

7.9 The important and growing role of Professional Science Master's degrees in meeting high-level energy and mining workforce development needs should be encouraged. (Medium Term)

7.10 Several interdisciplinary graduate Centers of Excellence in Earth Resources Engineering should be established at leading U.S. research universities to help focus attention on the exciting science and engineering challenges presented by the extractive and subsurface engineering industries, to provide more holistic earth resources curricula, and to develop the STEM professional expertise that will be needed by the mining industry. (Long Term)

7.11 The committee recommends that the National Science Foundation and the Department of Education consider supporting research into transformative models of educational preparation that produce STEM-capable and STEM-literate K-12 students who are ready to seamlessly transfer into the community college and university energy and mining technician and professional programs and into industry apprenticeship programs. The committee also recommends that researchers consider not only core knowledge and skills in STEM, but also the "big ideas" that link the four subject areas (as proposed earlier by NAE/NRC, 2009). Because this relates directly to this report's differentiation between the STEM professionals and the STEM technical workforce, the committee recommends that the U.S. Department of Labor also consider partnering in this research. It is important that this research supplement but not supplant the important work already under way in developing innovative for-credit higher education workforce programs that meet emerging industry needs. (Long Term)

7.12 Successful practices in math remediation should be accelerated to both advance students' readiness for postsecondary education and employability and reduce the extraordinary costs of remediation now burdening the entire postsecondary education system. (Long Term)

8

Overview of the Energy and Mining Workforce Using Federal Data Sources: Key Findings and Recommendations

Appendix B contains a detailed compilation and discussion of data for the overall United States energy and mining workforce, which has been drawn from federal data sources. It responds to Task 1 of the Statement of Task, which requests trends in the size, growth, and demographics of the U.S. energy and mining workforce, disaggregating each industry of interest—oil and gas, nuclear, nonfuel mining, coal mining, solar, wind, geothermal, and geologic carbon sequestration—by sector and occupation. The future demand for and supply of workers in these industries, sectors, and occupations is also discussed in response to Task 3 of the Statement of Task.

Appendix B mainly utilizes information available from the Bureau of Labor Statistics (BLS), since it is the primary federal agency responsible for collecting and disseminating information about the U.S. workforce. As an independent agency, the BLS is the single best source of objective information about the U.S. energy and mining workforce. However, information from the BLS (and other federal agencies) utilizes standardized coding schemes—such as standardized industry and occupation classifications—that limit the way in which the energy and mining workforce can be examined. Appendix B also utilizes information from the Department of Education's National Center for Education Statistics and the Department of Labor's Mine, Safety, and Health Administration. In addition, Appendix B also provides workforce information on the primary federal agencies responsible for management and oversight of energy and mining based on FedScope, which can be used to generate information on the federal civilian workforce.

Key findings and recommendations have been drawn from the data and discussion contained in Appendix B. These findings and recommendations are listed below.

KEY FINDINGS

8.1 The demographics of the energy and mining workforce do not mimic the overall U.S. workforce: the energy and mining workforce is predominantly male and has relatively little minority representation. Moreover, the U.S. labor force is expected to become more diverse by 2020. The energy and mining workforce is also older than the overall U.S. workforce: a majority of the energy and mining industries have more workers age 45 and older than workers under the age of 45. Taken together, these findings suggest that the energy and mining industries with workforces that are less diverse and older—such as mining—may experience greater difficulties replacing lost talent.

8.2 Key energy and mining occupations expected to experience the greatest increases in talent demand over the period 2010 to 2020 are boilermakers; geoscientists, except hydrologists and geographers; electrical power-line installers and repairers; and geological and petroleum technicians.

8.3 In the near term, key energy and mining occupations requiring postsecondary education that may experience the greatest difficulties acquiring talent with the requisite education are: geological and petroleum technicians; occupational health and safety specialists; nuclear technicians; petroleum engineers; nuclear engineers; and health and safety engineers, except mining safety engineers and inspectors. If annual growth rates of degrees and certificates conferred continue as they have over the past 5 years, these difficulties may continue in the longer-term for occupational health and safety specialists, geological and petroleum technicians, and health and safety engineers, except mining safety engineers and inspectors.

8.4 The primary shortcoming of using data from the Bureau of Labor Statistics to examine the energy and mining workforce is limitations associated with the NAICS system, the industrial classification system used by the BLS and other federal statistical agencies. These limitations reflect the speed with which the classification system changes to reflect changes in the industrial makeup of the U.S. economy and the way in which industrial classification codes are assigned to an establishment. These limitations likely result in an undercounting of energy and mining employment.

8.5 The workforces in key federal agencies responsible for the management and oversight of energy and mining are more demographically diverse than the workforces in the energy and mining industries they oversee, but are generally less demographically diverse than the overall U.S. workforce. Moreover, in each of these agencies, a majority of the workforce is 45 years old and older. The Mine Safety and Health Administration workforce is the least demographically diverse and the oldest, suggesting it runs a greater risk of losing talent due to retirement.

RECOMMENDATIONS TO MEET FUTURE LABOR REQUIREMENTS

The following recommendations should be initiated as soon as possible. They are ordered and labelled in terms of when they would be expected to be operational. The recommended actions are expected to continue for the long term. Medium term is defined as 2-5 years, and long term as more than 5 years.

8.1 The government and industry (through its national industry associations) should consider working together to find ways to attract younger workers, women, and minorities into energy and mining occupations and into the federal agencies responsible for the management and oversight of energy and mining. It would be beneficial to focus efforts on addressing potential talent gaps in the energy and mining occupations where talent demand is expected to be greatest. (Medium Term)

8.2 The Department of Education, in collaboration with the Department of Labor and national industry organizations, should consider working together to identify and implement strategies to increase the pipeline of workers with the postsecondary education necessary to work in the energy and mining industries, and particularly in occupations for which the supply of workers with the requisite education is anticipated to fall short of demand. (Medium Term)

8.3 The Department of Labor, through its Bureau of Labor Statistics, should determine and pursue a more effective way to partner with industry, through its national industry associations, to collect on a periodic basis key energy and mining workforce information that would facilitate the ongoing assessment of the demand for and supply of talent across the energy and mining industries. (Long Term)

9

Overarching Conclusions

The oil, natural gas, coal, nuclear, solar, wind, and geothermal industries all contribute to satisfying the nation's energy needs, and all are expected to remain pieces in the nation's energy quilt going forward. Related activities in the area of Carbon capture, use and storage are expected to continue enhancing the production of oil from mature fields, but carbon dioxide (CO_2) capture and sequestration is unlikely to become a significant industry without government policies, incentives, and regulations for large reductions in CO_2 emissions. The mining industry will continue to provide coal and nonfuel minerals that are necessary for the nation's well-being.

The present and future are bright for those in or seeking energy and mining jobs. Demand for energy and mining workers at all levels is expected to remain strong for the foreseeable future. The energy and mining industries in the United States are expected to continue to grow and to seek the qualified employees needed to do the work of providing essential energy and mineral resources to the nation. Strong international demand for energy and mineral resources and the workers to provide them also will keep the market for qualified domestic workers robust. Strong current and future demand for qualified energy and mining workers will continue to make the jobs in these industries very high paying, relative to jobs in other industries.

The United States has access to both mineral resources and energy and a workforce to provide them. However, there are workforce challenges that have to be overcome if the nation is to continue to have sufficient access to both. Two significant challenges are common across the energy and mining industries covered in this report—large numbers of pending retirements and a current and increasing need for STEM-capable workers at all levels.

Along with growing demand for energy and mineral resources, the U.S. energy and mining industries are facing a looming retirement bubble, caused by the pending retirement of large numbers of baby-boom workers from the overall domestic workforce. Both factors will continue to drive demand for workers. Baby boomers represent about one-third of the U.S. workforce, they are poised to retire in large numbers within this decade, and there are too few younger workers in the pipeline to replace them.

In addition, the oil and gas workforce is concentrated at the younger and older ends of the age spectrum, creating a gap in experience, training, and maturity between retiring workers and the younger workers that would remain. Because industry leadership typically is older, this gap will make it difficult to fill opening leadership positions. Much of the geothermal workforce parallels that of the oil and gas industry and the mineral exploration industry and it is affected by the same aging and transition as the oil and gas and mining workforces.

The energy and mining industries will need replacement workers with higher levels of education and different skills than their predecessors. A high percentage of energy and mining jobs require some education beyond high school, but the majority do not require a 4-year degree.

A strong foundation in STEM skills is needed for many energy and mining jobs, and the need is growing at all levels as STEM principles are increasingly applied in the workplace.

Unfortunately, the existing pipeline is inadequate to provide the needed STEM-capable workers to fill all of the current and expected future jobs. In addressing the shortfalls of the existing education pipeline, the goal would be to create an education system that can respond to changes in the economy more quickly and produce a more flexible, STEM-competent workforce, producing students with multiple skills and levels of skills that would be prepared to adjust more quickly to industry requirements and job availability by moving and advancing on career lattices.

Promising solutions are being pursued, and many will go beyond current educational structures. Community colleges are providing important new pathways for supplying the energy and mining workforce by providing direct alignment among their programs of study, the credentials they bestow, and industry education and skill requirements. Partnerships between 4-year colleges and universities and community colleges to create new pathways for STEM curriculum, with the first 2 years of STEM-related programs of study being offered at the community college and the second 2 years being offered at the university, could expand the capacity of the critical university degree programs.

The national solution being deployed by the U.S. manufacturing industry also could be a beneficial strategy for the energy and mining industries to pursue, in partnership with education and government. Innovative curricula delivered in nontraditional formats and pedagogies (e.g., nonlinear or just-in-time) that embed STEM concepts in contextualized examples (e.g., technology-enabled, skills-based competency delivery) that are rigorous and industry-recognized would enhance the mobility of students into the workforce.

Specialized higher-education programs at the bachelor’s and master’s levels are also important, especially for mining, petroleum engineering, and geology. An adequate supply of skilled scientists and engineers from universities is also essential to ensuring that the United States remains an international leader in technology. Reliance on workers from other countries to fill these ranks is decreasingly an option.

Existing immigration programs related to the workforce are not aligned with the need to increase the STEM professionals and STEM technical workforce. Although reformed policies could be helpful, it is most important to pursue strategies to produce our own talent.

The establishment of several interdisciplinary graduate Centers of Excellence in Earth Resources Engineering at leading U.S. research universities could help focus attention on the science and engineering challenges presented by the extractive industries (petroleum, mining, and geological engineering) and develop the professional expertise needed by industry.

Developing the necessary, educated, and skilled energy and mining workforce will require a strong partnership among business, education at all levels, and the government. No one sector can provide the workforce on its own. In addition, university research can advance technology and business practices, while contributing to workforce development by enriching undergraduate and graduate education and preparing better educators.

Industry image also plays a part in attracting students and workers into energy and mining programs of study and careers. The public perception of the extractive industries in the United States is often that they are environmentally damaging and their jobs are undesirable. (This perception arises from concerns over factors such as pollution, noise, environmental degradation, and health issues, for example.) This negative image dissuades some from pursuing careers in the more traditional energy and mining fields. Efforts by a partnership of industry organizations and educational institutions, incorporating timely and comprehensive information from government and other sources, to inform students, parents, educators, and public policy makers about the importance of the energy and mining industries and STEM education, and the career opportunities that are available in these industries, could help to overcome barriers created by negative industry images. The emerging renewable energy sectors are generally seen as positive, but some negative perceptions exist for them as well (e.g., questionable technology viability, long-term existence, and cost-effectiveness). Such a partnership also could educate the public about these industries and help to mitigate negative perceptions.

Employees of federal agencies involved in the energy and extractive industries are also a key part of the energy and mining workforce, since they are involved in all aspects of these industries. These agencies also face looming retirements and have difficulty in attracting and retaining qualified workers. Some factors, among others, that contribute to this problem are the federal government's inability to match industry salaries and benefits and the constrained practices of the government's personnel system. Foreign workers are not an effective solution, because few agencies can hire them owing to citizenship restrictions. Agencies also are reaching out to nontraditional students (such as women and ethnic minorities) and to returning military veterans. Although agency efforts are helping, revisions in agency recruitment, training, and employment arrangements could bring broader improvements.

Workers in energy and extractive industries are at higher risk for fatal injury than are workers in other fields as a whole. Also, in the mining, oil, and gas industries, looming retirements will create a significant gap between inexperienced and experienced workers, increasing the risk for the younger workers. Training is critical for new workers. In addition, it is important for experienced workers to mentor younger workers and for companies to capture what experienced, retiring workers know and use that knowledge to train new workers. Also, to maintain safety in an increasingly diverse workplace, it is important that supervisors and managers be trained in how to lead and communicate with a diverse workforce.

The United States cannot redesign its education programs and business–education partnerships to better provide a qualified energy and mining workforce without accurate data on occupations, jobs, and skill requirements. Although federal and other databases provide an abundance of information on the energy and mining workforce, the data currently available are neither sufficiently complete and up-to-date nor do they exist at a sufficient degree of granularity. A collaboration of government data-gathering agencies with industry would be needed to collect and analyze the data required for effective energy and mining workforce decision making and policy making.

Along with the challenges come opportunities. Growing energy and mining sectors combined with large numbers of pending workforce retirements are creating unprecedented opportunities for young people to enter these fields. The demographics of the United States are changing, with growing populations from other countries and increasing numbers of women and minority students entering the workforce and pursuing degrees and other certifications. It is key for the nation to look for new workers with both traditional and nontraditional backgrounds in order to provide future employees at all levels. Moreover, addressing the shortfalls of the current education pipeline with innovative new approaches to expanded workforce preparation can increase the flow of new, qualified workers into the workforce. The future is very bright if we choose to prepare for it.

OVERARCHING FINDINGS AND RECOMMENDATIONS

In considering the breadth of information covered in this study, the committee chose to formulate the following set of overarching findings and recommendations to capture the key, fundamental themes contained in the full array of their findings and recommendations. The committee's full findings and recommendations, along with the information and data to support them, are provided within the report. The overarching recommendations have equal importance and should be initiated as soon as possible. Indicated with each recommendation is the time frame expected for it to become fully operational after initiation. Short term is defined as 2 years or less, medium term as 2-5 years, and long term as more than 5 years. All are expected to continue for the long term.

Pathways

Traditional routes to degrees in higher education do not adequately align curriculum to energy and mining industry requirements, they are increasingly not affordable and accessible and, therefore, do not provide enough qualified STEM-educated workers and professionals to fulfil the nation's energy and mining workforce needs.

The goal in addressing the shortfalls of the current education pipeline is to create an education system that can respond to changes in the economy more quickly and produce a more flexible, STEM-competent workforce, resulting in students equipped with multiple skills and levels of skills, preparing them to adjust more quickly to industry requirements and job availability by moving and advancing on career lattices.

Finding 1: Community colleges are providing important new pathways for supplying the energy and mining workforce by providing direct alignment among their programs of study, the credentials they bestow, and industry education and skill requirements.

Finding 2: With a direct alignment to industry education and skill requirements, the success of education programs can be measured by successful attainment of employment and advancement opportunities in the energy and mining industries.

Recommendation 1: The Department of Education, in collaboration with the Department of Labor, state departments of education, and national industry organizations, should convene (perhaps in workshops or as a working group) critical industry, government, and educational leaders to create and support new approaches that provide multiple pathways in higher education that take full advantage of the attributes of our higher education system. Recognizing the differences in regional workforce requirements, these workshops and/or meetings should be convened in different parts of the country. These models would benefit greatly from including, for example:

- Community colleges integrating industry recognized credentials, their learning standards, and content, into associate degree programs, providing more "on" and "off" ramps to postsecondary education, resulting in stackable interim credentials with real value in the labor market, and leading to direct employment or continuing postsecondary educational opportunities; and

- Partnerships between 4-year colleges and universities and community colleges to create new pathways for STEM curriculum, with the first 2 years of STEM-related programs of study being offered at the community college and the second 2 years being offered at the university, thereby expanding the capacity of the critical university degree programs. (Short Term)

Business-Education-Government Partnership

No one sector—government, industry, or education—can provide the needed energy and mining workforce on its own. University research also can contribute to workforce development by enhancing the education pipeline.

Finding 3: Ensuring that the United States has the educated and skilled workforce necessary for the success of the energy and mining industries requires a strong partnership among business, education at all levels, and the government.

Finding 4: Technical research leads not only to innovation—the lifeblood of industry's business success—but also to better education and educators.

Recommendation 2: To address common goals and to provide a mechanism for industry's engagement with the education process and the graduates it produces, federal agencies (e.g., the National Science Foundation, DOE, Department of Defense, National Institute for Occupational Safety and Health, and National Institutes of Health) should consider providing increased research funding to universities, with matching funding from industry, with specific requirements to incorporate two outcomes from the research: (1) advancing technology or business processes to drive innovation and enrich graduate and undergraduate education; and (2) developing university faculty who work on the cutting edge of research to enhance the quality of higher education. The engagement of both faculty and graduate students in this research will extend the pool of STEM-qualified faculty for all educational levels. (Short Term)

Energy and Mining Information for the Public

Importantly, building the best educational pathways in the world and the most qualified STEM faculty for our educational institutions does not mean that more students will pursue energy and mining programs of study. "Build it and they may not come." The public perception of the mature extractive industries in the United States is often that they are environmentally damaging and their jobs are undesirable (due to concerns over pollution, noise, environmental degradation, and health issues, for example). This negative image dissuades some from pursuing careers in these industries. Also, although renewable energy is generally seen as positive, some negative perceptions (questionable technology viability, long-term existence, and cost-effectiveness, for example) exist that might dissuade people from joining those workforces. Information about all of these industries can educate the public about their importance to the nation and the career opportunities they offer. The government has a natural role to play in providing and disseminating such information as a complement to nongovernment sources. Information about these industries may also motivate students to pursue STEM courses and prepare for careers in energy and mining. For example, about 7,000 students drop out of high school every school day in the United States, and about 1.3 million students do not graduate each year. Also, in 2011, only 25 percent of graduating high school seniors met or surpassed the four ACT College Readiness Benchmarks in the areas of science, math, reading, and English.

Finding 5: Students mostly do not stay in STEM courses in K-12 that would prepare them for STEM postsecondary education or employment.

Recommendation 3: National industry organizations, in partnership with educational institutions, should embark on a national campaign to create and provide accurate and timely information on the industries and their careers, educational and career navigation resources, and experiential learning opportunities to explore jobs and career paths in energy and mining. They should work with the Department of Labor and other government institutions to ensure that timely government information is included. (Short Term)

Recommendation 4: In like fashion, national industry organizations and educational institutions should also embark on an informational campaign to educate students, parents, educators, and public policy makers about the importance of the energy and mining industries to our economic and national security, the relevance of STEM education to jobs and careers in these industries, and the opportunities available in these industries—again including timely government information. (Short Term)

Data

The nation cannot redesign its education programs and business-education partnerships to better provide a qualified energy and mining workforce without accurate data on occupations, jobs, and skill requirements.

Finding 6: Although the federal (and other) databases provide an abundance of information on the energy and mining workforce, such as employment estimates and demographic information, the data currently available for addressing the energy and mining workforce are not sufficiently consistent, comprehensive and up-to-date for these rapidly evolving, technology-infused industries and they do not exist at a sufficient degree of granularity.

Finding 7: To collect and analyze the data needed for effective energy and mining workforce decision and policy making, it is critical to foster the collaboration of government data-gathering agencies with industries that gather data.

Recommendation 5: The Department of Labor, through its Bureau of Labor Statistics, should determine and pursue a more effective way to partner with industry, through its national industry associations, to more quickly and accurately reflect the fast-paced change of job and occupation titles and characteristics, as well as the levels of education and training required in 21st century jobs.[1] (Medium Term)

Recommendation 6: The Bureau of Labor Statistics should work with industry and the Departments of Education and Labor to better define the STEM technical workforce needed to support STEM professions in our economy so that appropriate and useful data can be identified, collected, and analyzed. (Medium Term)

The Federal Workforce

Federal employees have a critical role in, and impact on, the success of the U.S. energy and mining industries. They are involved in all aspects of the energy and extractive industries, from initial access (through the permitting process), through production and the regulation of those activities, to closure and restoration during the reclamation process. Federal employees link industry's ability to produce energy and minerals with civil society's concerns about these industries. However, the National Nuclear Security Administration reports that a majority of mission-critical employees are currently eligible or will be eligible for retirement in the next 4 years. MSHA projections show that 46 percent of their coal-sector workforce will be eligible to retire within 5 years, and they expect to lose 40 percent of their metal/nonmetal workforce in the same period.

Finding 8: Federal agencies involved in the energy and extractive industries are facing high retirement rates and there is an acute need to replace the departing federal workforce.

Finding 9: Because of the relatively restrictive personnel processes that federal agencies must follow and the relatively higher compensation offered by industry, it is difficult for federal agencies to hire and retain the employees they need.

Recommendation 7: All involved federal agencies should review and revise recruitment, training, and employment arrangements for federal employees directly involved in minerals and energy policy, permitting, and production oversight to ensure the agencies' ability to attract and retain qualified federal workers. Industries involved in energy production and resource extraction should develop collaborative efforts to partner with government at all levels to develop solutions to the problem of recruiting and retaining quality public-sector employees. (Medium Term)

[1] Chapter 8 contains a set of specific recommendations that are based on a detailed overview of the energy and mining workforce, using federal data sources, presented in Appendix B.

REFERENCES

ACT, Inc. 2011. Condition of College and Career Readiness 2011. [online]. Available: http://www.act.org/research/policymakers/cccr11/pdf/ConditionofCollegeandCareerReadiness2011.pdf (accessed June 22, 2012).

Alliance for Excellent Education. 2010. High School Dropouts in America. Fact Sheet[online]. Available: http://www.all4ed.org/files/GraduationRates_FactSheet.pdf (accessed June 27, 2012).

Alliance for Excellent Education. 2011. Saving Now and Saving Later: How High School Reform Can Reduce the Nation's Wasted Remediation Dollars. Issue Brief [online]. Available: http://www.all4ed.org/files/SavingNowSavingLaterRemediation.pdf (accessed August 8, 2012). Alternative Power International. 2009. Wind Power Opportunities [online]. Available: http://www.altpowerinternational.com/wind-power/index.php (accessed August 28, 2012).

Andersen, M. A., H. Dayton, R. L. Albright, R. M. Byrnes, W. L. Fisher, H. Gilbert, C. A. Hansen, S. A. Holditch, L. G. Jackson, W. D. Johnson, M. A. Landry, W. H. Neal, R. F. Nelson, M. Oswalt, H. C. Pozzo, M. A. Rostand, M. T. Sambles, J. A. Scotti, and M. M. Sharma. 2007. Facing the Hard Truths About Energy. Human Resources. Topic Paper No. 23 for Hard Truths. National Petroleum Council, Committee on Global Oil and Gas, Washington, DC [online]. Available: http://www.npc.org/study_topic_papers/23-ttg-human-resources.pdf (accessed May 3, 2012).

Archer, C. L., and M. Z. Jacobson. 2007. Supplying baseload power and reducing transmission requirements by interconnecting wind farms. Journal of Applied Meteorology and Climatology 46(11):1701-1717.

ARI/Melzer (Advanced Research International, Inc., and Melzer Consulting). 2010. Optimization of CO_2 Storage in CO_2 Enhanced Oil Recovery Projects. Prepared by Advanced Research International, Inc., Arlington, VA, and Melzer Consulting, Midland, TX, for U.S. Department of Energy and Climate Change, November 30, 2010. Available: http://www.adv-res.com/pdf/1006-optimization-of-co2-storage-in-co2-enhanced-oil-re.pdf (accessed August 10, 2012).

ATEEC (Advanced Technology Environmental and Energy Center). 2011. Preparing Energy Technicians for the 21st Century Workforce: A Report of the National Energy Technician Education Summit, December 8-10, 2010, Washington, DC. Available: http://ateec.org/ateec-downloads/ateec-downloads/preparing-energy-technicians-for-the-21st-century-workforce-2.

AWEA (America Wind Energy Association). 2011a. AWEA Annual Market Report, Year Ending 2010 [online]. Available: http://www.awea.org/learnabout/publications/reports/AWEA-US-Wind-Industry-Market-Reports.cfm (accessed July 2, 2012).

AWEA (America Wind Energy Association). 2011b. U.S. Wind Industry: Market Update. Fact Sheet [online]. Available: http://www.awea.org/learnabout/publications/factsheets/upload/U-S-Wind-Industry-Market-Update-Factsheet-May-2011.pdf (accessed July 2, 2012).

AWEA (America Wind Energy Association). 2012a. AWEA Seal of Approval Program [online]. Available: http://www.awea.org/learnabout/education/awea_soa/index.cfm (accessed September 12, 2012).

AWEA (America Wind Energy Association). 2012b. U.S. Wind Industry Annual Market Report Year Ending 2011. Available: http://www.awea.org/suite/suite.cfm?CFID=264712527&CFTOKEN=69199343&jsessionid=78308d2414595cffd99e524d33797d67553a.

AWEA (America Wind Energy Association). 2012c. U.S. Wind Industry Fourth Quarter 2011 Market Report. Available: http://www.awea.org/learnabout/industry_stats/upload/4Q-2011-AWEA-Public-Market-Report_1-31.pdf (accessed September 10, 2012).

AWEA (America Wind Energy Association). 2013. U.S. Wind Industry Fourth Quarter 2012 Market Report. Available: http://www.awea.org/learnabout/publications/reports/upload/AWEA-Fourth-Quarter-Wind-Energy-Industry-Market-Report_Executive-Summary-4.pdf (accessed March 11, 2013).

Baker, M., C. Henkhaus, S. Swift, and K. Plantier. 2011. Texas Wind Energy Industry Workforce Assessment. Texas Wind Energy Institute, Lubbock, TX, and The Wind Alliance, Houston, TX [online]. Available: http://www.thewindalliance.org/Documents/TWC-Omnibus-Report-12-18-2011.pdf (accessed January 16, 2012).

Baker Hughes. 2012. Rotary Rig Count [online]. Available: http://investor.shareholder.com/bhi/rig_counts/rc_index.cfm (accessed June 8, 2012).

BEA (U.S. Bureau of Economic Analysis). 2012. Widespread Economic Growth Across States in 2011. News Release, June 5 [online]. Available: http://www.bea.gov/newsreleases/regional/gdp_state/gsp_newsrelease.htm (accessed August 29, 2012).

Benson, S. M. 2007. Monitoring geological storage of carbon dioxide. Pp. 73-100 in Carbon Capture and Geologic Sequestration: Integrating Technology, Monitoring, and Regulation, E. J. Wilson, and D. Gerard, eds. Ames, IA: Blackwell Scientific.

Berrigan, C. L. 2009. Testimony by Carol Berrigan, Senior Director, Industry Infrastructure and Supply Chain, Nuclear Energy Institute before the U.S. Senate Committee on Finance, November 10, 2009, Washington, DC [online]. Available: http://www.nei.org/publicpolicy/congressionaltestimony/november-10-2009-carol-berrigan/ (accessed July 24, 2012).

Berrigan, C. L. 2010. Testimony by Carol Berrigan, Senior Director, Industry Infrastructure and Supply Chain, Nuclear Energy Institute before the Blue Ribbon Commission on America's Nuclear Future, Subcommittee on Reactors and Fuel Cycle Technology, August 31, 2010, Washington, DC [online]. Available: http://www.nei.org/publicpolicy/congressionaltestimony/august-31-2010/ (accessed June 9, 2012).

Berrigan, C. L., and E. McAndrews-Benavides. 2011. Presentation at the First Meeting on Emerging Workforce Trends in the U.S. Energy and Mining Industries, March 29, 2011, Washington, DC.

Bleiwas, D. I. 2010. Byproduct mineral commodities used for the production of photovoltaic cells. U.S. Geological Survey Circular 1365 [online]. Available: http://pubs.usgs.gov/circ/1365/ (accessed November 15, 2012).

BHEF (Business Higher Education Forum). 2011. Aligning Higher Education STEM Production with Workforce Demand Through Professional Master's Degrees. Issues Brief [online]. Available: http://www.strategicedsolutions.org/sites/default/files/pdfs/Issue_Brief_PSM_Programs.pdf (accessed June 26, 2012).

BLM/USFS (U.S. Bureau of Land Management and U.S. Forest Service). 2008. Final Programmatic Environmental Impact Statement for Geothermal Leasing in the Western United States. FES 08-44. U.S. Department of Interior, Bureau of Land Management, and U.S. Department of Agriculture, Forest Service, Washington, DC [online]. Available: www.blm.gov/pgdata/etc/medialib/blm/wo/MINERALS__REALTY__AND_RESOURCE_PROTECTION_/energy/geothermal_eis/final_programmatic.Par.95063.File.dat/Geothermal_PEIS_final.pdf (accessed March 31, 2012).

Bloomfield, K. K., and G. L. Mines. 2000. Cycling geothermal resources to increase revenues. Geothermal Resources Council Transactions 24:105-108.

Bloomfield, K. K., and G. L. Mines. 2002. Predicting future performance from reservoir management cycling. Geothermal Resources Council Transactions 26:79-82.

BLS (U.S. Bureau of Labor Statistics). 2010. BLS Establishment Estimates Revised to Incorporate March 2010 Benchmarks, Table 4a: Effect of March 2010 Benchmark Revisions to All Employee Hours and Earnings Estimates, Selected Industries. [online]. Available: http://stats.bls.gov/ces/cesbmart10.pdf (accessed July 27, 2012).

BLS (U.S. Bureau of Labor Statistics). 2011a.BLS (2010)Current Employment Statistics (CES), Benchmark Tables, Table 4a. Effect of March 2010 benchmark revisions to all employee hours and earnings estimates, selected industries [online]. Available: http://www.bls.gov/web/empsit/cesbmtab.htm#Tab4b (accessed January 30, 2013).

BLS. 2011a. Quarterly Census of Employment and Wages 2010. U.S. Bureau of Labor Statistics [online]. Available: http://www.bls.gov/cew/cewbultn10.htm (accessed July 25, 2012).

BLS. 2011b. National Occupational Employment and Wage Estimates May 2011 [online]. Available: http://www.bls.gov/oes/current/oes_nat.htm#17-0000 (accessed August 29, 2012).

BLS. 2011c. Occupational Outlook Handbook: Career Guide to Industries-Section on Mining. U.S. Bureau of Labor Statistics [online]. Available: http://www.bls.gov/oco/ (accessed July 27, 2012).

BLS. 2011d. Quarterly Census of Employment and Wages 2010. U.S. Bureau of Labor Statistics [online]. Available: http://www.bls.gov/cew/cewbultn10.htm (accessed July 25, 2012).

BLS. 2011e. Labor Force Statistics from the Current Population Survey: Occupational and Industry Classification Systems Used in the Current Population Survey [online]. Available: http://www.bls.gov/cps/cpsoccind.htm (accessed September 14, 2012).

BLS (. 2011f. U.S. BureauDepartment of Labor Statistics). 2011b. National, Occupational Employment Statistics. Available: http://www.bls.gov/oes/oes_dl.htm. (accessed January 30, 2013).

BLS (U.S. Bureau of Labor Statistics). 2011c. Occupational Outlook Handbook: Career Guide to Industries–Section on Mining [online]. Available: http://www.bls.gov/oco/ (accessed July 27, 2012).

BLS (U.S. Bureau of Labor Statistics). 2011d. Quarterly Census of Employment and Wages 2010 [online]. Available: http://www.bls.gov/cew/cewbultn10.htm (accessed July 25, 2012).

BLS (U.S. Bureau of Labor Statistics). 2012a. Current Employment Statistics [online]. Available: http://www.bls.gov/ces/ (accessed August 29, 2012).

BLS (U.S. Bureau of Labor Statistics). 2012b. Employed Persons by Detailed Industry and Age, 2011 Annual Average. Labor Force Statistics from the Current Population Survey [online]. Available: http://www.bls.gov/cps/industry_age.htm (accessed August 20, 2012).

BLS (U.S. Bureau of Labor Statistics). 2012c. Employment Projections: Education and Training Data [online]. Available: http://www.bls.gov/emp/ep_education_training_system.htm (accessed September 14, 2012).

BLS (U.S. Bureau of Labor Statistics). 2012d. Employment Projections Program [online]. Available: http://www.bls.gov/emp/ (accessed September 14, 2012).

BLS (U.S. Bureau of Labor Statistics). 2012e. Employment Projections; Projections Methodology [online]. Available: http://www.bls.gov/emp/ep_projections_methods.htm/ (accessed September 14, 2012).

BLS (U.S. Bureau of Labor Statistics). 2012f. Job Opening and Labor Turnover Survey [online]. Available: http://www.bls.gov/jlt/home.htm (accessed August 29, 2012).

BLS (U.S. Bureau of Labor Statistics). 2012g. Occupational Employment Statistics [online]. Available: http://www.bls.gov/oes/(accessed September 14, 2012).

BLS (U.S. Bureau of Labor Statistics). 2012h. Quarterly Census of Employment and Wages: Employment and Wages [online]. Available: http://bls.gov/cew/ (accessed August 9, 2012).

BLS (U.S. Bureau of Labor Statistics). 2012i. Quarterly Census of Employment and Wages, Frequently Asked Questions [online]. Available: http://www.bls.gov/cew/cewfaq.htm (accessed September 14, 2012).

BLS (U.S. Bureau of Labor Statistics). 2012j. Standard Occupational Classification [online]. Available: http://www.bls.gov/SOC/ (accessed September 14, 2012).

Bowler, M., R. E. Ilg, S. Miller, E. Robison, and A. Polivka. 2003. Revisions to the Current Population Survey Effective in January 2003. Employment and Earning (February):4-23 [online]. Available: http://www.bls.gov/cps/rvcps03.pdf (accessed September 14, 2012).

Brady, J. 2009. An Aged Electic Grid Looks to a Brighter Future [online]. Available: http://www.npr.org/templates/story/story.php?storyId=103327321 (accessed April 19, 2012).

Brandon, C. N. 2012. Emerging Workforce Trends in the U.S. Mining Industry. Automated Systems Alliance Inc., for the SME, NMA, NSSGA, and IMA-NA, Society for Mining, Metallurgy and Exploration, Englewood, CO [online]. Available: http://www.smeny.org/sitebuildercontent/sitebuilderfiles/smeny_12_01.pdf (accessed July 26, 2012).

BRC (Blue Ribbon Commission on America's Nuclear Future). 2012. Report to the Secretary of Energy, June 29, 2011 [online]. Available: http://cybercemetery.unt.edu/archive/brc/20120620220235/http://brc.gov/sites/default/files/documents/brc_finalreport_jan2012.pdf (accessed June 11, 2012).

Butani, S. J., and A. M. Bartholomew. 1988a. Characterization of the 1986 Coal Mining Workforce. U.S. Bureau of Mines Information Circular 9192.

Butani, S. J., and A. M. Bartholomew. 1988b. Characterization of the 1986 Metal and Nonmetal Mining Workforce. U.S. Bureau of Mines Information Circular 9193 [online]. Available www.cdc.gov/niosh/mining/pubs/pdfs/ic9193.pdf (accessed April 18, 2012).

Carnevale, A. P., N. Smith, and J. Strohl. 2010. Help Wanted: Projections of Jobs and Education Requirements Through 2018. Georgetown University Center on Education and the Workforce [online]. Available: http://www9.georgetown.edu/grad/gppi/hpi/cew/pdfs/HelpWanted.FullReport.pdf (accessed June 27, 2012).

CBIA (Connecticut Business and Industry Association). 2009. Career Pathways: Energy and Green Technology—An Educator's Guide [online]. Available: http://www.cbia.com/edf/documents/CP-Energy-Green-Tech_09.pdf (accessed September 11, 2012).

Center for Strategic Leadership, U.S. Army War College, July 2011 Volume 7-11.

CEWD (Center for Energy Workforce Development). 2009. Gaps in the Energy Workforce Pipeline: 2009 CEWD Survey Results [online]. Available: http://www.cewd.org/mem_resources/2009%20Survey%20Exec%20Summary.pdf (accessed July 17, 2012).

CEWD (Center for Energy Workforce Development). 2010. Energy Industry Competency Model: Generation, Transmission and Distribution [online]. Available: http://www.cewd.org/curriculum/downloads/Energy%20Competency%20Model%20September%202010.pdf (accessed July 23, 2012).

CEWD (Center for Energy Workforce Development). 2011a. Gaps in the Energy Workforce Pipeline: 2011 CEWD Survey Results [online]. Available: http://www.cewd.org/surveyreport/CEWD-2011surveyreport-021512.pdf (accessed April 20, 2012).

CEWD (Center for Energy Workforce Development). 2011b. Troops to Energy Jobs Program: New Career Directions [online]. Available: http://www.troopstoenergyjobs.com/energy-careers-for-veterans.php (accessed August 23, 2012).

CEWD (Center for Energy Workforce Development). 2012a. About the Energy Industry Fundamentals Certificate Program [online]. Available: http://www.cewd.org/curriculum/about-the-eif-certificate.php (accessed June 13, 2012).

CEWD (Center for Energy Workforce Development). 2012b. Career Pathways Roadmaps [online]. Available: http://www.cewd.org/roadmap/ (accessed June 13, 2012).

Chupka, M. W., R. Earle, P. Fox-Penner, and R. Hledik. 2008. Transforming America's Power Industry: The Investment Challenge 2010-2030. The Brattle Group. Prepared for Edison Foundation [online]. Available: http://www.eei.org/ourissues/finance/Documents/Transforming_Americas_Power_Industry.pdf (accessed July 17, 2012).

Complete College America. 2011. Time is the Enemy [online]. Available: http://www.completecollege.org/docs/Time_Is_the_Enemy.pdf (accessed June 22, 2012).

Constable, G., and B. Somerville. 2003. A Century of Innovation: Twenty Engineering Achievements That Transformed Our Lives. Washington, DC: Joseph Henry Press.

Cooper, M., and D. Sussman. 2011. Nuclear power loses support in new poll. New York Times, March 22 [online]. Available: http://www.nytimes.com/2011/03/23/us/23poll.html (accessed July 7, 2012).

Cummings, M. 2011. NNSA at a Glance. Presentation at the Fifth Meeting on Emerging Workforce Trends in the U.S. Energy and Mining Industry**,** December 13, Washington, DC.
Davis, L. W. 2011. Prospects for Nuclear Power. NBER Working Paper No. 17674. National Bureau of Economic Research, Cambridge, MA [online]. Available: http://www.nber.org/papers/w17674 (accessed July 23, 2012).
DMACC (Des Moines Area Community College). 2009. Industrial Electro-Mechanical Technology Program Provides Training for Wind Energy and Technology Careers [online]. Available: https://go.dmacc.edu/programs/windenergy/documents/WindEnergyProgram.pdf (accessed September 11, 2012).
DOE (U.S. Department of Energy). 2001. Careers in Renewable Energy. DOE/GO-102001-1130, FS123. DOE, Energy Efficiency and Renewable Energy [online]. Available: http://www.nrel.gov/docs/fy01osti/28369.pdf (accessed September 11, 2012).
DOE (U.S. Department of Energy). 2008. 20% Wind Energy by 2030; Increasing Wind Energy's Contribution to U.S. Electricity Supply. DOE/GO-102008-2567. DOE, Energy Efficiency and Renewable Energy [online]. Available: http://www.20percentwind.org/20percent_wind_energy_report_revOct08.pdf (accessed May 21, 2012).
DOE (U.S. Department of Energy). 2010a. Carbon Sequestration Atlas of the United States and Canada, 3rd Ed. (Atlas III). National Energy Technology Laboratory [online]. Available: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/atlasIII/2010atlasIII.pdf (accessed August 10, 2012).
DOE (U.S. Department of Energy). 2010b. Site Screening, Selection, and Initial Characterization for Storage of CO_2 in Deep Geologic Formations. DOE/NETL-401/090808. National Energy Technology Laboratory [online]. Available: http://www.netl.doe.gov/technologies/carbon_seq/refshelf/BPM-SiteScreening.pdf (accessed August 14, 2012).
DOE (U.S. Department of Energy). 2011. SunShot Initiative: Solar Career Map [online]. Available: http://www1.eere.energy.gov/solar/careermap/ (accessed July 19, 2012).
DOE (U.S. Department of Energy). 2012a. Solar Instructor Training Network [online]. Available: http://www.sitnusa.org/ (accessed July 20, 2012).
DOE (U.S. Department of Energy). 2012b. The Smart Grid [online]. Available: http://www.smartgrid.gov (accessed April 19, 2012).
DOE (U.S. Department of Energy). 2012c. Wind Energy Education and Training Programs. Wind Powering America [online]. Available: http://www.windpoweringamerica.gov/schools/education/education_training.asp (accessed September 12, 2012).
DOE (U.S. Department of Energy). 2012d. The Smart Grid [online]. Available: http://www.windpoweringamerica.gov/schools_wfs_project.asp (accessed April 19, 2012).
Downey, J. 2012. NRC licenses nuclear plant in South Carolina. Charlotte Business Journal, March 30 [online] Available: http://www.bizjournals.com/charlotte/blog/power_city/2012/03/nrc-licenses-nuclear-plant-in-south.html?page=all (accessed August 8, 2012).
Duncan, J. 2011. MSHA Snapshot. Presentation at the Fifth Meeting on Emerging Workforce Trends in the U.S. Energy and Mining Industry**,** December 13, Washington, DC.
EEI (Edison Electric Institute). 2011. Transmission Projects: At a Glance [online]. Available: http://www.eei.org/ourissues/ElectricityTransmission/Documents/Trans_Project_intro.pdf (accessed July 3, 2012).
EIA (U.S. Energy Information Administration). 2000. The Changing Structure of the Electric Power Industry 2000: An Update. DOE/EIA-0562(00) [online]. Available: http://www.eia.gov/cneaf/electricity/chg_stru_update/update2000.pdf (accessed July 17, 2012).
EIA (U.S. Energy Information Administration). 2011a. Annual Energy Outlook 2011 with Projections to 2035. DOE/EIA-0383(2012 [online]. Available: http://www.eia.gov/forecasts/archive/aeo11/pdf/0383(2011).pdf (accessed August 29, 2012).

EIA (U.S. Energy Information Administration). 2011b. Annual Energy Outlook 2012, Table 74: Employment and Shipments by Industry, and Income and Employment by Region. http://www.eia.gov/forecasts/aeo/topic_macroeconomic.cfm.

EIA (U.S. Energy Information Administration). 2011c. Annual Energy Review 2010. DOE/EIA-0384(2010) [online]. Available: http://www.eia.gov/totalenergy/data/annual/archive/038410.pdf (accessed November 15, 2012).

EIA (U.S. Energy Information Administration). 2011d. Electric Power Annual 2010 [online]. Available: http://www.eia.gov/electricity/annual/pdf/epa.pdf (accessed August 24, 2012).

EIA (U.S. Energy Information Administration). 2012a. Annual Energy Outlook 2012 with Projections to 2035. DOE/EIA-0383(2012) [online]. Available: http://www.eia.gov/forecasts/aeo/pdf/0383(2012).pdf (accessed August 29, 2012).

EIA (U.S. Energy Information Administration). 2012b. Electric Power Monthly: February 2012. DOE/EIA-0226 (2012/02) [online]. Available: http://www.eia.gov/electricity/monthly/current_year/february2012.pdf (accessed August 24, 2012).

EIA (U.S. Energy Information Administration). 2012c. International Energy Statistics [online]. Available: http://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm (accessed August 29, 2012).

EIA (U.S. Energy Information Administration). 2012d. Monthly Energy Review: March 2012. DOE/EIA-0035(2012/03) [online]. Available: http://205.254.135.7/totalenergy/data/monthly/archive/00351203.pdf (accessed May 7, 2012).

EIA (U.S. Energy Information Administration). 2012e. Natural Gas, Data: U.S. Natural Gas Wellhead Price (Dollars per Thousand Cubic Feet) [online]. Available: http://www.eia.gov/dnav/ng/hist/n9190us3A.htm (accessed August 30, 2012).

EIA (U.S. Energy Information Administration). 2012f. Overview: Nuclear & Uranium— Boiling Water Reactor [online]. Available: http://www.eia.gov/cneaf/nuclear/page/nuc_reactors/bwr.html (accessed July 23, 2012).

EIA (U.S. Energy Information Administration). 2012g. Overview: Nuclear & Uranium—Pressurized-Water Reactor and Reactor Vessel [online]. Available: http://www.eia.gov/cneaf/nuclear/page/nuc_reactors/pwr.html (accessed July 23, 2012).

EIA (U.S. Energy Information Administration). 2012h.Available: http://www.eia.gov/petroleum/data.cfm (accessed August 24, 2012).

EIA (U.S. Energy Information Administration). 2012i. State Electricity Profiles [online]. Available: http://205.254.135.7/electricity/state/pdf/sep2010.pdf (accessed April 19, 2012).

Energy for Educators.org. 2009. Bringing Energy to Classroom. Idaho National Laboratory [online]. Available: http://www.energyforeducators.org/index.shtml (accessed August 2, 2012).

EPA (U.S. Environmental Protection Agency). 2011. Announcement of Federal Underground Injection Control (UIC) Class VI Program, September 9 [online]. Available: https://www.federalregister.gov/articles/2011/09/15/2011-23662/announcement-of-federal-underground-injection-control-uic-class-vi-program-for-carbon-dioxide-co2 (accessed August 10, 2012).

EPI (Energy Policy Institute). 2010. Economic and Employment Impacts of Small Modular Nuclear Reactors, Boise State University [online]. Available: http://epi.boisestate.edu/download.aspx?File=/3494/economic and employment impacts of smrs.pdf (accessed June 15, 2012).

EPRI (Electric Power Research Institute). 2011. Estimating the Costs and Benefits of the Smart Grid: A Preliminary Estimate of the Investment Requirements and the Resultant Benefits of a Fully Functioning Smart Grid [online]. Available: http://ipu.msu.edu/programs/MIGrid2011/presentations/pdfs/Reference%20Material%20-%20Estimating%20the%20Costs%20and%20Benefits%20of%20the%20Smart%20Grid.pdf (accessed July 17, 2012).

Fairhurst, C. 2010. Grand Challenges for Earth Resources Engineering. Presentation at DURA Annual Meeting and DUSEL PDR Rollout, September 2-3, Batavia, IL [online]. Available:

http://www.dusel.org/workshops/fallworkshop10/n_fairhurst.pdf (accessed August 8, 2012).

FedScope. 2012. Federal Human Resources Data. U.S. Office of Personal Management [online]. Available: http://www.fedscope.opm.gov/ (accessed September 17, 2012).

FLATE (Florida Advanced Technological Education Center). 2012. The Engineering Technology A.S./A.A.S Degree Program [online]. Available: http://fl-ate.org/projects/ET_frameworks/2012/ET%20Curriculum%20Reform%20Summary%202012.pdf (accessed August 23, 2012).

Fotta, B., and G. Bockosh. 2000. The aging workforce: An emerging issue in the mining industry. Pp. 33-45 in Proceedings of 31st Annual Institute on Mine Health and Safety Research, August 27-30, 2000, Roanoke, VA, M. Karmis, J. Langton, M. K. McCarter, and B. Rowe, eds. Blacksburg, VA: Virginia Polytechnic Institute and State University [online]. Available: www.cdc.gov/niosh/mining/pubs/pdfs/tawae.pdf (accessed April 19, 2012).

Fotta, B., and G. Bockosh, 2004. The Aging Workforce: An Emerging Issue in the Mining Industry. Atlanta, GA: Centers for Disease Control and Prevention. Available: http://stacks.cdc.gov/view/cdc/9739/ (accessed February 4, 2013).

Fowler, T. 2011. N. American oil output could top 40-year-old peak. Houston Chronicle, September 29 [online]. Available: http://www.chron.com/business/energy/article/N-American-oil-output-could-top-40-year-old-peak-2193837.php (accessed August 30, 2012).

Fox-Penner, P. 2010. Smart Power: Climate Change, the Smart Grid, and the Future of Electric Utilities. Washington, DC: Island Press.

Freeman, L. 2011. Global Talent Crisis. Presentation at the Conference Mine Management Risk-Based Decision Making, October 2, Bogota, Columbia.

Friedman, B. 2011. PV Markets Overview and PV Installation Labor Market Analysis. Presentation at the Third Meeting on Emerging Workforce Trends in the U.S. Energy and Mining Industries, August 22, Golden, CO.

FVSU (Fort Valley State University). 2012. Cooperative Development Energy Program [online]. Available: http://www.fvsu.edu/academics/cdep (accessed October 18, 2012).

GAO (U.S. Government Accountability Office). 2011a. Electricity Grid Modernization [online]. Available: http://www.gao.gov/new.items/d11117.pdf (accessed April 19, 2012).

GAO (U.S. Government Accountability Office). 2011b. Progress Being Made on Cybersecurity Guidelines, but Key Challenges Remain to Be Addressed. GAO 11-117 [online]. Available: http://www.gao.gov/assets/320/314410.pdf (accessed August 28, 2012).

GAO (U.S. Government Accountability Office). 2012. Cybersecurity: Challenges in Securing the Modernized Electricity Grid. Testimony before the Subcommittee on Oversight and Investigations, Committee on Energy and Commerce, U.S. House of Representatives, February 28 [online]. Available: http://www.gao.gov/assets/590/588913.pdf (accessed April 23, 2012).

GCCSI (Global CCS Institute). 2011. The Global Status CCS: 2011 [online]. Available: http://cdn.globalccsinstitute.com/sites/default/files/publications/22562/global-status-ccs-2011.pdf (accessed August 10, 2012).

GEA (Geothermal Energy Association). 2008. Current Use [online]. Available: www.geo-energy.org/currentUse.aspx (accessed March 31, 2012).

GEA (Geothermal Energy Association). 2012. Annual U.S. Geothermal Power Production and Development Report: April 2012 [online]. Available: www.geo-energy.org/reports/2012AnnualUSGeothermalPowerProductionandDevelopmentReport_Final.pdf (accessed April, 25, 2012).

Giffi, C. A., and E. S. DeRocco. 2011. Unwavering Commitment: The Public's View of the Manufacturing Industry Today. Deloitte and The Manufacturing Institute [online]. Available: http://www.deloitte.com/assets/Dcom-UnitedStates/Local%20Assets/Documents/us%20cip%202011PublicViewonManufacturingReport%20090811.pdf (accessed June, 28, 2012).

Gonzales, L., and C. Keane. 2011. Status of the Geoscience Workforce 2011. American Geological Institute, Alexandria, VA.

GWEC (Global Wind Energy Council). 2011. Global Wind Report: Annual 2010 Market Update [online]. Available: http://www.indianwindpower.com/pdf/gwecReport_2010.pdf (accessed May 4, 2012).

GWEC (Global Wind Energy Council). 2012. Global Wind Report: Annual Market Update 2011 [online]. Available: http://gwec.net/wp-content/uploads/2012/06/Annual_report_2011_lowres.pdf (accessed March 1, 2013).

Hamilton, J., and D. Liming. 2010. Careers in Wind Energy. U.S. Bureau of Labor Statistics, Washington, DC [online]. Available: http://www.bls.gov/green/wind_energy/wind_energy.pdf (accessed April 28, 2012).

Hance, C. N. 2005. Geothermal Industry Employment: Survey Results & Analysis. Geothermal Energy Association, Washington, DC [online]. Available: www.geo-energy.org/reports/Geothermal%20Industry%20Employment%20-%20Survey%20Results%20and%20Analysis%20September%202005.pdf (accessed March 31, 2012).

Hargreaves, S. 2012. First new nuclear reactors OK'd in over 30 years. CNNMoney, February 9[online]. Available: http://money.cnn.com/2012/02/09/news/economy/nuclear_reactors/index.htm (accessed June 14, 2012).

HCC (Houston Community College). 2012. Petroleum Engineering Technology. Northeast College [online]. Available: http://northeast.hccs.edu/portal/site/northeast/menuitem.d3fb9940a6548be831b40910507401ca/?vgnextoid=6c826cbc0f2e9110VgnVCM100000054710acRCRD&vgnextfmt=default (accessed September 5, 2012).

Heinze, L. R. 2004. Education and Big Crew Change. Presentation at SPE ATC&E, January 16, Denver, CO [online]. Available: http://www.mmsa.net/Publications/EducationEthicsA_lheinze.pdf (accessed September 5, 2012).

Heydt, G. T., A. Bose, W. T. Jewel, M. Kezmovic, J. D. McCalley, D. J. Ray, P. W. Sauer, C. Singh, and V. Vittal. 2009. Professional Resources to Implement the Smart Grid, Presentation at North American Power Symposium. October 4-6, Starkville, MS [online]. Available: http://www.ieee-pes.org/images/pdf/Heydt_Professional_Resources_Smart_Grid_2009_Adobe7.pdf (accessed April 23, 2012).

Holditch, S. A. 2009. What will the oil and gas industry do this time? JPT (February):20-35 [online]. Available: http://www.spe.org/jpt/print/archives/2009/02/JPT2009_02_7GuestEditorial.pdf (accessed September 5, 2012).

Holm, A. 2011. Geothermal Education and Training Guide. Geothermal Energy Association, Washington, DC [online]. Available: www.geo-energy.org/reports/2011GEAGeothermalEducationandTrainingGuide.pdf (accessed April 1, 2012).

Houston's Energy Future. 2011. Greater Houston Partnership's Energy Strategy [online]. Available: http://www.houstonenergyfuture.com/energy-collaborative/ (accessed September 5, 2012).

Howard, J. 2009. The Future of Work. Presentation to the Small Business Panel, Occupational Safety and Health Administration, July 2 [online]. Available: www.osha.gov/dcsp/smallbusiness/forums/aging_presentation/aging_presentation.ppt#615 (accessed April 27, 2012).

Hurst, C. 2010. China's Rare Earth Elements Industry: What Can the West Learn? Institute for the Analysis of Global Security, Potomac, MD [online]. Available: http://www.iags.org/rareearth0310hurst.pdf (accessed June 6, 2012).

IAEA (International Atomic Energy Agency). 2012a. Nuclear Fuels and Materials [online]. Available: http://www.iaea.org/OurWork/ST/NE/NEFW/Technical_Areas/NFC/home.html (accessed July 24, 2012).

IAEA (International Atomic Energy Agency). 2012b. PRIS (Power Reactor Information System) [online]. Available: http://www.iaea.org/pris/ (accessed July 24, 2012).

IEEE PES (Institute of Electrical and Electronics Engineers Power and Energy Society). 2009. Preparing the U.S. Foundation for Future Electric Energy Systems: A Strong Power and Energy Engineering Workforce, Management Steering Committee of the U.S. Power and Energy Engineering Workforce Collaborative [online]. Available: http://www.ieee-pes.org/images/pdf/US_Power_&_Energy_Collaborative_Action_Plan_April_2009_Adobe72.pdf (accessed June 12, 2012).

Ilmarinen, J. E. 2001. Aging workers. Journal of Occupational & Environmental Medicine 58(8):546-552 [online]. Available: http://oem.highwire.org/content/58/8/546.full (accessed November 20, 2012).

IMA (International Maritime Associates, Inc.). 2011. Floating Production System [online]. Available: http://www.imastudies.com/id282.htm (accessed August 30, 2012).

IMF (International Monetary Fund). 2012. World Economic and Financial Surveys: World Economic Outlook Database [online]. Available: http://www.imf.org/external/pubs/ft/weo/2012/01/weodata/download.aspx (accessed August 29, 2012).

IPCC (Inter-governmental Panel on Climate Change). 2005. Carbon Dioxide Capture and Storage. IPCC Special Report. Cambridge, UK: Cambridge University Press [online]. Available: http://www.ipcc-wg3.de/publications/special-reports/.files-images/SRCCS-WholeReport.pdf (accessed August 10, 2012).

IREC (Interstate Renewable Energy Council). 2012. Solar Energy Education and Training Best Practices: Curriculum and Program Development [online]. Available: http://sitnusa.org/sites/default/files/SITN_Curriculum%20and%20Program%20Development_FINAL_5-31-2012.pdf (accessed November 16, 2012).

iSeek . 2012. Wind Careers Path [online]. Available: http://www.iseek.org/industry/energy/careers/careers-in-wind.html (accessed September 11, 2012).

Ismail, N., and J. Haight. 2010. Older Workers: Asset or Liability for Your Company? The Case Study of Metal and Nonmetal Mines. Proceedings of American Society of Safety Engineers Professional Development Conference, June 13-16, Baltimore, MD, Session #731.

Jennejohn, D. 2010. Green Jobs Through Geothermal Energy. Geothermal Energy Association, Washington, DC [online]. Available: www.geo-energy.org/pdf/reports/GreenJobs_Through_Geothermal_Energy_Final_Oct2010.pdf (accessed March 31, 2012).

Jennejohn, D. 2011. Annual U.S. Geothermal Power Production and Development Report. Geothermal Energy Association, Washington, DC [online]. Available: geo-energy.org/pdf/reports/April2011AnnualUSGeothermalPowerProductionandDevelopmentReport.pdf (accessed on March 25, 2012).

Johnson, L. A., and E. D. Walker. 2010. Oil Production Waste Stream, a Source of Electrical Power. SGP-TR-188. Proceedings Thirty-Fifth Workshop Geothermal Reservoir Engineering, February 1-3, 2000, Stanford, CA [online]. Available: https://pangea.stanford.edu/ERE/pdf/IGAstandard/SGW/2010/johnson.pdf (accessed March 25, 2012).

Kagel, A. 2006. A Handbook on the Externalities, Employment, and Economics of Geothermal Energy. Geothermal Energy Association, Washington, DC [online]. Available: www.geo-energy.org/reports/Socioeconomics%20Guide.pdf (accessed March 31, 2012).

Keane, C. 2005. What Changes Are Afoot, Geoscience Departments: Developing Pathways to Strong Programs for the Future Website [online]. Available: http://serc.carleton.edu/departments/professional/keane05/changes.html (accessed May 8, 2012).

Kelly, J. 2011. DOE Small Reactor Program. Presentation at Small Modular Reactor Conference, March 29, Washington, DC [online]. Available: http://www.nrc.gov/reading-rm/doc-collections/commission/slides/2011/20110329/kelly-20110329.pdf (accessed July 5, 2012).

KEMA, Inc. 2008. The U.S. Smart Grid Revolution: KEMA's Perspectives for Job Creation. Prepared for GridWise Alliance [online]. Available:

http://www.smartgridnews.com/artman/uploads/1/KEMA_s_Perspectives_for_Job_Creation.pdf (accessed September 13, 2012).

King, P. 2011. Education: Texas Tech Wind Degree Takes Off. Texas Tech University, Media Room, November 30 [online]. Available: http://www.depts.ttu.edu/uc/omr/articles.php?id=224 (accessed January 16, 2012).

Kowalenko, K. 2011. The Smart Grid: A Primer [online]. Available: http://www.ieee-isgtla.org/smart-grids.html (accessed August 28, 2012).

Kramer, D. A., J. F. Papp, N. M. LaTurno, and J. Gambogi. 2013. Mine and Mineral Processing Plant Locations—Supplemental Information for USGS Map I-2654. Available: http://minerals.usgs.gov/minerals/pubs/mapdata/#map (accessed February 4, 2013).

Kuuskraa, V., T. Van Leewen, and M. Wallace. 2011. Improving Domestic Energy Security and Lowering CO_2 Emissions with “Next Generation” CO_2-Enhanced Oil Recovery (CO_2-EOR). DOE/NETL-2011/1504. U.S. Department of Energy, National Energy Technology Laboratory [online]. Available: http://www.netl.doe.gov/energy-analyses/pubs/NextGen_CO2_EOR_06142011.pdf (accessed August 10, 2012).

L’Ecuyer, M., C. Zoi, and J. S. Hoffman. 1993. Space Conditioning: The Next Frontier. EPA 430-R-93-004. Office of Air and Radiation, U.S. Environmental Protection Agency, Washington, DC.

Lowry, D., S. Molloy, and Y. Tan. 2006. The Labour Force Outlook in the Minerals Resources Sector: 2005 to 2015. National Institute of Labour Studies, Flinders University, Adelaide, Australia. Available: http://www.flinders.edu.au/sabs/nils-files/reports/MCA_Final.pdf (accessed February 4, 2013).

LtGovernors.com. 2012. Geothermal Resource Descriptions [online]. Available: http://energy.ltgovernors.com/geothermal-resource-descriptions.html (accessed September, 2012).

Lund, J. W., K. Gawell, T. L. Boyd, and D. Jennejohn. 2010. The United States of America Country Update 2010. Proceedings World Geothermal Congress 2010, April 25-29, Bali, Indonesia. [online]. Available: www.geothermal-energy.org/pdf/IGAstandard/WGC/2010/0102.pdf (accessed March 25, 2012).

MA Executive Office of Labor and Workforce Development. 2010. Career Moves: Your Guide to Growing Job Opportunities in Massachusetts [online]. Available: http://archives.lib.state.ma.us/bitstream/handle/2452/50195/ocn663905461.pdf?sequence=3 (accessed September 14, 2012).

Maitra, A. 2003. Distribution Reliability Indices Tracking Within the United States. Palo Alto, CA: Electric Power Research Institute.

Manufacturing Institute. 2011. Manufacturers’ National Talent Solution [online]. Available: http://www.themanufacturinginstitute.org/About/Institute-Presentations/~/media/0F4196C96EC245A18D6FDEEAF334C543.ashx (accessed August 8, 2012).

Manufacturing Institute. 2012. Dream It! Do It! Education and Workforce [online]. Available: http://www.themanufacturinginstitute.org/Education-Workforce/Dream-It-Do-It/Map/Map.aspx (accessed August 23, 2012).

Margolis, K. A. 2010. Underground coal mining injury: A look at how age and experience relate to days lost from work following an injury. Safety Science 48(4):417-421.

MCA (Minerals Council of Australia). 2012. Workforce Skills, Education & Training: Priorities and Principles of the Australian Minerals Industry [online]. Available: http://www.minerals.org.au/file_upload/files/publications/MCA%20Policy%20Brief%204-2012%20-%20Workforce%20skills%20education%20%20training.pdf (accessed February 3, 2013).

McCarter, M. K. 2007. Mining faculty in the United States: Current status and sustainability. Mining Engineering 50(9):28-33 [online]. Available: http://www.redorbit.com/news/education/1079018/mining_faculty_in_the_united_states_current_status_and_sustainability/ (accessed May 31, 2012).

National Institute for Occupational Safety and Health [online]. Available: http://www.cdc.gov/niosh/mining/UserFiles/works/pdfs/2012-152.pdf (accessed January 25, 2012).

McMahon, F., and M. Cervantes. 2010. Survey of Mining Companies 2009/2010, 2010 Mid-Year Update. Fraser Institute, Vancouver, BC. August 2010 [online]. Available: http://www.fraserinstitute.org/uploadedFiles/fraser-ca/Content/research-news/research/publications/miningsurvey-2010update.pdf (accessed June 6, 2012).

McWilliams, L. J., P. J. Lenart, J. L. Lancaster, and J. R. Zeiner, Jr. 2012. National Survey of the Mining Population, Part 1: Employees. NIOSH Information Circular 9527,Melzer, L. S. 2012. Carbon Dioxide Enhanced Oil Recovery (CO_2 EOR): Factors Involved in Adding Carbon Capture, Utilization and Storage (CCUS) to Enhanced Oil Recovery [online]. Available: http://neori.org/Melzer_CO2EOR_CCUS_Feb2012.pdf (accessed August 10, 2012).

Menzie, W. D., J. H. DeYoung, Jr., and W. G. Steblez. 2003. Some implications of changing patterns of mineral consumption. USGS Open-File Report 03-382, U.S. Geological Survey, Reston, VA [online]. Available: http://pubs.usgs.gov/of/2003/of03-382/of03-382.pdf (accessed February 1, 2013).

Messenger, R. A., and J. Ventre. 2010. *Photovoltaic Systems Engineering*, 3rd Ed. Boca Raton, FL: CRC Press.

MII (Mineral Information Institute). 2012a. Metal & Mineral Products Used to Make a Solar Panel. Solar Panel Fact Sheet [online]. Available: http://www.mii.org/pdfs/Solar-Panel.pdf (accessed July 12, 2012).

MII (Mineral Information Institute). 2012b. What Is in My Cell Phone? Cell Phone Fact Sheet [online]. Available: http://www.mii.org/pdfs/Cell-Phone.pdf (accessed July 12, 2012).

MII (Mineral Information Institute). 2012c. What Mineral Products & Metals Are Needed to Make Wind Turbines? Wind Turbines Fact Sheet [online]. Available: http://www.mii.org/pdfs/Wind-Turbines.pdf (accessed July 12, 2012).

Mints, P. 2008. Global Potential for Solar Electricity, A Supply and Demand Perspective. Presentation at PV Technology to Change the World, October 2 [online]. Available: http://ewh.ieee.org/r6/scv/eds/slides/20081002-Paula-Mints-Navigant.pdf (accessed July 19, 2012).

Mints, P. 2011. Price, Technology, and the Illusion of Control [online]. Available**:** http://www.renewableenergyworld.com/rea/news/article/2011/04/price--technology (accessed July 19, 2012).

MIT (Massachusetts Institute of Technology). 2010. The Future of the Nuclear Fuel Cycle [online]. Available: http://web.mit.edu/mitei/docs/spotlights/nuclear-fuel-cycle.pdf (accessed July 5, 2012).

MIT (Massachusetts Institute of Technology). 2011. The Future of the Electric Grid: An Interdisciplinary MIT Study [online]. Available: http://web.mit.edu/mitei/research/studies/documents/electric-grid-2011/Electric_Grid_Full_Report.pdf (accessed April 19, 2012).

MSHA (Mine Safety and Health Administration). 2011a. Mine Injury and Worktime, Quarterly: January-December 2010, Final Report. U.S. Department of Labor, Mine Safety and Health Administration [online]. Mining Industry Accident, Injuries, Employment, and Production Data: Address/Employment Self-Extracting Files. U.S. Department of Labor, Mine Safety and Health Administration [online]. Available: http://www.msha.gov/STATS/PART50/P50Y2K/AETABLE.HTM (accessed July 27, 2012).

MSHA (Mine Safety and Health Administration). 2011b.Available: http://www.msha.gov/Stats/Part50/WQ/MasterFiles/MIWQ%20Master_20105.pdf (accessed July 25, 2012).

MSHA (Mine Safety and Health Administration). 2012a. Accident Prevention Alert. Safety Flyers [online]. Available: http://www.msha.gov/alerts/safetyflyers/APA22012Experience.pdf (accessed August 20, 2012).

MSHA (Mine Safety and Health Administration). 2012b. Coal Fatalities for 1900 through 2011 [online]. Available: http://www.msha.gov/stats/centurystats/coalstats.asp (accessed April 18, 2012).

MSHA (Mine Safety and Health Administration). 2012c. Metal/Nonmetal Fatalities for 1900 through 2011 [online]. Available: http://www.msha.gov/stats/centurystats/mnmstats.asp (accessed April 18, 2012).

MSHA (Mine Safety and Health Administration). 2012d. Mining Industry Accident, Injuries, Employment, and Production Data Address/Employment Self-Extracting Files [online]. Available: http://www.msha.gov/stats/part50/p50y2k/aetable.htm (accessed August 20, 2012).

Muffler, L. J. P. 1979. Assessment of Geothermal Resources of the United States—1978. U.S. Geological Survey Circular 790 [online]. Available: http://pubs.usgs.gov/circ/1979/0790/report.pdf (accessed August 24, 2012).

Mufson, S. 2012. “Crunch time” at troubled nuclear fuel plant. The Washington Post, January 13 [online]. Available: http://www.washingtonpost.com/business/economy/crunch-time-at-troubled-nuclear-fuel-plant/2011/12/20/gIQAIpUJwP_story.html (accessed July 23, 2012).

NAE (National Academy of Engineering). 2010. Grand Challenges for Engineering [online]. Available: http://www.engineeringchallenges.org/Object.File/Master/11/574/Grand%20Challenges%20final%20book.pdf (accessed January 25, 2013).

NAE/NRC (National Academy of Engineering and National Research Council). 2009. Engineering in the K-12 Education: Understanding the Status and Improving the Prospects.

NAS/NAE/IOM (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine). 2007. Rising Above a Gathering Storm: Energizing and Employing America for a Brighter Economic Future. Washington, D.C.: National Academies Press.

NAS/NAE/IOM (National Academy of Sciences, National Academy of Engineering, and Institute of Medicine). 2010. Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5. Washington, DC: National Academies Press.

Nation, L. 2011. Geosalaries rise almost 8 percent. AAPG Explorer, April. American Association of Petroleum Geologists [online]. Available: http://www.aapg.org/explorer/salarysurvey.cfm (accessed May 8, 2012).

Nation, L. 2012. Geologists’ pay continues upward trend. AAPG Explorer (April) [online]. Available http://www.aapg.org/explorer/2012/04apr/salary_survey0412.cfm (accessed March 14, 2013).

Natural Resources Canada. 2012. Natural Resources Canada Employment information Bulletin, Minerals and Metals Sector. Available: http://www.nrcan.gc.ca/minerals-metals/publications-reports/4477#T1 (accessed February 1, 2013).

NBER (National Bureau of Economic Research, Business Cycle Dating Committee). 2008. Determination of the December 2007 Peak in Economic Activity (rev. December 11). Available: http://www.nber.org/cycles/dec2008.html.

NCEP (National Commission on Energy Policy). 2009. Appendix A: Bechtel report on design and construction. Pp 67-87 in Task Force on America's Future Energy Jobs [online]. (as cited in Berrigan 2009). Available: http://bipartisanpolicy.org/sites/default/files/NCEP%20Task%20Force%20on%20America's%20Future%20Energy%20Jobs%20-%20Final%20Report.pdf.

NCEP (National Commission on Energy Policy). 2010. Task Force on America’s Future Energy Jobs [online]. Available: http://bipartisanpolicy.org/sites/default/files/NCEP%20Task%20Force%20on%20America's%20Future%20Energy%20Jobs%20-%20Final%20Report.pdf (accessed July 17, 2012).

NCES (National Center for Education Statistics). 2010. Classification of Instructional Programs: CIP Code 2010 [online]. Available: http://nces.ed.gov/ipeds/cipcode/resources.aspx?y=55 (accessed September 14, 2012).

NCES/BLS (National Center for Education Statistics and U.S. Bureau of Labor Statistics). 2011. Guidelines for Using the CIP-SOC Crosswalk. Available: http://www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=1&sqi=2&ved=0CDAQFjAA&url=http%3A%2F%2Fwebdata.xwalkcenter.org%2Fftp%2Fdownload%2FSOCCIP2010%2FCIPSOCUsersGuideMarch152011.doc&ei=zsYjUYfgAcXw0gGGwIDwDw&usg=AFQjCNHsI-clz9iYyz0H3KaaTvicGw-rig&bvm=bv.42553238,d.dmg&cad=rja.

NEED.org. 2012. NEED Curriculum Guides—By Grade Level. National Energy Education Development Project [online]. Available: http://www.need.org/Curriculum-Guides-by-Grade-Level (accessed May 23, 2012).

NEI (Nuclear Energy Institute). 2012. Careers and Education [online]. Available: http://www.nei.org/careersandeducation/careersinthenuclearindustry/whatareemployerslookingfor/ (accessed June 13, 2012).

NEORI (National Enhanced Oil Recovery Initiative). 2012. Carbon Dioxide Enhanced Oil Recovery: A Critical Domestic Energy, Economic, and Environmental Opportunity [online]. Available: http://www.neori.org/NEORI_Report.pdf (accessed August 10, 2012).

NERC (North American Electric Reliability Corporation). 2006. Long-Term Reliability Assessment [online]. Available: http://www.nerc.com/files/LTRA2006.pdf (accessed July 17, 2012).

NERC (North American Electric Reliability Corporation). 2007. Long-Term Reliability Assessment 2007-2016 [online]. Available: http://www.nerc.com/files/LTRA2007.pdf (accessed July 17, 2012).

NERC (North American Electric Reliability Corporation). 2009. Long-Term Reliability Assessment 2009-2018 [online]. Available: http://www.nerc.com/files/2009_LTRA.pdf (accessed July 17, 2012).

Nesbit, S. P. 2012. Centralized interim storage: Past, present, and future. Radwaste Solutions 19(5):14-23..

Ness, R. 2011. The Bakken's Big and Growing Workforce Needs. Presentation at the Second Meeting on Emerging Workforce Trends in the U.S. Energy and Mining Industries**,** June 1, Austin, TX.

Newell, R. 2010. Annual Energy Outlook 2011, Reference Case. Early Release Overview. Presentation at The Paul H. Nitze School of Advanced International Studies, December 16 [online]. Available: http://www.eia.gov/neic/speeches/newell_12162010.pdf (accessed September 4, 2012).

NIOSH (National Institute for Occupational Safety and Health). 2012. Older Workers. Office of Mine Safety and Health Research Topic [online]. Available: http://www.cdc.gov/niosh/mining/topics/topicpage10.htm (accessed August 20, 2012).

NIOSH (National Institute for Occupational Safety and Health). 2013. Oil and Gas Extraction, Inputs: Occupational Safety and Health Risks [online]. Available: http://www.cdc.gov/niosh/programs/oilgas/risks.html (accessed January 25, 2013).

NMA (National Mining Association). 2011. Profile of the U.S. Coal Miner—2010 [online]. Available: http://www.nma.org/pdf/c_profile.pdf (accessed August 20, 2012).

North Carolina Wind Working Group. 2008. Benefiting North Carolina Communities with Offshore Wind Farms [online]. Available: http://www.repp.org/articles/static/1/binaries/NC_Economic_Development.pdf (accessed September 11, 2012).

NRC (National Research Council). 2002. Evolutionary and Revolutionary Technologies for Mining. Washington, DC: National Academy Press.

NRC (National Research Council). 2008a. Managing Minerals for a Twenty-first Century Military. Washington, DC: National Academies Press.

NRC (National Research Council). 2008b. Minerals, Critical Minerals, and the U.S. Economy, Washington, DC: National Academies Press.

NRC (National Research Council). 2011. Successful K-12 STEM Education: Identifying Effective Approaches in Science, Technology, Engineering, and Mathematics. Washington, DC: National Academies Press.

NRDC (Natural Resources Defense Council). 2012. U.S. Nuclear Regulatory Commission Halts Nuclear Reactor Licensing Decisions in Response to NRDC Lawsuit [online]. Available: http://www.nrdc.org/nuclear/nrc-waste-confidence-decision.asp#.UKlbjc4MU-Q.email (accessed November 19, 2012).

NREL (National Renewable Energy Laboratory). 2012. SunShot Vision Study. DOE/GO-102012-3037 [online]. Available: http://www1.eere.energy.gov/solar/pdfs/47927.pdf (accessed December 9, 2012).

NSB (National Science Board). 2010. Chapter 1-2 in Science and Engineering Indicators 2010. NSB 10-01. Arlington, VA: National Science Foundation [online]. Available: http://www.nsf.gov/statistics/seind10/pdf/seind10.pdf (accessed June 22, 2012).

Olson, J. E. 2011. Subsurface Engineering Workforce and Education. Presentation at the Third Meeting on Emerging Workforce Trends in the U.S. Energy and Mining Industries, August 23, Golden, CO.

OMB (Office of Management and Budget). 2011. North American Industry Classification System; Revision for 2012; Notice. Federal Register 76(Aug. 17):51240-51243.

OPM (Office of Personnel Management). 2009. Handbook of Occupational Groups and Families [online]. Available: http://www.opm.gov/fedclass/gshbkocc.pdf.

Oregon Green Career Parthways. 2012. Wind Energy [online]. Available: http://www.oregongreenpathways.org/1412/wind-energy-statewide (accessed September 11, 2012).

Pappas, S. 2012. Fukushima disaster chilled opinions on nuclear power. Live Science, March 13 [online]. Available: http://www.livescience.com/19020-fukushima-disaster-nuclear-power.html (accessed July 23, 2012).

Pierce, B. S., and K. O. Dennen. 2009. The National Coal Resource Assessment Overview. Professional Paper 1625-F, U.S. Geological Survey [online]. Available: http://pubs.usgs.gov/pp/1625f/ (accessed May 29, 2012).

Pennsylvania State University. 2012. Africa Array [online]. Available: http://www.africaarray.psu.edu/ (accessed September 5, 2012).

Poulton, M. 2012. Analysis of the Mining Engineering Faculty Pipeline. Presentation at SME Annual Meeting, Seattle, WA, February 20.

Pratt, R. G., P. J. Balducci, C. Gerkensmeyer, S. Katipamula, M. C. W. Kinter-Meyer, T. F. Sanquist, K. P. Schneider, and T. J. Secrest. 2010. The Smart Grid: An Estimation of the Energy and CO2 Benefits. PNNL-19112, Rev. 1, Pacific Northwest National Laboratory [online]. Available: http://energyenvironment.pnnl.gov/news/pdf/PNNL-19112_Revision_1_Final.pdf (accessed July 17, 2012).

Prentice, A. 2011. Most non-Chinese rare earth projects doomed: consultant. Reuters, November 1 [online]. Available: http://www.reuters.com/article/2011/11/01/us-rare-earths-lifton-idUSTRE7A03Q120111101 (accessed June 26, 2012).

PriceWaterhouseCoopers. 2009. The Economic Impacts of the Oil and Natural Gas Industry on the U.S. Economy: Employment, Labor Income and Value Added. Prepared for the American Petroleum Institute [online]. Available: http://www.api.org/newsroom/upload/industry_economic_contributions_report.pdf (accessed May 23, 2012).

Public Utility Commission of Texas. 2010. CREZ Projects [online]. Available: http://www.texascrezprojects.com/projects.aspx (accessed September 11, 2012).

Randazzo, A. 2011. Building a Sustainable Energy Workforce: The Get into Energy Career Pathways Model. Presentation to the Clean Energy Workforce Education Conference, March 10, Saratoga, NY [online]. Available: irecusa.org/wp-content/uploads/2011/03/Randazzo_Plenary.pdf (accessed April 23, 2012).

Ratcliff, D., and E. Snow. 2011. GeoFORCE Texas. Presentation at the Second Meeting on Emerging Workforce Trends in the U.S. Energy and Mining Industries, June 1, Austin, TX.

Raymond, L. R., J. Burkhard, A. Gould, J. J. Hamre, A. J. Kelly, R. F. Nelson, D. J. O'Reilly, D. L. Paul, J. Clay Sell, J. A. Slutz, F. A. Verrastro, and D. H. Yergin. 2007. Hard Truths: Facing the Hard Truths About Energy. National Petroleum Council, Committee on Global Oil and Gas, Washington, DC [online]. Available: http://downloadcenter.connectlive.com/events/npc071807/pdf-downloads/NPC_Facing_Hard_Truths.pdf (accessed May 3, 2012).

Reeves, S. 2005. An aging workforce's effect on U.S. employers. Forbes, September 29 [online]. Available: http://www.forbes.com/2005/09/28/career-babyboomer-work-cx_sr_0929bizbasics.html (accessed August 30, 2012).

Renner, J. L. 2008. Geothermal energy. Pp. 211-223 in Future Energy: Improved, Sustainable and Clean Options for Our Planet, T. M. Letcher, ed. Amsterdam: Elsevier.

Retzer, K., and R. Hill. 2011. Fatal injuries in the upstream oil and gas extraction industry. Well Servicing Magazine (September/October):18-21 [onlin`e]. Available: wellservicingmagazine.com/node/745 (accessed April 19, 2012).

Rio Tinto. 2012. Chartbook [online]. Available: http://www.riotinto.com/documents/investors_databook/Chartbook.pdf (accessed July 26, 2012).

Rivera, C. 2011. SAT scores for class of 2011 decline in every aspect. Los Angeles Times, September 15, 2011/sep/15/nation/la-na-0914-sat-scores-20110915 (accessed June 22, 2012).

Rogich, D. G. and G. R. Matos. 2008. The Global Flows of Metals and Minerals. U.S. Geological Survey Open-File Report 2008-1355 [online]. Available: http://pubs.usgs.gov/of/2008/1355/ (accessed February 4, 2013).

Rousset, J. M., P. Bismuth, and O. Soupa. 2011. Technical talent shortage could begin to limit growth. JPT (June):46-49 [online]. Available: http://www.spe.org/jpt/print/archives/2011/06/13TalentTech.pdf (accessed May 8, 2012).

Runyon, J. 2010. 2011 Outlook for clean energy jobs in the U.S.—beating the trend. Renewable Energy World, November 12 [online]. Available: http://www.renewableenergyworld.com/rea/news/article/2010/11/2011-outlook-for-clean-energy-jobs-in-the-u-s-beating-the-trend (accessed September 11, 2012).

Sampath, R., and M. Robinson. 2005. The Talent Crisis in Upstream Oil & Gas: Strategies to Attract and Engage Generation Y. Deloitte Research [online]. Available: http://www.deloitte.com/assets/Dcom-Canada/Local%20Assets/Documents/CA_ER_TalentCrisisUpstreamOilGas_18_11_2005.pdf (accessed September 4, 2012).

Sarubbi, J., and J. Ventre. 2012. Model Curriculum for Photovoltaic System Installers, World Renewable Energy Forum, May 13-17, Denver, CO [online]. Available: http://ases.conference-services.net/resources/252/2859/pdf/SOLAR2012_0262_full%20paper.pdf (accessed September 15, 2012).

SBC (Schlumberger Business Consulting). 2008. 2008 SBC O&G HR Benchmark, Extract 2008 O&G HR Forum, December 2, Paris [online]. Available: http://www.sbc.slb.com/Our_Work/Consulting_Expertise/Organization_Talent_Management/~/media/Files/HR_Forum/2008%20SBC%20HR%20Forum%20Presentations/2008%20SBC%20OG%20HR%20BenchmarkWebsite%20version.ashx (accessed June 7, 2012).

Scaglione, M. 2011. Presentation at the Third Meeting on Emerging Workforce Trends in the U.S. Energy and Mining Industries, August 22, Golden, CO.

Schill, M. 2008. U.S. Population Distribution, 2010. newgeography.com [online]. Available: http://www.newgeography.com/content/00124-us-population-distribution-2010 (accessed September 4, 2012).

Schott, M. 2011. Engaging a Community for Workforce Development. Presentation at the Second Meeting on Emerging Workforce Trends in the U.S. Energy and Mining Industries**,** June 1, Austin, TX.

SEIA/GTM (Solar Energy Industries Association and GTM Research). 2012a. U.S. Solar Market Insight Report, Q2 2012, Executive Summary [online]. Available: http://www.seia.org/research-resources/solar-market-insight-report-2012-q2 (accessed February 4, 2013).

SEIA/GTM (Solar Energy Industries Association and GTM Research). 2012b. U.S. Solar Market Insight Report, Q3 2012, Executive Summary [online]. Available: http://www.seia.org/research-resources/solar-market-insight-report-2012-q3 (accessed March 14, 2013).

Sherwood, L. 2011. U.S. Solar Market Trends 2010. Interstate Renewable Energy Council [online]. Available: http://irecusa.org/wp-content/uploads/2011/06/IREC-Solar-Market-Trends-Report-June-2011-web.pdf (accessed July 23, 2012).

Sherwood, L. 2012. U.S. Solar Market Trends 2011. Interstate Renewable Energy Council [online]. Available: http://www.irecusa.org/wp-content/uploads/IRECSolarMarketTrends-2012-Web-8-28-12.pdf (accessed December 9, 2012).

SME (Society of Mining, Metallurgy, and Exploration). 2007. SME Guide to Mineral and Material Science Schools. Littleton, Colo.: Society for Mining, Metallurgy and Exploration (SME).

SME (Society of Mining, Metallurgy, and Exploration). 2011. SME Guide to Mineral Schools 2011. Littleton, Colo.: Society for Mining, Metallurgy and Exploration (SME).

Sommers, D., and J. C. Franklin. 2012. Overview of projections to 2020. Monthly Labor Review 135(1):3-20 [online]. Available: http://www.bls.gov/opub/mlr/2012/01/art1full.pdf (accessed September 14, 2012).

Stephens, J. 2011. Protect Your New Workers. Presentation from the Texas Oil and Gas Association (TxOGA) Worker's Comp Purchasing Group to the Permian Basin STEPS Network, August, Midland, TX.

Sullivan, D., M. Osiadacz, T. Murphree, L. Rosenfeld, S. Smith, and B. Ford. 2009. Understanding and Predicting Changes in the Ocean Science, Technology, and Operations Workforce: Summary of Results and Recommendations. Presentation to the Joint Subcommittee on Ocean Science and Technology Webinar October 13, 2009 [online]. Available: www.marinetech.org/OSTO/webinar/ (accessed April 11, 2012).

Sum, A., I. Khatiwada, J. McLaughlin, and S. Palma. 2009. The Consequences of Dropping Out of High School, Northeastern University, Boston, MA [online]. Available: http://www.northeastern.edu/clms/wp-content/uploads/The_Consequences_of_Dropping_Out_of_High_School.pdf (accessed June 27, 2012).

Swift, A. 2012. Workforce and Education for the Wind Energy Industry. Presentation at American Meteorological Society—Washington Forum, April 11 [online]. Available: http://www.ametsoc.org/boardpges/cwce/docs/profiles/SwiftAndrew/2012-04-AWF.pdf (accessed May 4, 2012).

Tester, J. W., B. J. Anderson, A. S. Batchelor, D. B. Blackwell, R. DiPippo, E. L. Drake, J. Garnish, B. Livesay, M. C. Moore, K. Nichols, S. Petty, M. N. Toksöz, and R. W. Veatch, Jr. 2006. The Future of Geothermal Energy, Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century. External Report INL/EXT-06-11746. Idaho National Laboratory, Idaho Falls, ID [online]. Available: www.inl.gov/technicalpublications/Documents/3589644.pdf (accessed March 25, 2012).

Tilton, J. E. 2003. Creating wealth and competitiveness in mining. *Mining Engineering* 55(9):15-21.

Toossi, M. 2012. Labor force projections to 2020: A more slowly growing workforce. Monthly Labor Review 135(1):43-64.

TSF (The Solar Foundation). 2010. National Solar Job Census 2010: A Review of the U.S. Solar Workforce. The Solar Foundation, Green LMI Consulting, Inc., and Cornell University [online]. Available: thesolarfoundation.org/research/national-solar-jobs-census (accessed July 18, 2012).

TSF (The Solar Foundation). 2011. National Solar Job Census 2011: A Review of the U.S. Solar Workforce. The Solar Foundation, Green LMI Consulting, Inc., and Cornell University [online]. Available: thesolarfoundation.org/research/national-solar-jobs-census-2011 (accessed April 23, 2012).

TSF (The Solar Foundation). 2012. National Solar Job Census 2012: A Review of the U.S. Solar Workforce. The Solar Foundation, Green LMI Consulting, Inc., and Cornell University [online]. Available: http://thesolarfoundation.org/sites/thesolarfoundation.org/files/TSF%20Solar%20Jobs%20Census%202012%20Final.pdf (accessed December 9, 2012).

UAF (University of Alaska Fairbanks). 2012. GeoForce Alaska. Rural Alaska Honors Insitute [online]. Available: http://www.uaf.edu/rahi/geoforce-alaska/ (accessed October 18, 2012).

Upstill, G., and P. Hall, 2006. Innovation in the minerals industry. *Resource Policy* 31(3):137-145.

URENCO. 2012. Building and Operating URENCO USA [online]. Available: http://www.urenco.com/Content/33/LES.aspx (accessed August 9, 2012).

U.S. Department of Energy. 2009. Energy Innovation and Workforce Development: Strengthening Education and Training in the Subsurface Geosciences and Engineering for Energy Development. Document END09412. Available at http://www.energy.senate.gov/public/index.cfm/files/serve?File_id=445ef86d-0ac5-33f1-17f3-7256a980ad8f (accessed June 26, 2012).

U.S. Department of Labor. 2010. Advanced Manufacturing Competency Model. U.S. Department of Labor, Employment and Training Administration [online]. Available: http://www.careeronestop.org/competencymodel/Info_Documents/Advanced-Manufacturing.pdf (accessed August 8, 2012).

USGS (U.S. Geological Survey). 2001. Mineral Commodity Summaries 2000 [online]. Available: http://minerals.usgs.gov/minerals/pubs/mcs/2001/mcs2001.pdf (accessed July 25, 2012).

USGS (U.S. Geological Survey). 2002. Rare Earth Elements—Critical Resources for High Technology. Fact Sheet 087-02 [online]. Available: http://pubs.usgs.gov/fs/2002/fs087-02/ (accessed July 25, 2012).

USGS (U.S. Geological Survey). 2006. Recycled Cell Phones: A Treasure Trove of Valuable Metals. Fact Sheet 2006-3097 [online]. Available: http://pubs.usgs.gov/fs/2006/3097/fs2006-3097.pdf (accessed November 15, 2012).

USGS (U.S. Geological Survey). 2011. Mineral Commodity Summaries 2011 [online]. Available: http://minerals.usgs.gov/minerals/pubs/mcs/2011/mcs2011.pdf (accessed May 31, 2012).

USGS (U.S. Geological Survey). 2012. National GIS Data [online]. Available: http://energy.cr.usgs.gov/oilgas/noga/data.html (accessed August 30, 2012).

USGS (U.S. Geological Survey). 2013, 2013a. Mineral Commodity Summaries 2013. Available: http://minerals.usgs.gov/minerals/pubs/mcs/2013/mcs2013.pdf (accessed February 1, 2013).

USNRCUSGS, 2013b. Mine and Mineral Processing Plant Locations--Supplemental Information for USGS Map I-2654 [online]. Available: http://minerals.usgs.gov/minerals/pubs/mapdata/ (accessed February 8, 2013)

USNRC (U.S. Nuclear Regulatory Commission). 2011a. Expected New Nuclear Power Plant Applications [online]. Available: http://www.nrc.gov/reactors/new-reactors/new-licensing-files/expected-new-rx-applications.pdf (accessed August 9, 2012).

USNRC (U.S. Nuclear Regulatory Commission). 2011b. Decommissioning Nuclear Power Plants. Fact Sheet [online]. Available: http://www.nrc.gov/reading-rm/doc-collections/fact-sheets/decommissioning.html (accessed July 24, 2012).

USNRC (U.S. Nuclear Regulatory Commission). 2012. Reactor License Renewal Overview [online]. Available: http://www.nrc.gov/reactors/operating/licensing/renewal/overview.html (accessed July 24, 2012).

USPREF (U.S. Partnership for Renewable Energy Finance). 2012. Clean Energy and Tax Reform: How Tax Policy Can Help Renewable Energy Contribute to Economic Growth, Energy Security and a Balanced Budget [online]. Available: http://uspref.org/wp-content/uploads/2012/06/Clean-Energy-and-Tax-Reform-White-Paper.pdf (accessed July 19, 2012).

UT (University of Texas). 2011. GeoForce Texas Jackson School of Geosciences [online]. Available: http://www.jsg.utexas.edu/geoforce/ (accessed September 5, 2012).

Ventre, J., and J. Weissman. 2009. PV Workforce Development: A Survey of Industry Needs and Training Approaches. Presentation at the Third New Ideas in Educating a Workforce in Renewable Energy and Energy Efficiency Conference, November 18-20, Albany, NY.

Vest, C. M. 2011. Engineers: The Next Generation—Do We Need More? Who Will They Be? What Will They Do? President's Address at NAE Annual Meeting, October 16, Washington, DC [online]. Available: http://www.nae.edu/Activities/Events/AnnualMeetings/19611/53074.aspx (accessed August 8, 2012).

Virginia Center for Coal and Energy Research. 2008. Meeting Projected Coal Production Demands in the

U.S.A.: Upstream Issues, Challenges, and Strategies [online]. Available: http://bipartisanpolicy.org/sites/default/files/meeting%20projected%20coal%20production%20demands.pdf (accessed November 15, 2012).

Voinovich School of Leadership and Public Affairs. 2011. Green Jobs and Ohio Economy, Part 4. Education and Training Programs. Ohio University, The Voinovich School of Leadership and Public Affairs [online]. Available: http://ohiolmi.com/green/reports/Pt4EdTraining.pdf (accessed September 11, 2012).

Wade, L.V., J. Kohler, M. Sapko, and A. Morantz. 2012. An Independent Panel Assessment of an Internal Review of MSHA Enforcement Actions at the Upper Big Branch Mine South. Report to the U.S. Department of Labor, March 22 [online]. Available: www.msha.gov/PerformanceCoal/NIOSH/Independent%20Assessment%20Panel%20Report%20w_Errata.pdf (accessed April 11, 2012).

Wallace, R. 1976. The Miners. New York: Time-Life Books.

WebCASPAR. 2012. National Center for Education Statistics (NCES) Data Sources: Integrated Postsecondary Education Data System (IPEDS) Completions Survey [online]. Available: https://webcaspar.nsf.gov/ (accessed September 17, 2012).

Weeks, J. 2010. U.S. electrical grid undergoes massive transition to connect to renewables. Scientific American, April 28 [online]. Available: http://www.scientificamerican.com/article.cfm?id=what-is-the-smart-grid (accessed July 17, 2012).

WGA (Western Governors' Association). 2006. Clean and Diversified Energy Initiative: Geothermal Task Force Report [online]. Available: http://www.westgov.org/reports?start=24 (accessed on March 31, 2012).

White House. 2009. Cyberspace Policy Review: Assuring a Trusted and Resilient Information and Communications Infrastructure, [online]. Available: http://www.whitehouse.gov/assets/documents/Cyberspace_Policy_Review_final.pdf (accessed April 23, 2012).

White House. 2011. The President's Plan for a 21st Century Electric Grid. Fact Sheet [online]. Available: http://www.whitehouse.gov/sites/default/files/microsites/ostp/smart-grid-fact-sheet-6-13-2011.pdf (accessed April 23, 2012).

White House. 2012. Interagency Rapid Response Team for Transmission [online]. Available: http://www.whitehouse.gov/administration/eop/ceq/initiatives/interagency-rapid-response-team-for-transmission (accessed April 23, 2012).

Wilburn, D. R. 2011. Wind Energy in the United States and Materials Required for the Land-Based Wind Turbine Industry from 2010 through 2030. U.S. Geological Survey Scientific Investigations Report 2011-5036 [online]. Available: http://pubs.usgs.gov/sir/2011/5036/sir2011-5036.pdf (accessed May 21, 2012).

Williams, C. F., M. J. Reed, R. H. Mariner, J. DeAngelo, and S. P. Galanis, Jr. 2008. Assessment of Moderate- and High-Temperature Geothermal Resources of the United States. U.S. Geological Survey Fact Sheet 2008-3082 [online]. Available: pubs.usgs.gov/fs/2008/3082/pdf/fs2008-3082.pdf (accessed March 31, 2012).

Willrich, M. 2009. Electricity Transformation Policy for America: Enabling a Smart Grid, End-to-End. MIT-IPC-Energy Innovation Working Paper 09-003. Massachusetts Institute of Technology [online]. Available: http://web.mit.edu/ipc/research/energy/pdf/EIP_09-003.pdf (accessed April 20, 2012).

Windustry. 2012. Where Can I Find a School or Training Program Specific to Renewable Energy? Windustry [online]. Available: http://www.windustry.org/where-can-i-find-a-school-or-training-program-specific-to-renewable-energy (accessed September 12, 2012).

Wiser, R., and M. Bolinger. 2011. 2010 Wind Technologies Market Report. U.S. Department of Energy, Energy Efficiency and Renewable Energy [online]. Available: http://www1.eere.energy.gov/wind/pdfs/51783.pdf (accessed May 21, 2012).

Wittholz, H., and D. Pan. 2004. A Study of Supply Chain Capabilities in the Canadian Wind Power Industry. Industry Canada, Ottawa, Ontario [online]. Available: http://www.oreg.ca/docs/Wind%2520Power-Final%2520Rpt-edited.pdf (accessed May 21, 2012).

Woods, R. A. 2009. Employment outlook: 2008-2018 Industry output and employment projections to 2018. Monthly Labor Review. Available; http://www.bls.gov/opub/mlr/2009/11/art4full.pdf (accessed February 1, 2013).

World Nuclear Association. 2012a. Nuclear Power in the World Today [online]. Available: http://www.world-nuclear.org/info/inf01.html (accessed June 15, 2012).

World Nuclear Association. 2012b. Small Nuclear Power Reactors [online]. Available: http://www.world-nuclear.org/info/default.aspx?id=534&terms=SMR (accessed June 15, 2012).

World Nuclear Association. 2012c. U.S. Nuclear Fuel Cycle [online]. Available: http://www.world-nuclear.org/info/default.aspx?id=25739&terms=National%20Enrichment%20Facility (accessed August 9, 2012).

World Nuclear Association. 2012d. World Nuclear Power Reactors & Uranium Requirements [online]. Available: http://www.world-nuclear.org/info/reactors.html (accessed July 24, 2012).

EMERGING WORKFORCE TRENDS IN THE U.S. ENERGY AND MINING INDUSTRIES: A CALL TO ACTION

APPENDIXES

Appendixes A-E are available online at http://www.nap.edu/catalog.php?record_id=18250 and will be available upon release of the report.

A

Overview of the Federal Data Sources Most Relevant to the Energy and Mining Workforce

This appendix describes and evaluates the federal data sources that are most relevant to examining the energy and mining workforce. The appendix focuses heavily on information available from the Bureau of Labor Statistics (BLS) because it is the primary source of federally collected workforce information. Information from the Census Bureau, the Employment and Training Administration, the Mine Safety and Health Administration, and the National Center for Education Statistics is also discussed. Table A.1 at the end of Appendix A provides a high-level summary of the federal data sources that are most relevant to understanding the energy and mining workforce. The table outlines the information available in each source that is most pertinent to energy and mining, as well as the coverage or scope of the information, the periodicity of data releases, the method of data collection, and the primary use of the information. Although there is some degree of overlap in the information available in these data sources, each source serves a unique purpose. (Web addresses are provided in footnotes for each data source so that the reader can find more detailed information about the sources and data.)

CURRENT EMPLOYMENT STATISTICS[1]

The BLS Current Employment Statistics program conducts a monthly survey of approximately 141,000 establishments and provides the first indicator of current employment, hours, and earnings for the nation, states, and major metropolitan areas. The survey reflects workers covered by unemployment insurance laws (both private and public sector). To account for month-to-month changes in employment, hours, and earnings that are due to normal seasonal variation, estimates are also available on a seasonally adjusted basis. The program provides information for the private sector at a detailed industry level using the North American Industry Classification System (NAICS).[2] Thus, the program can be used to collect timely private-sector employment, hours, and earnings estimates for energy and mining industries. Government information is provided at the federal, state, and local government levels, but with very limited detail within each sector. Information is not available by occupation. The primary advantage of the information available through the Current Employment Statistics program is its timeliness—estimates for a given reference month are typically available early the next month. However, because of the speed with which the information is produced, estimates from the program

[1] For additional information on Current Employment Statistics, see http://www.bls.gov/ces/.
[2] For more information on the NAICS, see http://www.census.gov/eos/www/naics/.

undergo subsequent revisions to account for information that was not available at the time the initial information was released.

CURRENT POPULATION SURVEY[3]

The BLS Current Population Survey is a monthly survey of 60,000 households. The survey is conducted for the BLS by the Census Bureau and covers wage and salary workers, self-employed workers, and unpaid workers who worked 15 hours or more during the reference week in a family-operated enterprise. The survey's primary use is to provide a comprehensive look at the labor force, supplying information on both the employed and the unemployed, including information such as age, gender, race/ethnicity, veteran status, and educational attainment. Information is available by industry and by occupation, although the level of industry and occupational detail available by demographic characteristic varies. Unlike most other Bureau of Labor Statistics programs, the Current Population Survey uses the Census industry classification system to report information by industry. This system is based on the more often used NAICS taxonomy, although there is not a one-to-one mapping.[4] Similarly, the Current Population Survey uses the Census occupational classification system to report information by occupation. This system is based on the more commonly used Standard Occupation Code (SOC) taxonomy, but again, there is not a one-to-one mapping between the two.[5]

JOB OPENINGS AND LABOR TURNOVER SURVEY[6]

The BLS Job Openings and Labor Turnover Survey is a monthly survey of 16,000 establishments. The survey yields estimates of job openings, hires, and separations by industry and region. These estimates can be used to assess the existence of short-term labor shortages. However, because industry information is available only at a very high level (e.g., mining and logging; construction) and information is not available by occupation, these estimates are of limited value in understanding potential labor shortages in specific energy and mining industries and occupations.

QUARTERLY CENSUS OF EMPLOYMENT AND WAGES[7]

The BLS Quarterly Census of Employment and Wages provides a comprehensive view of employment and wages by industry. Unlike other BLS programs discussed in this appendix, the Quarterly Census of Employment and Wages is based on a census rather than on a survey. The program is a census of all workers covered by unemployment insurance laws (both private and

---

[3] For additional information on the Current Population Survey, see http://www.bls.gov/cps/home.htm.
[4] A crosswalk between the Census industry classification system and the NAICS taxonomy can be found at http://www.bls.gov/cps/cpsoccind.htm.
[5] A crosswalk between the Census occupation classification system and the SOC system can be found at http://www.bls.gov/cps/cpsoccind.htm.
[6] For additional information on the Job Openings and Labor Turnover Survey, see http://www.bls.gov/jlt/home.htm.
[7] For additional information on the Quarterly Census of Employment and Wages, see http://www.bls.gov/cew/home.htm.

public sector) and is based on quarterly tax reports submitted by establishments. In 2010, information was provided by more than 9 million establishments.[8] The best feature of the program is that it provides employment and wage information at the 6-digit NAICS code level—the lowest level of industry detail possible under the NAICS taxonomy.

OCCUPATIONAL EMPLOYMENT STATISTICS[9]

The BLS Occupational Employment Statistics program produces annual employment and wage estimates for the 800+ occupations that are part of the SOC system. Estimates include nonfarm wage and salary workers and are based on a survey of 1.2 million establishments conducted over a 3-year period. Using the NAICS taxonomy, the program also provides private-sector industry-specific employment estimates by occupation. For a variety of reasons (e.g., changes in occupational classification systems, changes in the survey reference period, and multiple years of data used to produce estimates), the BLS does not recommend using Occupational Employment Statistics data for time-series analyses (e.g., examining occupational employment over time). In terms of examining the energy and mining workforce, this program is useful for identifying the occupations that are most prevalent in a specific energy and mining industry and their corresponding wages.

EMPLOYMENT PROJECTIONS PROGRAM[10]

The BLS Employment Projections program produces 10-year labor market projections for the nation. The projections, which are updated every other year, are designed to reflect long-term trends in the economy. The program includes wage and salary workers, self-employed workers, and unpaid family workers. The most recent projections are for 2020 (using a base year of 2010). The program generates the following projections:

- Labor force,
- Aggregate economy and final demand (GDP),
- Industry output,
- Industry employment, and
- Employment and job openings by occupation.

The Employment Projections program classifies industries using the NAICS taxonomy and classifies occupations using the SOC system. Employment projections are also available by a combination of industry and occupation, although these projections include only private-sector wage and salary workers. The projections of job openings are not available by industry. Industry employment and employment and job openings by occupation are the most useful projections for examining the energy and mining workforce. Specifically, these projections are useful for

[8] *Employment and Wages Online Annual Averages, 2010*, Bureau of Labor Statistics, Quarterly Census of Employment and Wages (see http://www.bls.gov/cew/cewbultn10.htm).
[9] For additional information on Occupational Employment Statistics, see http://www.bls.gov/oes/home.htm.
[10] For additional information on the Employment Projections program, see http://www.bls.gov/emp/home.htm.

understanding which energy and mining industries are expected to experience increases in the demand for talent over the coming decade and in what specific occupations.[11]

AMERICAN COMMUNITY SURVEY[12]

The American Community Survey is a survey conducted by the Census Bureau that collects information from about 3 million households annually. The survey provides estimates of the characteristics of the population for the nation, states, cities, and counties, including demographic, social, economic, and housing characteristics. Unlike the BLS programs discussed above, the American Community Survey was not designed specifically to capture information about the labor force. However, the survey includes questions that allow for the generation of labor force estimates. Moreover, the survey provides industry information using the NAICS taxonomy and occupation information using the SOC taxonomy, which enables the generation of labor force estimates by industry and occupation. However, the level of detail available by industry and by occupation varies. For example, the utility system construction industry is included in the "construction" industry, and nuclear engineers are included in the "miscellaneous engineers" occupation. The primary advantage of the American Community Survey is the ability to generate estimates for small geographic areas, thus allowing communities to use the information for decision-making purposes.

O*NET[13]

The Employment and Training Administration's O*Net database is the nation's primary source of detailed occupational information. The information in the database comes from worker surveys as well as occupation experts and analysts. The 900+ occupations in the database are based on the SOC system, although there is not a one-to-one mapping between the two. Specifically, the O*Net database separates some SOC codes into multiple occupations. For example, rather than provide information on geological and petroleum technicians, an occupation that is part of the SOC system, O*Net separates this occupation into two more detailed occupations: geophysical data technicians and geological sample test technicians. The database contains information on the knowledge, skills, and abilities, tasks, work activities, experience, educational requirements, and tools and technology associated with a given occupation. An updated version of the O*Net database is typically released annually, although information on any given occupation is updated on an as-needed basis (i.e., only a subset of occupations are updated as part of each new release).

---

[11] For additional information on projection methods and uncertainty considerations, please refer to http://www.bls.gov/opub/mlr/2012/01/art1full.pdf and http://www.bls.gov/opub/hom/homch13.htm.
[12] For additional information on the American Community Survey, see http://www.census.gov/acs/www/.
[13] For additional information on O*NET, see http://www.onetcenter.org/.

MINE INJURY AND WORKTIME REPORTS[14]

Through its Mine Injury and Worktime Reports, the Mine Safety and Health Administration provides information on employment, hours worked, and injuries for coal and mineral mining operators and contractors. The information includes "personnel directly engaged in production, cleaning, milling, shipping, development, and maintenance and repair work, including direct supervisory and technical personnel and contract mining services."[15] The figures are compiled from reports submitted by operators and contractors as required under the Federal Mine Safety and Health Act of 1977, Public Law 91-173 as amended by Public Law 95-164. The primary use of this information is to help ensure safety and health in the nation's mining industry.[16] In terms of using this information to examine the mining workforce, the primary advantage it has over the information provided by the various BLS programs discussed earlier is that it reflects both mining operators and mining contractors; the latter are generally undercounted in BLS data because of the nature of the NAICS.[17]

INTEGRATED POSTSECONDARY EDUCATION DATA SYSTEM[18]

The National Center for Education Statistics' Integrated Postsecondary Education Data System (IPEDS) gathers information from all U.S. educational institutions—colleges, universities, technical schools, and vocational schools—that participate in any federal student financial aid program, representing more than 6,700 institutions. In addition to information on the number of degrees and certificates conferred (i.e., completions) by degree level and field of study, the survey collects a wide variety of information from these institutions, such as institutional characteristics, enrollment, student financial aid, student persistence and success, and institutional resources. Moreover, information on completions is available by gender, race/ethnicity, and citizenship status. IPEDS reports instructional program information using the Classification of Instructional Programs (CIP) taxonomy, which includes more than 1,200 programs.[19] For examining the energy and mining workforce, the IPEDS database is most useful for tracking the supply of new graduates receiving degrees or certificates in fields of study that feed into energy and mining occupations. The CIP-SOC crosswalk, which relates instructional programs to occupations, can be used to identify the specific programs that refeed into energy and mining occupations.

[14] For additional information on the Mine Injury and Worktime Reports, see http://www.msha.gov/accinj/accinj.htm.
[15] *Mine Injury and Worktime, Quarterly, January – December 2010*, U.S. Department of Labor, Mine Safety and Health Administration, p. 2.
[16] In addition, the National Institute of Occupational Safety and Health Office of Mine Safety and Health Research uses the Mine Safety and Health Administration data to produce databases specific to the mining industry in a user-friendly format, which are available for research and other purposes. Information on the mining databases is available at http://www.cdc.gov/niosh/mining/works/default.html.
[17] See Appendix B for a more detailed discussion of the shortcomings of using BLS data to examine the energy and mining workforce.
[18] For additional information on the Integrated Postsecondary Education Data System, see http://nces.ed.gov/ipeds/.
[19] A complete list of CIP codes is available at http://nces.ed.gov/ipeds/cipcode/default.aspx?y=55.

A POSSIBLE RESEARCH INITIATIVE FOR FUTURE DECISION MAKING ON ENERGY AND MINING WORKFORCE ISSUES

The key to making well-thought-out strategic decisions regarding workforce issues in energy and mining is having access to accurate and timely information. Although each of the data sources discussed in this appendix helps to paint a picture of the energy and mining workforce, collectively they fall short of creating a complete picture. The BLS and the Census Bureau provide a wealth of detailed information on the energy and mining workforce, such as industrial and occupational employment estimates and projections, and demographic characteristics such as age, gender, and race/ethnicity. However, these sources rely on the NAICS taxonomy (or derivatives of this taxonomy) to identify the industries that encompass energy and mining. As discussed in earlier chapters, the NAICS structure limits the way in which energy and mining can be examined. For example, the emerging energy sectors (e.g., solar, wind, geothermal) cannot be uniquely identified in the NAICS. Moreover, outsourcing of energy- and mining-related activities to contractors is not fully captured in the NAICS taxonomy, thus potentially undercounting energy and mining employment.

To facilitate the availability of accurate and timely information about the energy and mining workforce, one possible research initiative would be to design a process to collect and analyze, on an ongoing basis, key information about the energy and mining workforce. The initiative would involve identifying

- The primary users of the information and their goals and objectives in using the data;
- A definition of energy and mining that meets the needs of the primary data users;
- The specific data elements to capture;
- The key players who would be involved with collecting, maintaining, and analyzing the data;
- The role of each key player;
- A timeline for implementation; and
- Who would pay for the development and maintenance of the database.

Table A.1 Federal Data Sources That Are Most Relevant to Examining the Energy and Mining Workforce

Organization	Program/ Database	Information Available[a]	Scope	Periodicity of Data Releases	Collection Method	Primary use
Bureau of Labor Statistics	Current Employment Statistics	• Employment, hours, and earnings for the nation, states, and major metropolitan areas • Information for the private sector is available by detailed industry	Workers covered by unemployment insurance laws	Monthly	Survey of establishments	First economic indicator of current economic trends each month
Bureau of Labor Statistics	Current Population Survey	• Employed persons by occupation and demographics (e.g., age, gender) • Employed persons by industry and demographics (e.g., age, gender) • Employed persons by high-level industry and high-level occupation	Wage and salary workers, self-employed, and unpaid family workers	Monthly	Survey of households	Characteristics of the labor force
Bureau of Labor Statistics	Job Openings and Labor Turnover Survey	Estimates of job openings, hires, and separations by industry and region	All nonagricultural industries in the public and private sectors for the 50 states and the District of Columbia	Monthly	Survey of establishments	Demand-side indicators of labor shortages
Bureau of Labor Statistics	Quarterly Census of Employment and Wages program	Employment and wages for the nation, states, and major metropolitan areas by detailed industry, including the private sector and federal, state, and local governments	Workers covered by unemployment insurance laws	Quarterly	Quarterly tax reports submitted by establishments	Comprehensive view of employment and wages by industry

Bureau of Labor Statistics	Occupational Employment Statistics	• Employment estimates by detailed occupation and geographical area (e.g., nation, states, metropolitan area) • Private-sector industry-specific national employment estimates by detailed occupation	Wage and salary workers in nonfarm establishments	Annually	Survey of establishments	Employment for specific occupations
Bureau of Labor Statistics	Employment Projections Program	• Projected employment by detailed occupation • Projected employment by industry • Projected employment by industry and detailed occupation • Projected replacement rates and job openings by detailed occupation	Wage and salary workers, self-employed, and unpaid family workers	Every other year	Multiple sources including U.S. Census Bureau, Current Population Survey, Macroeconomic Advisers' WUMMSIM Model of the U.S. Economy, and Occupational Employment Statistics	Employment projections
Census Bureau	American Community Survey	Estimates of characteristics of the population for the nation, states, and cities and counties, including demographic, social, economic, and housing characteristics	Nation	Annually	Survey of households	Demographic, social, housing, and economic information about the U.S. population

Employment and Training Administration	O*NET	Occupational information such as the knowledge, skills, & abilities; tasks; experience and educational requirements associated with a given occupation	All 800+ occupations included in the federal Standard Occupation Code (SOC) system, plus an additional 100+ detailed occupations	Typically annually, although occupations only updated as needed	Combination of worker surveys and occupation experts	Nation's primary source of detailed occupational information
Mine Safety and Health Administration	Mine Injury and Worktime Reports	Employment, hours worked, and injuries for coal and mineral mining operators and contractors	Personnel directly engaged in production, cleaning, milling, shipping, development, and maintenance and repair work, including direct supervisory and technical personnel and contract mining services	Five times per year	Compiled from reports submitted by operators and contractors as required under the Federal Mine Safety and Health Act of 1977, Public Law 91-173 as amended by Public Law 95-164	Safety and health in the Nation's mining industry
National Center for Education Statistics	Integrated Postsecondary Education Data System	Information from colleges, universities, and technical and vocational institutions, including degrees and certificates conferred by field of study	Institutions that participate in federal student financial aid program	Annually	Institutional survey	Information on U.S. post-secondary educational institutions

[a]Does not necessarily include all of the information available through a specific program. The list reflects information that is most relevant to understanding the U.S. energy and mining workforce.

B

Overview of the Energy and Mining Workforce Using Federal Data Sources

This appendix addresses Task 1, which requests trends in the size, growth, and demographics of the United States energy and mining workforce, disaggregating each industry of interest—oil and gas, nuclear, nonfuel mining, coal mining, solar, wind, geothermal, and geological carbon sequestration—by sector and occupation. The future demand for and supply of workers in these industries, sectors, and occupations is also discussed, as requested in Task 3. This appendix primarily utilizes information available from the Bureau of Labor Statistics (BLS) because it is the primary federal agency responsible for collecting and disseminating information about the U.S. workforce. The agency provides information on a wide range of workforce-related topics, including employment, productivity, pay and benefits, inflation and prices, workplace injuries, consumer spending and time use, and unemployment. As an independent agency, the BLS is the single best source of objective information about the U.S. energy and mining workforce. However, information from the BLS (and other federal agencies) utilizes standardized coding schemes, such as standardized industry and occupation classifications, that limit the way in which the energy and mining workforce can be examined. These limitations are discussed. Other data sources utilized in this appendix include information from the Department of Education's National Center for Education Statistics (NCES) and the Department of Labor's Mine Safety and Health Administration (MSHA). This appendix also provides workforce information on the primary federal agencies responsible for management and oversight of energy and mining based on FedScope, an online tool that enables users to generate information on the federal civilian workforce.

A PRIMER ON THE NORTH AMERICAN INDUSTRY CLASSIFICATION SYSTEM[1]

The North American Industry Classification System (NAICS) is the standard industrial classification system used by statistical agencies, such as the BLS. The NAICS replaced the Standard Industrial Classification (SIC) System in the late 1990s. Information presented in this appendix is based on the 2007 NAICS taxonomy, the most recent version available.[2] Each industry in the system is assigned a six-digit NAICS code. The first two digits of the code designate the economic sector, the third digit designates the subsector, the fourth digit designates the industry group, the fifth digit designates the NAICS industry, and the sixth digit designates the national industry. National industry is the narrowest industry categorization available in the

[1] Source for the information in this primer: U.S. Census Bureau, North American Industry Classification System, (http://www.census.gov/eos/www/naics/).
[2] See the following for information on the 2012 NAICS: "Office of Management and Budget: North American Industry Classification System; Revision for 2012; Notice." *Federal Register* 76 (17 August 2011): 51240-51243.

NAICS. There are more than 1,000 six-digit NAICS codes.[3] The following is an example for NAICS 221113 (Nuclear Electric Power Generation):

221113	=	Nuclear Electric Power Generation (national industry)
22111	=	Electric Power Generation (NAICS industry)
2211	=	Electric Power Generation, Transmission and Distribution (industry group)
221	=	Utilities (subsector)
22	=	Utilities (sector)

A NAICS code is assigned to an establishment, not to an organization or business, and is based on the primary business activity at the establishment. According to the Census Bureau, an establishment is "generally a single physical location where business is conducted or where services or industrial operations are performed (e.g., factory, mill, store, hotel, movie theater, mine, farm, airline terminal, sales office, warehouse, or central administrative office)."[4] Thus, if an organization or business has more than one establishment, then a NAICS code will be assigned to each of its establishments. The primary business activity of an establishment is determined in theory by the processes used to produce goods or services (i.e., it is a production-oriented concept). In practice, a government agency will typically use revenue, value of shipments, or employment to identify the primary business activity of an establishment.

A CONCEPTUAL ISSUE: HOW BROADLY TO DEFINE ENERGY AND MINING

To make effective use of BLS information to paint a picture of the U.S. energy and mining workforce, an important first step is to identify the relevant NAICS codes. In attempting this exercise, a key conceptual question arises—namely, how broadly to define energy and mining. For example, a narrow definition might include only the following two NAICS sectors:

- NAICS 21: Mining, Quarrying, and Oil and Gas Extraction
- NAICS 22: Utilities

A very broad definition of energy and mining might also include industries within the following NAICS sectors:

- NAICS 23: Construction (e.g., Oil and Gas Pipeline and Related Structures Construction)
- NAICS 31-33: Manufacturing (e.g., Petroleum Refineries)
- NAICS 42: Wholesale Trade (e.g., Industrial Machinery and Equipment Merchant Wholesalers)
- NAICS 44-45: Retail Trade (e.g., Gasoline Stations)
- NAICS 48-49: Transportation and Warehousing (e.g., Pipeline Transportation of Natural Gas)

---

[3] A comprehensive list of 2007 NAICS codes can be found at http://www.census.gov/cgi-bin/sssd/naics/naicsrch?chart=2007.
[4] U.S. Census Bureau, North American Industry Classification System, Frequently Asked Questions (see http://www.census.gov/eos/www/naics/faqs/faqs.html).

- NAICS 53: Real Estate and Rental and Leasing (e.g., Construction, Mining, and Forestry Machinery and Equipment Rental and Leasing)
- NAICS 54: Professional, Scientific, and Technical Services (e.g., Engineering services)
- NAICS 81: Other Services (e.g., Commercial and Industrial Machinery and Equipment (except Automotive and Electronic) Repair and Maintenance)

The following two considerations were used to identify the energy and mining NAICS sectors to examine in this appendix:

1. How central the sector is to the energy and mineral security requirements of the United States. For example, wholesale and retail trade, equipment leasing, and equipment and machinery repair are less central to energy and mineral security requirements than activities further up the supply chain, such as extraction, power generation, pipeline construction, and refining.
2. The difficulty of determining what percent of an industry is related directly to energy and mining. For example, Engineering Services is a six-digit NAICS code (the narrowest possible) and encompasses many different types of engineering services in addition to energy- and mining-related engineering services (e.g., chemical engineering services, environmental engineering services, traffic engineering consulting services). It would be very difficult to determine the fraction of the workforce within this NAICS code that relates specifically to energy and mining.

On the basis of the above considerations, the following NAICS sectors are included in this appendix:

- NAICS 21: Mining, Quarrying, and Oil and Gas Extraction
- NAICS 22: Utilities
- NAICS 23: Construction
- NAICS 31-33: Manufacturing
- NAICS 48-49: Transportation and Warehousing

A PRACTICAL ISSUE: IDENTIFYING RELEVANT ENERGY AND MINING NAICS

The section above defines energy and mining from a conceptual point of view as consisting of mining, quarrying, and extraction activities; utilities activities; construction activities; manufacturing activities; and transportation and warehousing activities. However, examining the size, growth, and demographics of the energy and mining workforce using BLS information requires the identification of the specific NAICS codes within each of these sectors that are related to energy and mining. For example, in addition to electric power generation and natural gas distribution, the utilities sector (NAICS 22) includes water supply and irrigation systems activities and sewage treatment facilities, which are not related to energy and mining. The following NAICS categories define energy and mining for the purposes of collecting workforce information:

- NAICS 211: Oil and Gas Extraction

- NAICS 212: Mining (except Oil and Gas)
- NAICS 213: Support Activities for Mining[5]
- NAICS 2211: Electric Power Generation, Transmission and Distribution
- NAICS 2212: Natural Gas Distribution
- NAICS 22133: Steam and Air-Conditioning Supply[6]
- NAICS 2371: Utility System Construction[7]
- NAICS 324: Petroleum and Coal Products Manufacturing
- NAICS 331: Primary Metal Manufacturing
- NAICS 33313: Mining and Oil and Gas Field Machinery Manufacturing
- NAICS 333611: Turbine and Turbine Generator Set Units Manufacturing
- NAICS 486: Pipeline Transportation

In addition to examining the energy and mining workforce as a whole, another objective of this task is to collect workforce information for each of the eight industries outlined in the statement of task: oil and gas, nuclear, nonfuel mining, coal mining, solar, wind, geothermal, and geological carbon sequestration. Table B.1 outlines how NAICS codes have been mapped to the eight industries outlined in the statement of task.[8] In some cases, a higher-level NAICS code is used to identify an industry of interest (e.g., three-digit NAICS); in other cases, a six-digit NAICS code is used because of overlap across industries. For example, because the entire "Oil and Gas Extraction" subsector (NAICS 211) applies only to oil and gas, the three-digit NAICS code is used to capture this area. On the other hand, "Support Activities for Mining" (NAICS 213) includes NAICS categories that are relevant to oil and gas as well as to mining. Thus, six-digit NAICS codes are included to reflect these different industries (e.g., NAICS 213112, Support Activities for Oil and Gas Operations; NAICS 213114, Support Activities for Metal Mining).

As an example of how to read Table B.1, the following NAICS categories are identified as relevant to nonfuel mining:

- NAICS 2122: Metal Ore Mining
- NAICS 2123: Nonmetallic Mineral Mining and Quarrying
- NAICS 213114: Support Activities for Metal Mining
- NAICS 213115: Support Activities for Nonmetallic Minerals (except Fuels) Mining
- NAICS 331: Primary Metal Manufacturing
- NAICS 333131: Mining Machinery and Equipment Manufacturing

---

[5] Establishments in NAICS 213 provide "support services, on a contract or fee basis, required for the mining and quarrying of minerals and for the extraction of oil and gas." These activities "are also often performed in-house by mining operators." Source: U.S. Census Bureau, North American Industry Classification System, 2007 NAICS Descriptions (http://www.census.gov/cgi-bin/sssd/naics/naicsrch?code=213&search=2007%20NAICS%20Search).
[6] NAICS 22133 includes geothermal steam production.
[7] NAICS 2371 includes some activities that are not energy and mining, such as communication line construction and water and sewer line construction. However, because the 6-digit NAICS codes for these activities are combined with activities that are relevant to energy and mining, such as geothermal drilling and power plant construction, there is no way to distinguish them using the NAICS taxonomy.
[8] This mapping reflects input from the Census Bureau, although the final mapping was determined by the committee.

Note, however, that not all of the NAICS codes in the table are uniquely mapped to one of the eight industries. For example, NAICS 22112 (Electric Power Transmission, Control, and Distribution) is related to oil and gas, nuclear, coal mining, solar, wind, and geothermal. Moreover, none of the NAICS codes matches to geological carbon sequestration.[9] NAICS codes for the emerging industries—solar, wind, and geothermal—overlap substantially with each other and none of the industries maps uniquely to a NAICS code.[10] On the other hand, with the exception of nuclear, NAICS categories match up fairly well to the more mature industries—oil and gas, nonfuel mining, and coal mining—with only a modest amount of overlap.

[9] The Census Bureau suggested that geologic carbon sequestration is a secondary activity that would be difficult to classify since an establishment is classified to a NAICS code according to its primary activity.
[10] The 2012 version of the NAICS taxonomy includes distinct codes for Solar Electric Power Generation, Wind Electric Power Generation, Geothermal Electric Power Generation, and Biomass Electric Power Generation.

TABLE B.1 Mapping of Energy and Mining NAICS Codes to the Eight Industries Outlined in the Statement of Task

NAICS Code	NAICS Title	Oil and Gas	Nuclear	Nonfuel Mining	Coal Mining	Solar	Wind	Geoth	Geol Carbon Seq
Mining, Quarrying, and Oil and Gas Extraction Sector (NAICS 21)									
211	Oil and Gas Extraction	x							
2121	Coal Mining				x				
2122	Metal Ore Mining			x					
2123	Nonmetallic Mineral Mining and Quarrying			x					
213111	Drilling Oil and Gas Wells	x							
213112	Support Activities for Oil and Gas Operations	x							
213113	Support Activities for Coal Mining				x				
213114	Support Activities for Metal Mining			x					
213115	Support Activities for Nonmetallic Minerals (except Fuels) Mining			x					
Utilities Sector (NAICS 22)									
221112	Fossil Fuel Electric Power Generation	x			x				
221113	Nuclear Electric Power Generation		x						
221119	Other Electric Power Generation					x	x	x	
22112	Electric Power Transmission, Control, and Distribution	x	x		x	x	x	x	
2212	Natural Gas Distribution	x							
22133	Steam and Air-Conditioning Supply							x	
Construction Sector (NAICS 23)									
23711	Water and Sewer Line and Related Structures Construction							x	
23712	Oil and Gas Pipeline and Related Structures Construction	x							
23713	Power and Communication Line and Related Structures Construction		x			x	x	x	
Manufacturing Sector (NAICS 31-33)									
32411	Petroleum Refineries	x							
331	Primary Metal Manufacturing			x					
333131	Mining Machinery and Equipment Manufacturing			x	x				
333132	Oil and Gas Field Machinery and Equipment Manufacturing	x							
333611	Turbine and Turbine Generator Set Units Manufacturing	x					x	x	
Transportation and Warehousing Sector (NAICS 48-49)									
486	Pipeline Transportation	x							

Prepublication Version

The previous exercise suggests that BLS data are not particularly useful for understanding the workforces in the emerging energy industries. However, BLS data are useful for understanding the oil and gas, nuclear, nonfuel mining, and coal mining workforces.

ENERGY AND MINING WORKFORCE: EMPLOYMENT

The BLS Quarterly Census of Employment and Wages program provides employment information for the United States (as well as states and major metropolitan areas) by detailed industry. The program includes workers covered by unemployment insurance laws, which represents 99.7 percent of wage and salary civilian employment (BLS, .[11] The program excludes self-employed workers and collects information from quarterly tax reports submitted by establishments. Table B.2 presents 2010 average annual employment by sector for each energy and mining NAICS code under consideration. As defined here, employment in energy and mining exceeds 2.25 million. The largest industries are electric power generation, transmission, and distribution (21.7 percent of total employment); utility system construction (17 percent); primary metal manufacturing (16 percent); and support activities for mining (12.9 percent). The vast majority of energy and mining employment (>95 percent) is concentrated in the private sector. Governments, primarily local, play a modest role in electric power generation, transmission, and distribution; natural gas distribution; and utility system construction.

TABLE B.2 Average Annual U.S. Energy and Mining Employment, by NAICS Code and Sector, 2010

NAICS Code	NAICS Title	All Sectors	Private Sector	Federal Gov't	State Gov't	Local Gov't
211	Oil and Gas Extraction	158,423	158,423			
212	Mining (except Oil and Gas)	203,766	203,498			268
213	Support Activities for Mining	289,709	289,709			
2211	Electric Power Generation, Transmission, and Distribution	489,233	395,960	12,801	3,849	76,623
2212	Natural Gas Distribution	115,138	108,605			6,533
22133	Steam and Air-Conditioning Supply	2,191	1,935			256
2371	Utility System Construction	382,267	380,665	5		1,597
324	Petroleum and Coal Products Manufacturing	110,972	110,972			
331	Primary Metal Manufacturing	361,211	361,211			
33313	Mining and Oil and Gas Field Machinery Manufacturing	70,335	70,335			
333611	Turbine and Turbine Generator Set Units Manufacturing	26,646	26,646			
486	Pipeline Transportation	43,151	42,265			886
TOTAL		**2,253,042**	**2,150,224**	**12,806**	**3,849**	**86,163**

NOTE: A blank cell indicates that data are not disclosable or are not applicable.
SOURCE: Bureau of Labor Statistics Quarterly Census of Employment and Wages.

[11] Source: Bureau of Labor Statistics, Quarterly Census of Employment and Wages, Frequently Asked Questions, http://www.bls.gov/cew/cewfaq.htm.

Table B.3 shows average annual energy and mining employment for 2005-2010. While total energy and mining employment remained virtually unchanged since 2005, employment grew at an annual rate of 3.2 percent[12] from 2005 until 2008 and fell at an annual rate of -4.7 percent from 2008 until 2010, with the latter likely due to the recession that began at the end of 2007.[13] Despite the recession, some industries have seen increases in employment since 2005. Most notably, employment in the turbine and turbine generator set units manufacturing industry, which "comprises establishments primarily engaged in manufacturing turbines (except aircraft); and complete turbine generator set units, such as steam, hydraulic, gas, and wind,"[14] grew at an annual rate of 6.5 percent from 2005 to 2010. Moreover, the following industries grew at an annual rate of more than 4.5 percent: support activities for mining (5.3 percent); mining and oil and gas field machinery manufacturing (4.8 percent); and oil and gas extraction (4.7 percent). Declines in employment were concentrated in primary metal manufacturing, which experienced a decline in employment of more than 100,000 from 2005 to 2010. Tables C.1, C.2, C.3, and C.4 in Appendix C show average annual energy and mining employment by sector for 2005-2010.

TABLE B.3 Average Annual U.S. Energy and Mining Employment, by NAICS Code, 2005-2010

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
211	Oil and Gas Extraction	125,818	134,858	146,081	160,081	160,688	158,423
212	Mining (except Oil and Gas)	211,880	219,691	219,932	223,149	207,118	203,766
213	Support Activities for Mining	223,277	262,498	294,264	330,168	273,910	289,709
2211	Electric Power Generation, Transmission, and Distribution	489,022	484,680	488,106	495,528	498,785	489,233
2212	Natural Gas Distribution	115,394	115,170	114,941	115,860	116,785	115,138
22133	Steam and Air-Conditioning Supply	2,023	1,887	1,881	1,965	2,106	2,191
2371	Utility System Construction	394,744	425,559	446,014	448,797	395,257	382,267
324	Petroleum and Coal Products Manufacturing	112,241	113,056	115,169	116,248	114,506	110,972
331	Primary Metal Manufacturing	464,836	463,139	455,683	443,867	363,744	361,211
33313	Mining and Oil and Gas Field Machinery Manufacturing	55,692	63,627	71,677	75,690	71,574	70,335

[12] Growth rates in this chapter are calculated using the compound annual growth rate formula: (Ending value ÷ Beginning value)$^{1/N}$ – 1, where N is the number of periods that have elapsed between the beginning and ending values.
[13] The National Bureau of Economic Research determined that the recent recession began in December 2007. Source: *Determination of the December 2007 Peak in Economic Activity*, 11 December 2008, National Bureau of Economic Research, Business Cycle Dating Committee.
[14] See 2007 NAICS definition of 333611 Turbine and Turbine Generator Set Units Manufacturing (http://www.census.gov/cgi-bin/sssd/naics/naicsrch?code=333611&search=2007%20NAICS%20Search).

333611	Turbine and Turbine Generator Set Units Manufacturing	19,484	19,797	21,663	25,037	26,093	26,646
486	Pipeline Transportation	39,628	40,363	41,216	42,042	42,285	43,151
TOTAL		**2,254,039**	**2,344,325**	**2,416,627**	**2,478,432**	**2,272,851**	**2,253,042**

SOURCE: Bureau of Labor Statistics Quarterly Census of Employment and Wages. Additional tabulations by the National Research Council.

The primary advantage of using the Quarterly Census of Employment and Wages to examine current and historic employment is the level of industry detail available. Specifically, employment information is available at the six-digit-level NAICS code, which facilitates the disaggregation of employment into the industries of interest for this study. A drawback is its exclusion of self-employed workers, which will result in an undercount of employment in energy and mining. The BLS Current Population Survey includes self-employed workers, although with less industry detail available. This survey of households captures information by industry based on the 2007 Census industry classification system. The system is derived from the 2007 NAICS taxonomy; however, there is not a one-to-one mapping between the 2007 Census industry codes and the 2007 NAICS codes. Using a crosswalk that maps the two classification systems, Table B.4 shows 2010 employment counts for the energy and mining Census industries that are generally comparable to the energy and mining NAICS industries.[15] Table C.5 in Appendix C provides a mapping of energy and mining NAICS industries to Census industries and outlines key differences. Across the available industries, employment in energy and mining is more than 300,000 higher using the Current Population Survey than the Quarterly Census of Employment and Wages. This difference is presumably due in part to the inclusion of self-employed workers in the former survey. Moreover, in five of the seven industries, the Current Population Survey employment count figure exceeds that from the Quarterly Census of Employment and Wages. On a relative basis, these differences are largest in petroleum and coal products manufacturing and support activities for mining. Note, however, that there are other differences between the two surveys that could help explain these observed differences. For example, because the Current Population Survey is a household survey, whereas the Quarterly Census of Employment and Wages is an establishment survey, the industry information provided in each might differ, resulting in differences in industry classification.

[15] The full crosswalk can be found at http://www.bls.gov/cps/cpsoccind.htm.

TABLE B.4 Employment for Energy and Mining Census Industries That Are Comparable to Energy and Mining NAICS Industries, 2010

NAICS Code	NAICS Title	Comparable Census Code(s)	2010 employment (annual average)	
			Quarterly Census of Employment and Wages	Current Population Survey
211	Oil and Gas Extraction	0370	158,423	75,000
212	Mining (except Oil and Gas)	0380, 0390, 0470	203,766	204,000
213	Support Activities for Mining	0490	289,709	440,000
2211	Electric Power Generation, Transmission and Distribution	0570	489,233	670,000
2212	Natural Gas Distribution	0580, 0590	115,138	97,000
324	Petroleum and Coal Products Manufacturing	2070-2090	110,972	190,000
486	Pipeline Transportation	6270	43,151	56,000
TOTAL			**1,410,392**	**1,732,000**

SOURCE: Bureau of Labor Statistics Quarterly Census of Employment and Wages and the BLS Current Population Survey. Additional tabulations by the National Research Council.

The BLS also produces employment projections by industry through its Employment Projections Program.[16] The most recent estimates project employment in 2020 using a base year of 2010. These projections are meant to reflect long-term trends in the economy and assume that the economy will be at full employment in 2020.[17] The BLS notes that "given the severity of the most recent recession and the slowness of recovery to date . . . the current set of projections faces more uncertainty than usual" (Sommers and Franklin, 2012, p. 5), suggesting that the projections need to be used with caution. Projections are not available for all of the energy and mining NAICS codes discussed in this appendix and, for those available, the projections are available for private-sector wage and salary workers. Table B.5 presents employment projections for the energy and mining NAICS codes for which projections are available.[18] Total private sector employment across these energy and mining NAICS codes is expected to grow by 84,300 between 2010 and 2020, which translates into an annual growth rate of 0.4 percent. However, specific industries are expected to see more sizable changes in employment. The industry expected to see the largest gain in employment is utility system construction, which is expected to experience an increase in employment of more than 125,000, amounting to an annual growth rate of 2.8 percent. The electric power generation, transmission and distribution industry is expected to experience the largest absolute decline in employment (more than 35,000 jobs), while the pipeline transportation industry is expected to experience the largest relative decline in employment (-2.6 percent per year between 2010 and 2020).

[16] The Employment Projections Program includes wage and salary workers, self-employed workers, and unpaid family workers. Source: Bureau of Labor Statistics, Employment Projections Program, Projections Methodology, http://www.bls.gov/emp/ep_projections_methods.htm.
[17] For a detailed discussion of the projection methodology, see the following: *Overview of projections to 2020*, Dixie Sommers and James C. Franklin, Monthly Labor Review, January 2012, pp. 3-20.
[18] These NAICS represent more than 95 percent of 2010 energy and mining employment as defined in this chapter.

TABLE B.5 Private-Sector U.S. Energy and Mining 2010 Employment and 2020 Projections, by NAICS Code

NAICS Code	NAICS Title	2010 (base year)	2020 (projected)
211	Oil and Gas Extraction	158,900	182,100
212	Mining (except Oil and Gas)	202,900	203,200
213	Support Activities for Mining	294,100	295,400
2211	Electric Power Generation, Transmission and Distribution	396,900	361,400
2212	Natural Gas Distribution	108,000	95,800
2371	Utility System Construction	390,100	515,500
324	Petroleum and Coal Products Manufacturing	114,000	100,000
331	Primary Metal Manufacturing	360,700	366,300
486	Pipeline Transportation	42,400	32,600
TOTAL		**2,068,000**	**2,152,300**

SOURCE: Bureau of Labor Statistics Employment Projections Program.

ENERGY AND MINING WORKFORCE: DEMOGRAPHICS

Through its Current Population Survey, the BLS also captures demographic information about the U.S. workforce. Table B.6 shows key demographic information for the energy and mining workforce. As a comparison, the top row of the table provides demographic information for the U.S. workforce, age 16 years and older. The energy and mining workforce is predominantly male. The highest representation of women is found in the natural gas distribution industry (28.4 percent); the lowest is found in coal mining (6 percent). Moreover, the energy and mining workforce is generally less racially and ethnically diverse than the U.S. workforce as a whole.[19] This lack of demographic diversity is most prominent in coal mining. The most demographic diversity is found in the natural gas distribution industry. The energy and mining workforce is also generally older than the overall U.S. workforce. The industries with the highest median age are nonmetallic mineral mining and quarrying (47.8 years old); natural gas distribution (47.6 years old); and water, steam, air-conditioning, and irrigation systems (47.4 years old). Moreover, a majority of the energy and mining industries have more workers age 45 and older than workers under age 45, suggesting that the loss of talent due to retirements over the next 20 years is likely to disproportionately affect energy and mining. This phenomenon is most notable in the natural gas distribution industry, in which 40.2 percent of workers are under the age of 45 (compared with 56.1 percent for the U.S. workforce as a whole). Those industries with the lowest median age are support activities for mining (40.9 years old) and electric and gas as

[19] Under federal guidelines released in 2003, individuals are first asked to identify whether they consider themselves Hispanic/Latino (an ethnicity designation) and second to identify their race (White, Black or African American, American Indian or Alaska Native, Asian, Native Hawaiian or Other Pacific Islander). Thus, in the tables from the Current Population Survey included in this chapter, Hispanic/Latino ethnicity and the race categories shown are not mutually exclusive. For additional information, see the following: Mary Bowler, Randy E. Ilg, Stephen Miller, Ed Robison, and Anne Polivka, *Revisions to the Current Population Survey Effective in January 2003*, Bureau of Labor Statistics, Current Population Survey.

well as other combinations (42.3 years old). Furthermore, 63 percent of workers in the former industry are under age 45.

According to BLS projections, the U.S. labor force is expected to become more diverse. For example, by 2020 the civilian labor force is expected to be 62.3 percent White non-Hispanic, compared with 67.5 percent in 2010, 72 percent in 2000, and 77.7 percent in 1990 (Toossi, 2012, p. 44). These changing demographics suggest that, all else equal, the energy and mining industries with workforces that are both less diverse and older, such as coal mining and nonmetallic mineral mining and quarrying, may experience greater difficulties replacing lost talent.

TABLE B.6 Demographic Information for the U.S. Energy and Mining Workforce by Census Industry, 2010

Census industry	Women (%)	Black or African American (%)	Asian (%)	Hispanic or Latino (%)	16-19 years (%)	20-24 years (%)	25-34 years (%)	35-44 years (%)	45-54 years (%)	55-64 years (%)	65 years and Over (%)	Median Age (years)
U.S. WORKFORCE, 16 YRS+	**47.2**	**10.8**	**4.8**	**14.3**	**3.1**	**9.1**	**21.7**	**22.0**	**23.9**	**15.6**	**4.5**	**42.0**
0370: Oil and gas extraction	18.0	5.9	3.5	12.8		6.7	28.0	17.3	29.3	17.3	1.3	45.1
0380: Coal mining	6.0	0.4		0.4		7.4	17.0	23.4	29.8	20.2	1.1	46.4
0390: Metal ore mining						2.9	25.7	22.9	25.7	20.0	5.7	43.4
0470: Nonmetallic mineral mining and quarrying	7.9	0.1	0.8	12.5		5.3	21.3	16.0	32.0	20.0	5.3	47.8
0490: Support activities for mining	16.3	7.2	1.1	19.7	0.7	8.9	28.6	24.8	23.4	11.8	1.8	40.9
0570: Electric power generation, transmission, and distribution	21.4	9.4	1.5	7.9	0.3	4.9	20.1	21.0	33.9	18.2	1.3	45.4
0580: Natural Gas Distribution	28.4	13.7	3.1	18.8		1.0	19.6	19.6	37.1	19.6	3.1	47.6
0590: Electric and gas, and other combinations	20.4	11.9	2.8	11.7		9.9	16.5	26.4	30.8	15.4		42.3
0670: Water, steam, air-conditioning, and irrigation systems	21.9	11.1	2.0	12.7	0.4	4.2	15.8	22.4	32.8	20.1	3.9	47.4
2070-2090: Petroleum and Coal Products	19.2	11.5	5.3	13.6	1.1	2.1	16.8	27.9	33.7	15.8	2.1	45.8
2670-2990: Primary metals and fabricated metal products	15.9	6.2	2.2	15.0	1.0	6.0	18.3	24.4	29.0	18.0	3.3	44.7
3080: Construction, mining, and oil field machinery	16.2	7.0	4.3	10.2		5.2	29.1	16.4	23.9	22.4	3.7	45.1
3180: Engines, turbines, and power transmission equipment	17.7	2.5	3.6	10.0		1.9	20.4	25.9	20.4	25.9	3.7	45.9
6270: Pipeline Transportation	16.9	3.0		14.9	1.8	3.6	14.3	25.0	33.9	19.6	1.8	45.3

NOTES: A blank cell indicates data are not available or are not applicable. Age distribution figures may not add up to 100% because of rounding. SOURCE: Bureau of Labor Statistics Current Population Survey. Additional tabulations by the National Research Council.

ENERGY AND MINING WORKFORCE: OCCUPATIONS

The BLS Occupational Employment Statistics program produces employment estimates for more than 800 occupations. The estimates are based on a survey of U.S. business establishments and reflect nonfarm wage and salary workers. The most recent data are as of May 2010. Occupations are classified using the Standard Occupational Classification (SOC) system.[20] Moreover, the program provides private-sector occupational employment estimates by industry, using NAICS codes.[21] Estimates are not available for all of the energy and mining NAICS codes included in this appendix, although the NAICS codes with available occupational employment information represent more than 95 percent of 2010 private-sector energy and mining employment.[22] Table C.6 in Appendix C provides private-sector employment estimates for the 300-plus occupations found in these energy and mining NAICS categories.[23]

Table B.7 provides a condensed list of occupations that constitute 1 percent or more of private-sector energy and mining employment. These occupations collectively represent 50 percent of total energy and mining employment. The most common occupations are construction laborers (4.39 percent of energy and mining employment), electrical power-line installers and repairers (4.11 percent), and operating engineers and other construction equipment operators (3.63 percent). For a majority of these 27 occupations, employment in energy and mining represents less than 15 percent of total employment in the occupation. For example, 11.8 percent of all construction laborers are in energy and mining; the remaining 88.2 percent are in other industries such as residential and nonresidential construction. On the other hand, for some occupations, employment in energy and mining represents more than 90 percent of total occupational employment, such as roustabouts, oil and gas (95.4 percent of occupational employment); service unit operators, oil, gas, and mining (94.6 percent); and helpers–extraction workers (93.9 percent).

Table B.7 Employment Estimates for Private-Sector Energy and Mining Occupations with 1 Percent or More of Energy and Mining Employment, 2010.

Standard Occupation Code	Standard Occupation Title	2010 Employment	Percent of Energy and Mining Employment	Percent of Occupation Employment
47-2061	Construction Laborers	87,300	4.39	11.8
49-9051	Electrical Power-Line Installers and Repairers	81,790	4.11	90.2
47-2073	Operating Engineers and Other Construction Equipment Operators	72,150	3.63	27.5

[20] See http://www.bls.gov/SOC/ for more detail on the Standard Occupational Classification (SOC) system.
[21] The Occupational Employment Statistics program produces occupational employment information at the federal, state, and local government levels, but does not distinguish this information by industry.
[22] Occupational employment information is available for the following energy and mining NAICS: 211, 212, 213, 2211, 2212, 2371, 324, 331, and 486 (and not available for NAICS 22133, 33313, and 333611).
[23] Occupational employment estimates for each NAICS code with available data can be found at the following: http://www.bls.gov/oes/current/oessrci.htm.

47-1011	First-Line Supervisors of Construction Trades and Extraction Workers	56,110	2.82	13.1
47-5071	Roustabouts, Oil and Gas	46,650	2.35	95.4
53-3032	Heavy and Tractor-Trailer Truck Drivers	41,940	2.11	2.9
11-1021	General and Operations Managers	39,810	2.00	2.5
51-1011	First-Line Supervisors of Production and Operating Workers	39,340	1.98	7.4
49-9041	Industrial Machinery Mechanics	39,090	1.97	15.0
49-9071	Maintenance and Repair Workers, General	38,320	1.93	3.9
51-8093	Petroleum Pump System Operators, Refinery Operators, and Gaugers	36,690	1.85	87.3
47-5013	Service Unit Operators, Oil, Gas, and Mining	34,650	1.74	94.6
49-1011	First-Line Supervisors of Mechanics, Installers, and Repairers	32,630	1.64	9.2
43-4051	Customer Service Representatives	32,280	1.62	1.6
43-9061	Office Clerks, General	31,250	1.57	1.4
51-8013	Power Plant Operators	30,350	1.53	92.5
47-2111	Electricians	28,050	1.41	5.8
53-7062	Laborers and Freight, Stock, and Material Movers, Hand	26,960	1.36	1.4
51-4121	Welders, Cutters, Solderers, and Brazers	24,800	1.25	8.0
47-2152	Plumbers, Pipefitters, and Steamfitters	24,190	1.22	7.2
43-3031	Bookkeeping, Accounting, and Auditing Clerks	23,240	1.17	1.6
49-9012	Control and Valve Installers and Repairers, Except Mechanical Door	22,960	1.16	65.6
43-6014	Secretaries and Administrative Assistants, Except Legal, Medical, and Executive	22,360	1.12	1.6
47-5081	Helpers—Extraction Workers	21,930	1.10	93.9
51-9061	Inspectors, Testers, Sorters, Samplers, and Weighers	21,060	1.06	5.2
13-2011	Accountants and Auditors	20,810	1.05	2.2
17-2171	Petroleum Engineers	20,610	1.04	74.4

NOTE: The table includes occupations in the following energy and mining NAICS codes: 211, 212, 213, 2211, 2212, 2371, 324, 331, 486 (and excludes 22133, 33313, and 333611 because data by occupation are not available for these NAICS codes).
SOURCE: Bureau of Labor Statistics Occupational Employment Statistics program. Additional tabulations by the National Research Council.

Key Energy and Mining Occupations

The most common occupations discussed above are not necessarily the most important occupations from the standpoint of meeting the energy and mineral security requirements of the United States. In fact, the statement of task asks explicitly about the availability of skilled labor. Examining the availability of such talent requires a definition of skilled labor. For the purposes of this appendix, a high-skill occupation is defined as one that requires any of the following: (1) postsecondary education (e.g., vocational training, associate's degree, and bachelor's degree), (2) a year or more of experience in a related occupation, or (3) long-term on-the-job training or apprenticeship.[24] This definition can be operationalized using the BLS's recently updated Education and Training Classification System. The system assigns to each occupation in the SOC system the typical education required for entry, work experience (if any) generally considered to be necessary by employers, and the typical amount of on-the-job-training needed to become competent in the occupation.[25] Table C.7 in Appendix C provides the education, experience, and training requirements for energy and mining occupations and identifies those occupations that are high skill. Based on the prior definition, more than 50 percent of energy and mining occupations are high skill. However, many of these high-skill occupations play a relatively small role in the overall energy and mining workforce, either because there are few people employed in these occupations (such as economists and real estate brokers) or because a relatively small percentage of occupational employment is in energy and mining (such as credit analysts and lawyers). For the purposes of this appendix, key energy and mining occupations are defined as those meeting all of the following criteria: (1) it is a high-skill occupation, (2) employment in the occupation represents at least 0.10 percent of total industry employment, and (3) at least 10 percent of employment in the occupation is in energy and mining. Table B.8 lists the energy and mining occupations that meet these criteria.

TABLE B.8 Key Energy and Mining Occupations

Standard Occupation Code	Standard Occupation Title
17-2071	Electrical Engineers
17-2111	Health and Safety Engineers, Except Mining Safety Engineers and Inspectors
17-2131	Materials Engineers
17-2151	Mining and Geological Engineers, Including Mining Safety Engineers
17-2161	Nuclear Engineers
17-2171	Petroleum Engineers
17-3029	Engineering Technicians, Except Drafters, All Other
19-2042	Geoscientists, Except Hydrologists and Geographers
19-4041	Geological and Petroleum Technicians
19-4051	Nuclear Technicians

[24] This definition of a high skill occupation is based on one developed by the Massachusetts Office of Labor and Workforce Development. See *Career Moves: Your Guide to Growing Job Opportunities in Massachusetts*, Executive Office of Labor and Workforce Development, January 2010, p. 19.
[25] For additional information on the Education and Training Classification System see http://www.bls.gov/emp/ep_education_training_system.htm.

29-9011	Occupational Health and Safety Specialists
47-1011	First-Line Supervisors of Construction Trades and Extraction Workers
47-2011	Boilermakers
49-2095	Electrical and Electronics Repairers, Powerhouse, Substation, and Relay
49-3042	Mobile Heavy Equipment Mechanics, Except Engines
49-9041	Industrial Machinery Mechanics
49-9044	Millwrights
49-9051	Electrical Power-Line Installers and Repairers
49-9052	Telecommunications Line Installers and Repairers
51-8011	Nuclear Power Reactor Operators
51-8012	Power Distributors and Dispatchers
51-8013	Power Plant Operators
51-8021	Stationary Engineers and Boiler Operators
51-8092	Gas Plant Operators
51-8093	Petroleum Pump System Operators, Refinery Operators, and Gaugers
53-7021	Crane and Tower Operators
53-7032	Excavating and Loading Machine and Dragline Operators

Demand for Talent in Key Energy and Mining Occupations

As part of the Employment Projections Program, the BLS generates projections of employment growth, replacement rates, and job openings by occupation over the period 2010 to 2020. These projections reflect private-sector as well as government employment and include wage and salary workers, self-employed workers, and unpaid family workers. Projected employment growth for an occupation is based on factors such as expectations regarding population growth, labor force growth, GDP growth, changes in industry output, productivity changes, and technology changes (BLS, 2012e). In using these projections, however, the BLS cautions that "[b]ecause levels of many variables are low in 2010 relative to their historical behavior, projected growth rates may appear more robust than they would otherwise be" (Sommers and Franklin, 2012, p. 4) Keeping this caution in mind, if employment in an occupation is expected to grow, this growth creates job openings. However, even if employment in an occupation is expected to remain steady (or decline), people leave occupations for a variety of reasons (e.g., retirement or career change) and all or a portion of these separations will need to be replaced. Thus, additional job openings are created when existing workers leave an occupation. Table B.9 shows projected employment growth, replacement rates, and job openings (due to growth and replacement needs) over the period 2010-2020 for key energy and mining occupations. As a benchmark, the top row provides information for all occupations across the nation.

TABLE B.9 Projected Employment Growth, Replacement Rates, and Job Openings for Key Energy and Mining Occupations

Standard Occupation Code	Standard Occupation Title	Projections (2010-2020)		
		Growth in employment (%)	Replacement rate (%)	Job Openings, (thousands)
All occupations across the U.S.		**14.3**	**23.6**	**54,787.4**
17-2071	Electrical Engineers	7.0	24.1	47.8
17-2111	Health and Safety Engineers, Except Mining Safety Engineers and Inspectors	13.0	21.8	8.2
17-2131	Materials Engineers	8.7	27.6	8.1
17-2151	Mining and Geological Engineers, Including Mining Safety Engineers	9.6	22.0	2.0
17-2161	Nuclear Engineers	10.2	22.0	6.2
17-2171	Petroleum Engineers	17.0	22.0	11.8
17-3029	Engineering Technicians, Except Drafters, All Other	4.7	19.1	16.8
19-2042	Geoscientists, Except Hydrologists and Geographers	21.2	29.6	17.1
19-4041	Geological and Petroleum Technicians	14.7	33.7	7.0
19-4051	Nuclear Technicians	13.5	33.7	3.3
29-9011	Occupational Health and Safety Specialists	8.5	35.2	25.7
47-1011	First-Line Supervisors of Construction Trades and Extraction Workers	23.5	23.0	259.7
47-2011	Boilermakers	21.3	38.2	11.8
49-2095	Electrical and Electronics Repairers, Powerhouse, Substation, and Relay	4.9	24.6	6.9
49-3042	Mobile Heavy Equipment Mechanics, Except Engines	16.2	26.0	52.5
49-9041	Industrial Machinery Mechanics	21.6	19.2	117.1
49-9044	Millwrights	-4.8	20.9	7.6
49-9051	Electrical Power-Line Installers and Repairers	13.2	35.3	52.7
49-9052	Telecommunications Line Installers and Repairers	13.6	18.4	51.4
51-8011	Nuclear Power Reactor Operators	3.6	35.5	2.0
51-8012	Power Distributors and Dispatchers	-3.0	35.5	3.6
51-8013	Power Plant Operators	-2.5	35.5	14.4
51-8021	Stationary Engineers and Boiler Operators	6.2	22.0	10.6
51-8092	Gas Plant Operators	-6.5	32.6	4.5
51-8093	Petroleum Pump System Operators, Refinery Operators, and Gaugers	-14.0	32.6	14.4
53-7021	Crane and Tower Operators	15.7	27.2	17.2
53-7032	Excavating and Loading Machine and Dragline Operators	17.3	29.6	28.9

NOTE: Projected job openings are due to growth and replacement needs.
SOURCE: Bureau of Labor Statistics Employment Projections Program.

The projections indicate that employment across all occupations in the nation is expected to increase by 14.3 percent over the period 2010 to 2020. Moreover, the replacement rate over this period is 23.6 percent, suggesting that roughly one in four jobs will need to be replaced over the 10-year period. This combination of employment growth and replacements is expected to result in job openings of approximately 55 million between 2010 and 2020. In comparison, some key energy and mining occupations are expected to experience relatively low employment growth rates, such as nuclear power reactor operators (3.6 percent growth rate). Others are expected to see declines in employment, most notably petroleum pump system operators, refinery operators, and gaugers (−14.0 percent). The occupations with the highest expected employment growth are first-line supervisors of construction trades and extraction workers (23.5 percent), industrial machinery mechanics (21.6 percent), boilermakers (21.3 percent), and geoscientists, except hydrologists and geographers (21.2 percent). Replacement rates range from a low of 18.4 percent for telecommunications line installers and repairers to a high of 38.2 percent for boilermakers. Boilermaker is an occupation that is expected to experience both a high projected employment growth rate and a high projected replacement rate, suggesting that this occupation is likely to experience relatively high increases in talent demand over the period 2010-2020. The occupation expected to see the largest number of job openings over the 10-year period is first-line supervisors of construction trades and extraction workers (259,700 job openings), followed by industrial machinery mechanics (117,100 job openings).

DEGREES CONFERRED IN KEY ENERGY AND MINING-RELATED EDUCATIONAL PROGRAMS

For a subset of key energy and mining occupations, the typical education required for entry into the occupation is some amount of postsecondary education. Specifically, eight occupations require a bachelor’s degree, such as electrical engineers, nuclear engineers, and occupational health and safety specialists; three require an associate’s degree, such as geological and petroleum technicians; and one occupation (electrical and electronics repairers, powerhouse, substation, and relay) requires a postsecondary nondegree award (e.g., a certificate). For these occupations, the availability of talent is determined in large part by the number of people receiving degrees and certificates in fields of study that are relevant to these occupations. To facilitate the understanding of this important link between fields of study and the occupational labor market, the NCES and the BLS have created a crosswalk relating instructional programs to occupations. The instructional programs are based on the Classification of Instructional Programs (CIP) taxonomy and the occupations are based on the SOC System.[26] The CIP taxonomy includes more than 1,200 instructional programs.[27] According to the NCES and the BLS, “A CIP-SOC relationship must indicate a ‘direct’ relationship, that is, programs in the CIP category are preparation directly for entry into and performance in jobs in the SOC category” (NCES/BLS, 2011, p. 3)

Applying the CIP-SOC crosswalk to key energy and mining occupations that require some amount of postsecondary education yields 47 instructional programs that feed into these 12 occupations. Table C.8 in Appendix C lists the instructional programs associated with each occupation. Most of the occupations have more than one related instructional program. For

---

[26] The CIP-SOC crosswalk can be found at http://nces.ed.gov/ipeds/cipcode/resources.aspx?y=55.
[27] A complete list of CIP codes is available at http://nces.ed.gov/ipeds/cipcode/default.aspx?y=55.

example, the materials engineers occupation is associated with five instructional programs: ceramic sciences and engineering, materials engineering, metallurgical engineering, textile sciences and engineering, and polymer/plastics engineering. For one occupation (electrical and electronics repairers, powerhouse, substation, and relay), there is no corresponding instructional program, likely because an insufficient number of educational institutions offer a program that directly prepares an individual for this occupation.

Information on the number of degrees and certificates conferred for each instructional program is provided through the NCES Integrated Postsecondary Education Data System (IPEDS). This information is available for all but six of the instructional programs that feed into key energy and mining occupations that require some amount of postsecondary education. Five of these six instructional programs—electrical, electronics, and communications engineering, other; welding engineering technology/technician; chemical engineering technology/technician; packaging science; and marine sciences—are new to the CIP taxonomy and information is not yet available. For the sixth program, geochemistry and petrology, the lack of information is presumably because no educational institution offers a degree or certificate in this specific area. Table B.10 shows the number of degrees and certificates conferred in 2009 across the fields of study that are relevant to each key energy and mining occupation that requires postsecondary education. The table breaks down degrees and certificates conferred into the following categories: doctorate degrees, master's degrees, bachelor's degrees, associate's degrees, post-master's certificates, postbaccalaureate certificates, 2- but less than 4 year certificates, 1- but less than 2-year certificates, and less than 1-year certificates. The occupations that typically require an associate's degree or higher upon entry are italicized; the remaining occupations typically require a bachelor's degree or higher upon entry. Two tables in Appendix C provide additional detail. Table C.9 shows the latter information for the period 2005-2009. Table C.10 shows the number of degrees and certificates conferred in 2009 for each field of study that is relevant to key energy and mining occupations that require postsecondary education.

TABLE B.10 Number of U.S. Degrees and Certificates Conferred in 2009 Across Instructional Programs Related to Key Energy and Mining Occupations That Require Postsecondary Education

Standard Occupation Code	Standard Occupation Title	Degree Level	Degrees/Certificates Conferred (2009)
17-2071	Electrical Engineers	Doctorate degrees	1,819
		Master's degrees	9,281
		Bachelor's degrees	11,862
		Associate's degrees	180
		Post-master's certificates	78
		Postbaccalaureate certificates	33
		1- but less than 2-year certificates	2
		Less than 1-year certificates	11
17-2111	Health and Safety Engineers, Except Mining Safety Engineers and Inspectors	Doctorate degrees	134
		Master's degrees	560
		Bachelor's degrees	570
		Associate's degrees	7
		Post-master's certificates	7
		Postbaccalaureate certificates	14

17-2131	Materials Engineers	Doctorate degrees	542
		Master's degrees	719
		Bachelor's degrees	1,096
		Associate's degrees	1
		Post-master's certificates	1
		Postbaccalaureate certificates	1
		1- but less than 2-year certificates	1
		Less than 1-year certificates	1
17-2151	Mining and Geological Engineers, Including Mining Safety Engineers	Doctorate degrees	14
		Master's degrees	131
		Bachelor's degrees	309
		Postbaccalaureate certificates	5
		1- but less than 2-year certificates	2
17-2161	Nuclear Engineers	Doctorate degrees	81
		Master's degrees	252
		Bachelor's degrees	373
		Post-master's certificates	3
		Post-baccalaureate certificates	5
		Less than 1-year certificates	25
17-2171	Petroleum Engineers	Doctorate degrees	52
		Master's degrees	251
		Bachelor's degrees	690
		Associate's degrees	1
		Post-master's certificates	2
		Postbaccalaureate certificates	12
		1- but less than 2-year certificates	3
		Less than 1-year certificates	1
17-3029	*Engineering Technicians, Except Drafters, All Other*	*Doctorate degrees*	*8*
		Master's degrees	*101*
		Bachelor's degrees	*819*
		Associate's degrees	*2,992*
		2- but less than 4-year certificates	*16*
		1- but less than 2-year certificates	*1,049*
		Less than 1-year certificates	*1,135*
19-2042	Geoscientists, Except Hydrologists and Geographers	Doctorate degrees	611
		Master's degrees	1,315
		Bachelor's degrees	3,801
		Associate's degrees	92
		Post-master's certificates	19
		Post-baccalaureate certificates	20
		Less than 1 year certificates	11
19-4041	*Geological and Petroleum Technicians*	*Master's degrees*	*1*
		Bachelor's degrees	*11*
		Associate's degrees	*101*
		1- but less than 2 year certificates	*29*
		Less than 1 year certificates	*19*
19-4051	*Nuclear Technicians*	*Master's degrees*	*23*
		Bachelor's degrees	*121*

		Associate's degrees	*109*
		1- but less than 2-year certificates	*21*
		Less than 1-year certificates	*18*
29-9011	Occupational Health and Safety Specialists	Doctorate degrees	67
		Master's degrees	551
		Bachelor's degrees	812
		Associate's degrees	372
		Post-master's certificates	8
		Postbaccalaureate certificates	23
		2- but less than 4-year certificates	3
		1- but less than 2-year certificates	91
		Less than 1-year certificates	68

NOTE: Occupations in *italic* typically require an associate's degree or higher upon entry; the remaining occupations typically require a bachelor's degree or higher upon entry.
SOURCE: National Center for Education Statistics, Integrated Postsecondary Education Data System (IPEDS) Completions Survey (accessed via WebCASPAR). Additional tabulations by the National Research Council.

For the occupations that typically require a bachelor's degree or higher upon entry, virtually all degrees and certificates in related fields of study are conferred at this level or higher. The only exception is occupational health and safety specialists where more than 25 percent of degrees and certificates are conferred at the associate's degree level or the prebaccalaureate certificate level.[28] For the occupations that typically require an associate's degree or higher upon entry, a majority of degrees and certificates are conferred at this level or higher, although for one occupation—engineering technicians, except drafters, all other—more than a third are conferred at the certificate level.[29]

Comparing the number of degrees and certificates conferred with the projected number of job openings can provide insight into which occupations may be at greater risk from low talent availability. Table B.11 shows for each key energy and mining occupation that requires postsecondary education, the number of degrees and certificates conferred in 2009 at or above the typical education level for entry; projected job openings per year over the period 2010-2020;[30] the number of degrees and certificates conferred per projected job opening; annual growth rate of degrees/certificates conferred at or above the typical entry education level over the period 2005-2009; and the projected number of degrees/certificates conferred at or above the typical entry education level in 2020 based on the latter growth rates. The occupation with the largest number of degrees and certificates conferred relative to the projected number of job openings is electrical engineers. Specifically, slightly more than 23,000 bachelor's degrees and postbachelor's degrees and certificates in fields relevant to electrical engineering were conferred in 2009; the number of job openings projected per year over the period 2010-2020 is 4,780. These figures suggest that there are approximately 4.8 newly degreed potential job candidates for each projected job opening.[31] However, the number of degrees and certificates conferred that are

[28] For this exercise, post-master's certificates and post-baccalaureate certificates are included in the bachelor's degree or above category.
[29] For this exercise, 2 but less than 4 year certificates are included in the associate's degree or higher category.
[30] The projected number of job openings per year equals the total number of projected job openings over the period 2010-2020 (from Bureau of Labor Statistics' Employment Projections Program) divided by 10.
[31] This exercise abstracts from other occupations competing for individuals with these same degrees and certificates. For example, according to the CIP-SOC crosswalk, those obtaining a degree or certificate in a field relevant to electrical engineering may also be prepared to become aerospace engineers.

relevant to the electrical engineering occupation has been on the decline since 2005 (the annual growth rate over the period 2005-2009 was −2.2 percent), suggesting that the number of newly degreed job candidates for each projected job opening may be on the decline. At the other extreme, 113 degrees were conferred in 2009 in instructional programs that feed into the geological and petroleum technicians occupation, while there are projected to be 700 job openings per year until 2020. These figures suggest that employers may have a difficult time finding geological and petroleum technicians with the requisite education. Although the annual growth rate of degrees conferred in fields relevant to this occupation was relatively high over the period 2005-2009 (17.6 percent), this continued growth rate would yield fewer than 700 new graduates in 2020.

In the near term, key energy and mining occupations requiring post-secondary education that may experience the greatest difficulties acquiring talent with the requisite education are geological and petroleum technicians; occupational health and safety specialists; nuclear technicians; petroleum engineers; nuclear engineers; and health and safety engineers, except mining safety engineers and inspectors. If annual growth rates of degrees and certificates conferred continue as they have over the past five years, these difficulties may continue in the longer-term for occupational health and safety specialists; geological and petroleum technicians; and health and safety engineers, except mining safety engineers and inspectors.

In the near term, key energy and mining occupations requiring postsecondary education that may experience the greatest difficulties acquiring talent with the requisite education are geological and petroleum technicians; occupational health and safety specialists; nuclear technicians; petroleum engineers; nuclear engineers; and health and safety engineers, except mining safety engineers and inspectors. If annual growth rates of degrees and certificates conferred continue as they have over the past 5 years, these difficulties may continue over the longer term for occupational health and safety specialists; geological and petroleum technicians; and health and safety engineers, except mining safety engineers and inspectors.

TABLE B.11 Comparison of the Number of Degrees/Certificates Conferred in Instructional Programs Related to Key Energy and Mining Occupations That Require Postsecondary Education to Projected Job Openings

Standard Occupation Code	**Standard Occupation Title**	**(A) Degrees/Certificates Conferred at or Above Typical Entry Education Level, 2009**	**(B) Projected job Openings per Year, 2010-2020**	**(A÷B) Degrees/Certificates Conferred per Projected Job Opening**	**Annual Growth Degrees/Certificates Conferred at or Above Typical Entry Education Level, 2005-2009 (%)**	**Projected Degrees/Certificates Conferred at or Above Typical Entry Education Level, 2020**
17-2071	Electrical Engineers	23,073	4,780	4.8	-2.2	18,099
17-2111	Health and Safety Engineers, except Mining Safety Engineers and Inspectors	1,285	820	1.6	0.8	1,402
17-2131	Materials Engineers	2,359	810	2.9	2.5	3,096
17-2151	Mining and Geological Engineers, Including Mining Safety Engineers	459	200	2.3	11.6	1,534
17-2161	Nuclear Engineers	714	620	1.2	9.0	1,841
17-2171	Petroleum Engineers	1,007	1,180	0.9	12.9	3,822
17-3029	Engineering Technicians, Except Drafters, All Other	3,936	1,680	2.3	1.2	4,477
19-2042	Geoscientists, Except Hydrologists and Geographers	5,766	1,710	3.4	2.7	7,718
19-4041	Geological and Petroleum Technicians	113	700	0.2	17.6	675
19-4051	Nuclear Technicians	253	330	0.8	21.3	2,110
29-9011	Occupational Health and Safety Specialists	1,461	2,570	0.6	3.3	2,084

: The projected number of job openings per year equals the total number of projected job openings over the period 2010-2020 (from Bureau of Labor Statistics Employment Projections Program) divided by 10.
SOURCE: National Center for Education Statistics Integrated Postsecondary Education Data System (IPEDS) Completions Survey (accessed via WebCASPAR) and Bureau of Labor Statistics Employment Projections Program. Additional tabulations by the National Research Council.

EXAMINING WORKFORCES OF THE MATURE ENERGY AND MINING INDUSTRIES

As mentioned earlier, information from the BLS is more useful for understanding the workforces of mature energy and mining industries than the workforces of emerging ones. However, as can be seen in Table B.1, there are NAICS codes that overlap across industries even for the mature energy and mining industries. For example, NAICS 333131 (Mining Machinery and Equipment Manufacturing) involves both nonfuel mining and coal mining. Thus, the examination below of the workforces in the mature energy and mining industries is limited to NAICS categories that are unique to a given industry. Although this method may underestimate the size of the workforce in each industry, it will provide a cleaner picture of the trends.

Oil and Gas

NAICS codes that are unique to oil and gas include the following activities: oil and gas extraction, drilling oil and gas wells, support activities for oil and gas operations, natural gas distribution, oil and gas pipeline and related structures construction, petroleum refineries, oil and gas field machinery and equipment manufacturing, and pipeline transportation. Table B.12 provides 2010 average annual employment by sector for each oil and gas NAICS code. Oil and gas employment across these NAICS categories is 817,498, the vast majority of which is in the private sector. The largest industries are support activities for oil and gas operations (24.7 percent of oil and gas employment), oil and gas extraction (19.4 percent), and natural gas distribution (14.1 percent).

TABLE B.12 Average Annual U.S. Oil and Gas Employment, by NAICS Code and Sector, 2010

NAICS Code	NAICS Title	All Sectors	Private Sector	Federal Gov't	State Gov't	Local Gov't
211	Oil and Gas Extraction	158,423	158,423			
213111	Drilling Oil and Gas Wells	74,491	74,491			
213112	Support Activities for Oil and Gas Operations	201,685	201,685			
2212	Natural Gas Distribution	115,138	108,605			6,533
23712	Oil and Gas Pipeline and Related Structures Construction	92,319	92,039			280
32411	Petroleum Refineries	72,689	72,689			
333132	Oil and Gas Field Machinery and Equipment Manufacturing	59,602	59,602			
486	Pipeline Transportation	43,151	42,265			886
TOTAL		**817,498**	**809,799**			**7,699**

NOTE: A blank cell indicates that data are not disclosable or are not applicable.
SOURCE: Bureau of Labor Statistics, Quarterly Census of Employment and Wages.

Table B.13 shows average annual oil and gas employment for 2005-2010. Employment in oil and gas grew by almost 140,000 over the period 2005-2010, with an annual growth rate of 3.8 percent. Growth was concentrated in the period 2005-2008, at an annual rate of 9.2 percent. The largest growth was in support activities for oil and gas operations with an annual growth rate of 6.7 percent over the period 2005-2010. Employment over this period grew in all of the oil and gas NAICS codes except for natural gas distribution, where employment essentially remained the same. Tables C.11 and C.12 in Appendix C show average annual oil and gas employment for 2005-2010 for the private sector and local government, respectively.

TABLE B.13 Average Annual U.S. Oil and Gas Employment, by NAICS Code, 2005-2010

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
211	Oil and Gas Extraction	125,818	134,858	146,081	160,081	160,688	158,423
213111	Drilling Oil and Gas Wells	66,691	79,818	84,525	92,640	67,756	74,491
213112	Support Activities for Oil and Gas Operations	145,725	171,127	197,100	223,635	193,589	201,685
2212	Natural Gas Distribution	115,394	115,170	114,941	115,860	116,785	115,138
23712	Oil and Gas Pipeline and Related Structures Construction	71,849	83,408	97,114	111,254	98,501	92,319
32411	Petroleum Refineries	68,427	69,124	72,337	75,099	75,588	72,689
333132	Oil and Gas Field Machinery and Equipment Manufacturing	45,293	52,382	60,045	63,827	60,360	59,602
486	Pipeline Transportation	39,628	40,363	41,216	42,042	42,285	43,151
TOTAL		**678,825**	**746,250**	**813,359**	**884,438**	**815,552**	**817,498**

SOURCE: Bureau of Labor Statistics Quarterly Census of Employment and Wages. Additional tabulations by the National Research Council.

Employment projections for the private sector are available for only a subset of oil and gas NAICS codes (see Table B.14). Employment in the oil and gas extraction industry is expected to grow by 23,200, amounting to an annual growth rate of 1.4 percent. Employment in the natural gas distribution and pipeline transportation industries, on the other hand, is projected to decline by 22,000 over the 10-year period. On net, employment across these industries is expected to increase by a modest 0.4 percent between 2010 and 2020, which translates into an increase of 1,200 jobs.

TABLE B.14 Private-Sector U.S. Oil and Gas 2010 Employment and 2020 Projections, by NAICS Code

NAICS Code	NAICS Title	2010 (base year)	2020 (projected)
211	Oil and Gas Extraction	158,900	182,100
2212	Natural Gas Distribution	108,000	95,800
486	Pipeline Transportation	42,400	32,600
TOTAL		**309,300**	**310,500**

SOURCE: Bureau of Labor Statistics Employment Projections Program.

Table C.13 in Appendix C shows key demographic information for the oil and gas industries for which information is available.[32] Relatively few women are employed in oil and gas in comparison with the overall U.S. workforce. Pipeline transportation has the lowest representation (16.9 percent), while natural gas distribution has the highest (28.4 percent). In

[32] Demographic information is by Census industries. See Table C.14 in Appendix C for a mapping of oil and gas NAICS industries to Census industries.

terms of racial and ethnic diversity, a sizable percentage of the oil and gas workforce is Hispanic/Latino. This figure is notably high in natural gas distribution (18.8 percent). Moreover, close to 14 percent of the natural gas distribution workforce is Black/African American. On the other hand, a very small percentage of those employed in pipeline transportation are Black/African American (3 percent) and there are too few Asians to report. In terms of age, the oil and gas workforce is relatively old in comparison with the overall U.S. workforce. The industries with the highest median age are natural gas distribution (47.6 years old) and petroleum refining (46.0 years old). With the exception of oil and gas extraction, the percentage of the workforce age 45 and older exceeds 50 percent for all oil and gas industries. These figures suggest that these oil and gas industries may experience difficulties replacing talent lost to retirements.

Tables C.15, C.16, and C.17 in Appendix C provide 2010 employment estimates for the 20 largest occupations in the oil and gas extraction, natural gas distribution, and pipeline transportation industries, respectively. These occupations account for more than 50 percent of total employment in each industry. The largest occupations in oil and gas extraction are petroleum engineers (8.56 percent of industry employment); roustabouts, oil and gas (6.24 percent); and wellhead pumpers (5.17 percent). The largest occupations in natural gas distribution are customer service representatives (8.81 percent); control and valve installers and repairers, except mechanical door (7.7 percent); and plumbers, pipefitters, and steamfitters (5.18 percent). The largest occupations in pipeline transportation are petroleum pump system operators, refinery operators, and gaugers (15.9 percent); gas plant operators (8.46 percent); and industrial machinery mechanics (5.55 percent).

Nuclear Energy

Nuclear electric power generation is the only nuclear-energy-related activity that is associated with a unique NAICS code. Table B.15 provides 2010 average annual employment by sector for this industry. Table B.16 shows average annual employment over the period 2005-2010. Across all sectors, employment in the nuclear electric power generation industry is 56,778, of which close to 93 percent is found in the private sector. The remainder is in the federal government (2.4 percent) and local government (5 percent). Employment in this industry increased over the period 2005-2009, but fell below 2005 levels in 2010 due to declines in local government employment (see Tables C.18, C.19, and C.20 in Appendix C). BLS employment projections, demographic information, and employment information by occupation are not available for the nuclear electric power generation industry.

TABLE B.15 Average Annual U.S. Nuclear Energy Employment, by NAICS Code and Sector, 2010

NAICS Code	NAICS Title	All Sectors	Private Sector	Federal Gov't	State Gov't	Local Gov't
221113	Nuclear Electric Power Generation	56,778	52,582	1,381		2,815
TOTAL		**56,778**	**52,582**	**1,381**		**2,815**

NOTE: A blank cell indicates that data are not disclosable or are not applicable.
SOURCE: Bureau of Labor Statistics, Quarterly Census of Employment and Wages.

TABLE B.16 Average Annual U.S. Nuclear Energy Employment, by NAICS Code, 2005-2010

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
221113	Nuclear Electric Power Generation	60,620	61,746	61,434	60,059	61,957	56,778
TOTAL		**60,620**	**61,746**	**61,434**	**60,059**	**61,957**	**56,778**

SOURCE: Bureau of Labor Statistics Quarterly Census of Employment and Wages. Additional tabulations by the National Research Council.

Nonfuel Mining

NAICS codes that are unique to nonfuel mining reflect the following activities: metal ore mining, nonmetallic mineral mining and quarrying, support activities for metal mining, support activities for nonmetal minerals (except fuels) mining, and primary metal manufacturing. Table B.17 shows 2010 average annual employment by sector for each of these activities, while Table B.18 shows average annual employment across sectors over the period 2005-2010. Employment across these industries is 489,259, virtually all of which is in the private sector. The largest industry is primary metal manufacturing (73.8 percent of employment), followed by nonmetallic mineral mining and quarrying (17.7 percent). Because of reductions in employment in these two largest industries, nonfuel mining employment has fallen by more than 100,000 since 2005. Although employment fell in all of the nonfuel mining industries over the period 2008-2010, metal ore mining and support activities for nonfuel mining experienced annual growth rates of more than 4 percent over the 2005-2010 period. Tables C.21 and C.22 in Appendix C show average annual nonfuel mining employment for 2005-2010 for the private sector and local government, respectively.

TABLE B.17 Average Annual U.S. Nonfuel Mining Employment, by NAICS Code and Sector, 2010

NAICS Code	NAICS Title	All Sectors	Private Sector	Federal Gov't	State Gov't	Local Gov't
2122	Metal Ore Mining	35,953	35,953			
2123	Nonmetallic Mineral Mining and Quarrying	86,687	86,419			268
213114	Support Activities for Metal Mining	3,118	3,118			
213115	Support Activities for Nonmetal Minerals (except Fuels) Mining	2,290	2,290			
331	Primary Metal Manufacturing	361,211	361,211			
TOTAL		**489,259**	**488,991**			**268**

NOTE: A blank cell indicates that data are not disclosable or are not applicable.
SOURCE: Bureau of Labor Statistics' Quarterly Census of Employment and Wages.

TABLE B.18 Average Annual U.S. Nonfuel Mining Employment, by NAICS Code, 2005-2010

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
2122	Metal Ore Mining	29,250	31,883	35,901	40,156	34,100	35,953
2123	Nonmetallic Mineral Mining and Quarrying	108,180	109,160	107,428	101,899	91,018	86,687
213114	Support Activities for Metal Mining	2,315	2,582	2,896	3,357	2,538	3,118
213115	Support Activities for Nonmetal Minerals (except Fuels) Mining	1,773	1,888	2,216	2,428	2,064	2,290
331	Primary Metal Manufacturing	464,836	463,139	455,683	443,867	363,744	361,211
TOTAL		**606,354**	**608,652**	**604,124**	**591,707**	**493,464**	**489,259**

SOURCE: Bureau of Labor Statistics Quarterly Census of Employment and Wages. Additional tabulations by the National Research Council.

Private-sector employment projections (see Table B.19) are available for a subset of the nonfuel mining NAICS codes: metal ore mining, nonmetallic mineral mining and quarrying, and primary metal manufacturing. Employment in the latter two industries is expected to increase by 17,200 between 2010 and 2020, but it is expected to decline by 8,300 in metal ore mining, resulting in a net increase of 8,900 jobs in nonfuel mining.

TABLE B.19 Private-Sector U.S. Nonfuel Mining 2010 Employment and 2020 Projections, by NAICS Code

NAICS Code	NAICS Title	2010 (base year)	2020 (projected)
2122	Metal Ore Mining	36,400	28,100
2123	Nonmetallic Mineral Mining and Quarrying	85,900	97,500
331	Primary Metal Manufacturing	360,700	366,300
TOTAL		**483,000**	**491,900**

SOURCE: Bureau of Labor Statistics' Employment Projections Program.

Table C.23 in Appendix C shows demographic information for a subset of the nonfuel mining workforce where information is available.[33] In comparison with the overall U.S. workforce, women make up a relatively small percentage of the nonfuel mining workforce. The highest representation is in foundries (16.3 percent female) and the lowest is in nonmetallic mineral mining and quarrying (7.9 percent). The latter industry also employs few Blacks/African Americans (0.1 percent) and Asians (0.8 percent). Hispanics constitute a relatively large share of the aluminum production and processing workforce (22.8 percent) and a notably small share of the nonferrous metal (except aluminum) production and processing workforce (5.3 percent). The nonfuel mining workforce is also older than the overall U.S. workforce. The industry with the oldest workforce is aluminum production and processing with a median age of 48.2. Moreover, close to 59 percent of the aluminum production and processing workforce is 45 years old or older.

Tables C.25, C.26, and C.27 in Appendix C provide 2010 employment estimates for the 20 largest occupations in the metal ore mining, nonmetal mining, and primary metal manufacturing industries, respectively. The largest occupations in the metal ore mining industry

[33] Demographic information is by Census industries. See Table C.24 in Appendix C for a mapping of nonfuel mining NAICS industries to Census industries.

are operating engineers and other construction equipment operators (8.92 percent of industry employment); mobile heavy equipment mechanics, except engines (8.4 percent); and heavy and tractor-trailer truck drivers (5.78 percent). In nonmetal mining, the most common occupations are petroleum pump system operators, refinery operators, and gaugers (15.9 percent); gas plant operators (8.46 percent); and industrial machinery mechanics (5.55 percent). The largest primary metal manufacturing occupations are first-line supervisors of production and operating workers (4.75 percent); rolling machine setters, operators, and tenders, metal and plastic (4.61 percent); and maintenance and repair workers, general (4.18 percent).

In addition to the BLS, the MSHA also collects workforce information on the nonfuel mining industry. Specifically, the agency collects employment information (including office workers) related to metal mining, nonmetal mining, stone mining, and sand and gravel mining. These figures show employment of 225,643 in 2010 (MSHA, 2011b, Tables 2 and 6). Of this total, 160,146 are employed as nonfuel mining operators; the remaining 65,497 are nonfuel mining contractors. The comparable figure from the BLS Quarterly Census of Employment and Wages for 2010 is 128,048,[34] suggesting that the latter figures are undercounting nonfuel mining employment. This undercounting is likely due in large part to limitations associated with the NAICS taxonomy that results in the undercounting of contractor employment. In particular, if a nonfuel mining contractor engages in more than one activity and the primary activity is not the provision of nonfuel mining services, the NAICS code for this establishment will not fall under nonfuel mining and the corresponding employment will not be included as part of nonfuel mining.

Coal Mining

NAICS that are unique to coal mining reflect coal mining activities and support activities for coal mining. The latter support activities are similar to activities performed by coal mining operators, but are performed on a contract or fee basis. Table B.20 shows 2010 average annual coal mining employment by sector. Table B.21 shows average annual employment across sectors from 2005 to 2010. Employment in these two coal mining activities totals 89,252, all of which is in the private sector. Since 2005, coal mining employment has grown at an annual rate of 1.9 percent, representing an increase in employment of about 8,000 over the period 2005-2010. Unlike the energy and mining industries discussed above, coal mining did not experience a decline in employment during the recent recession. By 2020, however, private-sector employment in the coal mining industry (excluding support activities) is expected to decrease modestly to 77,500 (see Table B.22).

[34] This figure reflects metal ore mining (NAICS 2122), nonmetallic mineral mining and quarrying (NAICS 2123), support activities for metal mining (NAICS 213114), and support activities for nonmetal minerals (except fuels) mining (NAICS 213115).

TABLE B.20 Average Annual U.S. Coal Mining Employment, by NAICS Code and Sector, 2010

NAICS Code	NAICS Title	All Sectors	Private Sector	Federal Gov't	State Gov't	Local Gov't
2121	Coal Mining	81,126	81,126			
213113	Support Activities for Coal Mining	8,126	8,126			
TOTAL		**89,252**	**89,252**			

NOTE: A blank cell indicates that data are not disclosable or are not applicable.
SOURCE: Bureau of Labor Statistics Quarterly Census of Employment and Wages.

TABLE B.21 Average Annual U.S. Coal Mining Employment, by NAICS Code, 2005-2010

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
2121	Coal Mining	74,450	78,648	76,604	81,095	82,000	81,126
213113	Support Activities for Coal Mining	6,773	7,083	7,527	8,109	7,963	8,126
TOTAL		**81,223**	**85,731**	**84,131**	**89,204**	**89,963**	**89,252**

NOTE: All coal mining employment is in the private sector.
SOURCE: Bureau of Labor Statistics' Quarterly Census of Employment and Wages. Additional tabulations by the National Research Council.

TABLE B.22 Private-Sector U.S. Coal Mining 2010 Employment and 2020 Projections, by NAICS Code

NAICS Code	NAICS Title	2010 (base year)	2020 (projected)
2121	Coal Mining	80,600	77,500
TOTAL		**80,600**	**77,500**

SOURCE: Bureau of Labor Statistics Employment Projections Program.

Table C.28 in Appendix C shows demographic information for the coal mining industry workforce.[35] In comparison with the overall U.S. workforce, the coal mining industry has few women and little racial and ethnic diversity. Women make up 6 percent of the workforce, while Black/African Americans and Hispanic/Latino workers each constitute less than 0.5 percent of the workforce (there are too few Asians to report). The median age in this industry is 46.4, with slightly more than 51 percent of the workforce age 45 or older.

Table C.30 in Appendix C provides 2010 private-sector employment estimates for the 20 largest occupations in the coal mining industry (excluding support activities). These occupations encompass more than 78 percent of total employment in this industry. The three largest occupations are operating engineers and other construction equipment operators (10.89 percent of total employment); continuous mining machine operators (10.67 percent); and roof bolters, mining (6.69 percent).

In addition to the nonfuel mining industry, MSHA also collects workforce information on the coal mining industry. The agency collects employment information (including office workers) related to underground mines, surface mines, preparation plants, and independent shops/yards. The 2010 figures show total operator employment of 89,209 and total contractor

---

[35] Demographic information is by Census industries. See Table C.29 in Appendix C for a mapping of coal mining NAICS industries to Census industries.

employment of 46,324 (MSHA, 2011b, Tables 1 and 5). The comparable 2010 figure based on the BLS Quarterly Census of Employment and Wages is 89,252.[36] As with nonfuel mining, these results suggest that the BLS figures undercount coal mining employment, likely because of the undercounting of contractor employment.

SHORTCOMINGS OF BUREAU OF LABOR STATISTICS DATA

The primary shortcoming of using BLS data to examine the energy and mining workforce is limitations of the NAICS, the standard industrial classification system used by the BLS and other federal statistical agencies. The system was designed to provide "uniformity and comparability in the presentation of . . . statistical data"[37] across federal agencies. Although this uniformity and comparability can be useful, it constrains the way in which industries can be examined. The dominant constraint as it relates to this study is the way in which the NAICS system handles the emerging energy sectors that are relevant to this study, namely, solar, wind, geothermal, and geological carbon sequestration. None of these emerging industries is represented by unique NAICS codes, making it unfeasible to examine the workforce in each of these areas using BLS data. This limitation may be rectified over time as NAICS codes are updated to reflect the changing nature of the U.S. economy's industrial makeup. For example, in the 2007 version of the system, NAICS 221119 (Other Electric Power Generation) includes solar, wind, and geothermal energy. In the 2012 version, separate NAICS codes are available for solar electric power generation, wind electric power generation, and geothermal electric power generation. It will be several years, however, before these changes make their way into all of the data sources available from the BLS and other agencies.

Another constraint imposed by the NAICS system is the way in which NAICS codes are assigned. As mentioned earlier, NAICS codes are assigned to an establishment. If an establishment engages in more than one activity, a single NAICS code is assigned on the basis of the primary activity at that establishment. As an example, if an establishment engages in the processing of natural gas as its primary activity, but also engages in carbon capture and storage as a secondary activity, the NAICS code for this establishment will reflect only the natural gas processing. Moreover, information captured about this establishment, such as employment, will be allocated to the primary NAICS code. Since geological carbon sequestration is often a secondary activity, employment information for this emerging industry will be difficult to estimate using the NAICS code system. A related constraint of the NAICS system is the outsourcing of energy- and mining-related activities. If an energy- and mining-related task is outsourced or contracted out to an establishment whose primary activity is not the provision of energy and mining services, the NAICS code for this establishment will not fall under the energy and mining umbrella. In such a case, employment related to the provision of energy and mining services will not be included in energy and mining employment counts, thus undercounting employment. As an example, establishments engaged in energy and mining-related engineering services (e.g., petroleum engineering services, mining engineering services) are classified as part of the more generic engineering services NAICS code. Another example is staffing companies

[36] This figure reflects coal mining (NAICS 2121) and support activities for coal mining (NAICS 213113).
[37] U.S. Census Bureau, North American Industry Classification System, Frequently Asked Questions (see http://www.census.gov/eos/www/naics/faqs/faqs.html).

that provide workers to companies that engage in energy and mining activities. In both cases, these workers would not be classified as part of energy and mining.

FEDERAL AGENCIES RESPONSIBLE FOR OVERSIGHT OF ENERGY AND MINING

There are a wide variety of federal agencies responsible for management and oversight of energy and mining. Some of these agencies are dedicated solely to energy and mining, such as MSHA and the Nuclear Regulatory Commission, whereas others engage in a number of activities, a subset of which are related to energy and mining, such as the Occupational Safety and Health Administration and the Bureau of Land Management. The following are key federal agencies responsible for management and oversight of energy and mining:

- Bureau of Indian Affairs;
- Bureau of Land Management;
- Bureau of Ocean Energy Management, Regulation and Enforcement;[38]
- Department of Energy;
- Federal Energy Regulatory Commission
- Mine Safety and Health Administration;
- National Institute for Occupational Safety and Health;
- Nuclear Regulatory Commission;
- Occupational Safety and Health Administration;
- Office of Surface Mining Reclamation and Enforcement;
- Pipeline and Hazardous Materials Safety Administration; and
- U.S. Geological Survey.

Workforce information for these agencies has been compiled from FedScope, an online tool available from the U.S. Office of Personnel Management that enables users to generate information on the federal civilian workforce.[39] An exception is the National Institute for Occupational Safety and Health, which is not reported separately in FedScope.[40] Table B.23 provides employment information for these federal agencies as of the fiscal year-end for 2007-2011 (note that historical information is not available for all agencies).

---

[38] On October 1, 2011, the Bureau of Ocean Energy Management, Regulation and Enforcement was replaced by the Bureau of Ocean Energy Management and the Bureau of Safety and Environmental Enforcement. Since workforce information is not yet available for these two new agencies, this chapter reports workforce information for the Bureau of Ocean Energy Management, Regulation and Enforcement.
[39] FedScope can be accessed at http://www.fedscope.opm.gov/.
[40] The National Institute for Occupational Safety and Health is reported in FedScope as part of the Centers for Disease Control.

TABLE B.23 Employment for Key Federal Agencies Responsible for Management and Oversight of Energy and Mining, Fiscal Years 2007-2011

Agency	2007	2008	2009	2010	2011
Bureau of Indian Affairs	9,432	9,136	9,256	9,420	9,138
Bureau of Land Management	11,344	11,413	11,779	11,846	11,471
Bureau of Ocean Energy Management, Regulation and Enforcement	1,619	1,643	1,695	1,769	1,182
Department of Energy	14,945	15,448	15,826	16,625	14,893
Federal Energy Regulatory Commission					1,488
Mine Safety and Health Administration	2,260	2,321	2,394	2,351	2,330
National Institute for Occupational Safety and Health[a]					1,200
Nuclear Regulatory Commission	3,750	4,080	4,151	4,211	4,111
Occupational Safety and Health Administration	2,076	2,087	2,126	2,291	2,272
Office of Surface Mining Reclamation and Enforcement	531	523	524	528	519
Pipeline and Hazardous Materials Safety Administration	363	363	375	430	444
U.S. Geological Survey	8,750	8,875	9,016	9,246	9,078
TOTAL (excluding Federal Energy Regulatory Commission and National Institute for Occupational Safety and Health)	**55,070**	**55,889**	**57,142**	**58,717**	**55,438**
TOTAL					**58,126**

[a]Employment Information for 2011 is from the National Institute for Occupational Safety and Health Web site and reflects the approximate number of scientists employed at the agency (see http://www.cdc.gov/niosh/about.html).
NOTE: Employment is as of the fiscal year-end (September 30), except as noted. A blank cell indicates that information is not available.
SOURCE: FedScope (except as noted).

Despite the recent recession, employment in these agencies generally increased from 2007 to 2010. On a relative basis, the agencies with the largest annual growth in employment over this period were the Pipeline and Hazardous Materials Safety Administration (5.8 percent annual growth), the Nuclear Regulatory Commission (3.9 percent), and the Department of Energy (3.6 percent). However, except for the Pipeline and Hazardous Materials Safety Administration, employment fell from 2010 to 2011 in the remaining agencies for which historical employment information is available. The Bureau of Ocean Energy Management, Regulation and Enforcement and the Department of Energy experienced the largest declines (−33.2 percent and −10.4 percent, respectively). For these latter two agencies, as well as the Bureau of Indian Affairs and the Office of Surface Mining Reclamation and Enforcement, 2011 employment levels fell below 2007 levels.

Table B.24 provides demographic information for each agency under consideration as of the fiscal year end 2011. Generally speaking, the workforces in the federal agencies that oversee energy and mining are more diverse than the energy and mining workforces. Compared with the U.S. workforce as a whole, however, these agencies tend to have relatively low female representation and, for certain agencies, relatively low minority representation. An exception is the Bureau of Indian Affairs which is 53.8 percent female and 89.4 percent minority. The agencies with the lowest female representation are MSHA (23.6 percent), the Pipeline and Hazardous Materials Safety Administration (32.4 percent), and the Bureau of Land Management (35.7 percent). Those with the lowest minority representation are MSHA (9.0 percent), the U.S. Geological Survey (12.3 percent), and the Bureau of Land Management (15.7 percent). Note that MSHA has both the lowest female representation and the lowest minority representation of these agencies. The lack of diversity in this agency mimics the lack of diversity in the mining industry that was discussed earlier in the appendix.

The federal agency workforces that oversee energy and mining are considerably older than the energy and mining workforce and the overall U.S. workforce. In all of the agencies under consideration, more than 50 percent of the workforce is 45 years old or older; in most of the agencies this figure exceeds 60 percent. The oldest workforce is in MSHA where more than 75 percent of the workforce is 45 years old or older, with more than 40 percent between 55 and 64 years old.

TABLE B.24 Demographic Characteristics of Employees at Key Federal Agencies Responsible for the Management and Oversight of Energy and Mining, 2011

Agency	**Female (%)**	**Minority (%)**	**< 20 Years (%)**	**20-24 Years (%)**	**25-34 Years (%)**	**35-44 Years (%)**	**45-54 Years (%)**	**55-64 Years (%)**	**65 Years and Over (%)**
Bureau of Indian Affairs	53.8	89.4	0.0	1.5	12.6	22.0	30.4	27.9	5.5
Bureau of Land Management	35.7	15.7	1.0	6.0	20.7	19.6	25.2	24.9	2.6
Bureau of Ocean Energy Management, Regulation and Enforcement	45.1	20.8	0.2	2.4	15.7	17.8	26.6	32.9	4.6
Department of Energy	37.6	24.0	0.1	1.5	14.1	19.2	33.9	26.9	4.3
Federal Energy Regulatory Commission	44.0	32.9	0.1	3.0	25.3	17.9	23.1	25.6	5.0
Mine Safety and Health Administration	23.6	9.0	0.3	0.8	8.2	14.6	29.9	42.0	4.2
Nuclear Regulatory Commission	39.2	31.4	0.1	1.4	17.9	16.2	31.6	26.2	6.5
Occupational Safety and Health Administration	43.8	30.8	0.3	1.8	12.1	21.1	31.4	29.9	3.4
Office of Surface Mining Reclamation and Enforcement	46.2	25.2	1.0	6.4	11.8	12.3	23.9	38.9	5.8
Pipeline and Hazardous Materials Safety Administration	32.4	33.1	0.2	0.9	14.6	20.3	31.3	27.9	4.7
U.S. Geological Survey	37.9	12.3	0.6	5.8	16.5	20.0	28.2%	25.4%	3.5%

NOTES: Employment is as of the fiscal year-end 2011 (September 30). Minority is defined as those who self-identify as Hispanic/Latino, American Indian/Alaskan Native, Asian, Black/African American, Native Hawaiian/Pacific Islander, or Of More Than One Race.
Source: FedScope. Additional tabulations by the National Research Council.

Within the Federal Government, occupations are generally allocated into two categories: (1) white collar occupations and (2) trade, craft, or labor occupations. Within the former category there are more than 20 high-level occupational groups (e.g., engineering and architecture) and more than 400 occupations fall within these groups (e.g., electrical engineer, petroleum engineering). Within the trade, craft, or labor category, there are more than 30 high-level job families (e.g., electrical installation and maintenance) and close to 300 occupations fall within these families (e.g., electrician, electrical equipment repairer).[41] Table C.31 in Appendix C shows the distribution of 2011 employment across occupational groups and job families at the federal agencies under consideration in this appendix. The white collar occupational groups are represented by 00xx-Miscellanous Occupations through 22xx-Information Technology; the trade, craft, or labor job families are represented by 25xx-Wire Communication Equipment Installation and Maintenance through 88xx-Aircraft Overhaul. Groups or families with 5 percent or more of total agency employment are highlighted.

Occupations within these workforces are predominantly white collar. All of the agencies have a sizable administrative staff, particularly the Office of Surface Mining Reclamation and Enforcement where the General Admin, Clerical, and Office Svcs occupational group represents close to 40 percent of the workforce. The workforces in these agencies are generally concentrated in a small number of occupational groups. For example, the Nuclear Regulatory Commission has 18 occupational groups and job families with .10 percent or more of total agency employment; however, more than 75 percent of total agency employment is concentrated in 3 occupational groups—Engineering and Architecture (45.2 percent); General Admin, Clerical, & Office Svcs (22.5 percent); and Physical Sciences (10.8 percent). Only two agencies have more than 50 percent of their workforce in a single occupational group: the Mine Safety and Health Administration has 68.8 percent of its workforce in the Investigation group and the U.S. Geological Survey has 50.7 percent of its workforce in the Physical Sciences group. Tables C.32- C.42 in Appendix C provide employment counts for the 20 largest occupations within each key agency responsible for the management and oversight of energy and mining.

KEY FINDINGS

B.1 The demographics of the energy and mining workforce do not mimic the overall U.S. workforce: the energy and mining workforce is predominantly male and has relatively little minority representation. Moreover, the U.S. labor force is expected to become more diverse by 2020. The energy and mining workforce is also older than the overall U.S. workforce: a majority of the energy and mining industries have more workers age 45 and older than workers under the age of 45. Taken together, these findings suggest that the energy and mining industries with workforces that are less diverse and older—such as mining—may experience greater difficulties replacing lost talent.

B.2 Key energy and mining occupations expected to experience the greatest increases in talent demand over the period 2010 to 2020 are boilermakers; geoscientists, except hydrologists and geographers; electrical power-line installers and repairers; and geological and petroleum technicians.

---

[41] For additional detail on occupational groups and job families see the *Handbook of Occupational Groups and Families*, May 2009, Office of Personnel Management (http://www.opm.gov/fedclass/gshbkocc.pdf).

B.3 In the near term, key energy and mining occupations requiring postsecondary education that may experience the greatest difficulties acquiring talent with the requisite education are: geological and petroleum technicians; occupational health and safety specialists; nuclear technicians; petroleum engineers; nuclear engineers; and health and safety engineers, except mining safety engineers and inspectors. If annual growth rates of degrees and certificates conferred continue as they have over the past 5 years, these difficulties may continue in the longer-term for occupational health and safety specialists; geological and petroleum technicians; and health and safety engineers, except mining safety engineers and inspectors.

B.4 The primary shortcoming of using data from the Bureau of Labor Statistics to examine the energy and mining workforce is limitations associated with the NAICS system, the industrial classification system used by the BLS and other federal statistical agencies. These limitations reflect the speed with which the classification system changes to reflect changes in the industrial makeup of the U.S. economy and the way in which industrial classification codes are assigned to an establishment. These limitations likely result in an undercounting of energy and mining employment.

B.5 The workforces in key federal agencies responsible for the management and oversight of energy and mining are more demographically diverse than the workforces in the energy and mining industries they oversee, but are generally less demographically diverse than the overall U.S. workforce. Moreover, in each of these agencies, a majority of the workforce is 45 years old and older. The Mine Safety and Health Administration workforce is the least demographically diverse and the oldest, suggesting it runs a greater risk of losing talent due to retirement.

RECOMMENDATIONS TO MEET FUTURE LABOR REQUIREMENTS

The following recommendations should be initiated as soon as possible. They are ordered and labeled in terms of when they would be expected to be operational. The recommended actions are expected to continue for the long term. Medium term is defined as 2-5 years, and long term as more than 5 years.

B.1 The government and industry (through its national industry associations) should consider working together to find ways to attract younger workers, women, and minorities into energy and mining occupations and into the federal agencies responsible for the management and oversight of energy and mining. It would be beneficial to focus efforts on addressing potential talent gaps in the energy and mining occupations where talent demand is expected to be greatest. (Medium Term)

B.2 The Department of Education, in collaboration with the Department of Labor and national industry organizations, should consider working together to identify and implement strategies to increase the pipeline of workers with the postsecondary education necessary to work in the energy and mining industries, and particularly in occupations for which the supply of workers with the requisite education is anticipated to fall short of demand. (Medium Term)

B.3 The Department of Labor, through its Bureau of Labor Statistics, should determine and pursue a more effective way to partner with industry, through its national industry associations, to collect on a periodic basis key energy and mining workforce information that would facilitate the ongoing assessment of the demand for and supply of talent across the energy and mining industries. (Long Term)

C

Data on the Energy and Mining Workforce from Federal Data Sources

TABLE C.1. Average annual U.S. energy and mining private sector employment, by NAICS code (2005-2010).

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
211	Oil and Gas Extraction	125,818	134,858	146,081	160,081	160,688	158,423
212	Mining (except Oil and Gas)	211,321	219,243	219,932	223,149	206,769	203,498
213	Support Activities for Mining	223,277	262,498	294,264	330,168	273,910	289,709
2211	Electric Power Generation, Transmission and Distribution	398,381	394,403	395,970	402,504	404,500	395,960
2212	Natural Gas Distribution	106,478	106,351	106,287	107,988	108,915	108,605
22133	Steam and Air-Conditioning Supply	1,913	1,777	1,771	1,857	1,995	1,935
2371	Utility System Construction	393,908	424,661	444,931	447,404	393,857	380,665
324	Petroleum and Coal Products Manufacturing	112,241	113,056	115,169	116,248	114,506	110,972
331	Primary Metal Manufacturing	464,836	463,139	455,683	443,867	363,744	361,211
33313	Mining and Oil and Gas Field Machinery Manufacturing	55,692	63,627	71,677	75,690	71,574	70,335
333611	Turbine and Turbine Generator Set Units Manufacturing	19,484	19,797	21,663	25,037	26,093	26,646
486	Pipeline Transportation	37,910	38,676	40,303	41,116	41,384	42,265
TOTAL		**2,151,259**	**2,242,086**	**2,313,731**	**2,375,109**	**2,167,935**	**2,150,224**

Source: BLS 2011d. Additional tabulations by the National Research Council.

TABLE C.2. Average annual U.S. energy and mining federal government employment, by NAICS code (2005-2010).

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
211	Oil and Gas Extraction						
212	Mining (except Oil and Gas)						
213	Support Activities for Mining						
2211	Electric Power Generation, Transmission and Distribution	12,525	12,437	12,315	12,033	12,381	12,801
2212	Natural Gas Distribution						
22133	Steam and Air-Conditioning Supply						
2371	Utility System Construction	6	6	6	5	5	5
324	Petroleum and Coal Products Manufacturing						
331	Primary Metal Manufacturing						
33313	Mining and Oil and Gas Field Machinery Manufacturing						
333611	Turbine and Turbine Generator Set Units Manufacturing						
486	Pipeline Transportation						
TOTAL		**12,531**	**12,443**	**12,321**	**12,038**	**12,386**	**12,806**

Note: A blank cell indicates data is not disclosable or is not applicable.
Source: BLS 2011d.

TABLE C.3. Average annual U.S. energy and mining state government employment, by NAICS code (2005-2010).

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
211	Oil and Gas Extraction						
212	Mining (except Oil and Gas)						
213	Support Activities for Mining						
2211	Electric Power Generation, Transmission and Distribution	4,015	3,961	3,962	3,856	3,873	3,849
2212	Natural Gas Distribution						
22133	Steam and Air-Conditioning Supply						
2371	Utility System Construction						
324	Petroleum and Coal Products Manufacturing						

331	Primary Metal Manufacturing						
33313	Mining and Oil and Gas Field Machinery Manufacturing						
333611	Turbine and Turbine Generator Set Units Manufacturing						
486	Pipeline Transportation						
TOTAL		**4,015**	**3,961**	**3,962**	**3,856**	**3,873**	**3,849**

Note: A blank cell indicates data is not disclosable or is not applicable.
Source: **BLS 2011d**.

TABLE C.4. Average annual U.S. energy and mining local government employment, by NAICS code (2005-2010).

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
211	Oil and Gas Extraction						
212	Mining (except Oil and Gas)	559	448			349	268
213	Support Activities for Mining						
2211	Electric Power Generation, Transmission and Distribution	74,101	73,879	75,859	77,135	78,031	76,623
2212	Natural Gas Distribution	8,916	8,819	8,654	7,872	7,870	6,533
22133	Steam and Air-Conditioning Supply	110	110	110	108	111	256
2371	Utility System Construction	830	892	1,077	1,388	1,395	1,597
324	Petroleum and Coal Products Manufacturing						
331	Primary Metal Manufacturing						
33313	Mining and Oil and Gas Field Machinery Manufacturing						
333611	Turbine and Turbine Generator Set Units Manufacturing						
486	Pipeline Transportation	1,718	1,687	913	926	901	886
TOTAL		**86,234**	**85,835**	**86,613**	**87,429**	**88,657**	**86,163**

Note: A blank cell indicates data is not disclosable or is not applicable.
Source: **BLS 2011d**.

TABLE C.5. Mapping of U.S. energy and mining NAICS industries to Census industries.

NAICS Code	NAICS Title	Census Code	Census Title
211	Oil and Gas Extraction	0370	Oil and gas extraction
212	Mining (except Oil and Gas)	0380	Coal mining
		0390	Metal ore mining
		0470	Nonmetallic mineral mining and quarrying
213	Support Activities for Mining	0490	Support activities for mining
2211	Electric Power Generation, Transmission and Distribution	0570	Electric power generation, transmission, and distribution
2212	Natural Gas Distribution	0580	Natural gas distribution
		0590	Electric and gas, and other combinations[1]
22133	Steam and Air-Conditioning Supply	0670	Water, steam, air-conditioning, and irrigation systems[2]
2371	Utility System Construction	N/A	N/A[3]
324	Petroleum and Coal Products Manufacturing	2070-2090	Petroleum and coal products manufacturing
331	Primary Metal Manufacturing	2670-2990	Primary metals and fabricated metal products manufacturing[4]
33313	Mining and Oil and Gas Field Machinery Manufacturing	3080	Construction, and mining and oil and gas field machinery manufacturing[5]
333611	Turbine and Turbine Generator Set Units Manufacturing	3180	Engines, turbines, and power transmission equipment manufacturing[6]
486	Pipeline Transportation	6270	Pipeline transportation

[1] Parts of both NAICS 2211 and 2212.
[2] Includes NAICS 22131 (Water Supply and Irrigation Systems)
[3] The Census industry coding system has a single code representing the entire construction sector (NAICS 23)
[4] Includes NAICS 332 (Fabricated Metal Product Manufacturing)
[5] Includes NAICS 33312 (Construction Machinery Manufacturing)
[6] Includes NAICS 333612 (Speed Changer, Industrial High-Speed Drive, and Gear Manufacturing), 333613 (Mechanical Power Transmission Equipment Manufacturing), and 333618 (Other Engine Equipment Manufacturing).
SOURCE: BLS 2011d,e.

TABLE C.6. Employment estimates for U.S. private sector energy and mining occupations, 2010.

Standard Occupation Code	Standard Occupation Title	2010 Employment	Percent of Energy and Mining Employment	Percent of Occupation Employment
11-1011	Chief Executives	5,110	0.26%	2.2%
11-1021	General and Operations Managers	39,810	2.00%	2.5%
11-2021	Marketing Managers	1,870	0.09%	1.2%
11-2022	Sales Managers	3,070	0.15%	1.0%
11-2031	Public Relations and Fundraising Managers	590	0.03%	1.3%
11-3011	Administrative Services Managers	3,500	0.18%	1.9%
11-3021	Computer and Information Systems Managers	2,290	0.12%	0.9%
11-3031	Financial Managers	7,170	0.36%	1.7%
11-3051	Industrial Production Managers	9,500	0.48%	6.7%
11-3061	Purchasing Managers	1,340	0.07%	2.3%
11-3071	Transportation, Storage, and Distribution Managers	1,490	0.07%	2.0%
11-3111	Compensation and Benefits Managers	550	0.03%	2.1%
11-3121	Human Resources Managers	1,490	0.07%	2.8%
11-3131	Training and Development Managers	340	0.02%	1.4%
11-9021	Construction Managers	10,820	0.54%	5.9%
11-9041	Architectural and Engineering Managers	7,150	0.36%	4.5%
11-9121	Natural Sciences Managers	310	0.02%	1.0%
11-9141	Property, Real Estate, and Community Association Managers	1,690	0.09%	1.2%
11-9161	Emergency Management Directors	310	0.02%	8.1%
11-9199	Managers, All Other	6,850	0.34%	3.0%
13-1021	Buyers and Purchasing Agents, Farm Products	50	0.00%	0.5%
13-1022	Wholesale and Retail Buyers, Except Farm Products	170	0.01%	0.2%
13-1023	Purchasing Agents, Except Wholesale, Retail, and Farm Products	8,550	0.43%	4.0%
13-1031	Claims Adjusters, Examiners, and Investigators	170	0.01%	0.1%
13-1041	Compliance Officers	4,260	0.21%	4.8%
13-1051	Cost Estimators	6,050	0.30%	3.3%
13-1078	Human Resources, Training, and Labor Relations Specialists, All Other	4,240	0.21%	1.3%
13-1081	Logisticians	3,520	0.18%	4.6%
13-1111	Management Analysts	7,800	0.39%	1.8%
13-1141	Compensation, Benefits, and Job Analysis Specialists	1,520	0.08%	1.8%
13-1151	Training and Development Specialists	4,490	0.23%	2.5%
13-1161	Market Research Analysts and Marketing Specialists	2,820	0.14%	1.1%
13-1199	Business Operations Specialists, All Other	14,730	0.74%	2.3%
13-2011	Accountants and Auditors	20,810	1.05%	2.2%
13-2021	Appraisers and Assessors of Real Estate	40	0.00%	0.1%
13-2031	Budget Analysts	430	0.02%	1.6%

13-2041	Credit Analysts	220	0.01%	0.4%
13-2051	Financial Analysts	4,710	0.24%	2.2%
13-2061	Financial Examiners	70	0.00%	0.4%
13-2099	Financial Specialists, All Other	800	0.04%	0.7%
15-1111	Computer and Information Research Scientists	30	0.00%	0.2%
15-1121	Computer Systems Analysts	7,230	0.36%	1.6%
15-1131	Computer Programmers	1,670	0.08%	0.5%
15-1132	Software Developers, Applications	1,920	0.10%	0.4%
15-1133	Software Developers, Systems Software	1,340	0.07%	0.4%
15-1141	Database Administrators	740	0.04%	0.8%
15-1142	Network and Computer Systems Administrators	3,750	0.19%	1.3%
15-1150	Computer Support Specialists	4,590	0.23%	0.9%
15-1179	Information Security Analysts, Web Developers, and Computer Network Architects	1,840	0.09%	0.8%
15-1799	Computer Occupations, All Other	1,470	0.07%	1.5%
15-2031	Operations Research Analysts	580	0.03%	1.2%
17-1021	Cartographers and Photogrammetrists	290	0.01%	4.0%
17-1022	Surveyors	1,390	0.07%	3.6%
17-2041	Chemical Engineers	2,540	0.13%	9.5%
17-2051	Civil Engineers	5,630	0.28%	3.2%
17-2061	Computer Hardware Engineers			
17-2071	Electrical Engineers	17,370	0.87%	12.4%
17-2072	Electronics Engineers, Except Computer	640	0.03%	0.6%
17-2081	Environmental Engineers	1,950	0.10%	5.6%
17-2111	Health and Safety Engineers, Except Mining Safety Engineers and Inspectors	2,160	0.11%	11.1%
17-2112	Industrial Engineers	7,120	0.36%	3.5%
17-2131	Materials Engineers	2,920	0.15%	14.5%
17-2141	Mechanical Engineers	5,050	0.25%	2.3%
17-2151	Mining and Geological Engineers, Including Mining Safety Engineers	2,870	0.14%	50.4%
17-2161	Nuclear Engineers	6,760	0.34%	44.2%
17-2171	Petroleum Engineers	20,610	1.04%	74.4%
17-2199	Engineers, All Other	7,890	0.40%	7.5%
17-3011	Architectural and Civil Drafters	350	0.02%	0.4%
17-3012	Electrical and Electronics Drafters	2,370	0.12%	8.5%
17-3013	Mechanical Drafters	1,090	0.05%	1.7%
17-3019	Drafters, All Other	500	0.03%	3.4%
17-3022	Civil Engineering Technicians	950	0.05%	2.3%
17-3023	Electrical and Electronics Engineering Technicians	11,290	0.57%	9.0%
17-3024	Electro-Mechanical Technicians	910	0.05%	5.9%
17-3025	Environmental Engineering Technicians	730	0.04%	4.9%
17-3026	Industrial Engineering Technicians	2,210	0.11%	3.7%
17-3027	Mechanical Engineering Technicians	1,860	0.09%	4.3%
17-3029	Engineering Technicians, Except Drafters, All Other	5,060	0.25%	12.3%
17-3031	Surveying and Mapping Technicians	3,040	0.15%	7.1%
19-1032	Foresters	210	0.01%	8.0%

19-2012	Physicists	220	0.01%	1.9%
19-2031	Chemists	1,930	0.10%	2.9%
19-2032	Materials Scientists	40	0.00%	0.5%
19-2041	Environmental Scientists and Specialists, Including Health	1,890	0.10%	4.7%
19-2042	Geoscientists, Except Hydrologists and Geographers	8,240	0.41%	34.5%
19-2099	Physical Scientists, All Other	480	0.02%	4.1%
19-3011	Economists	90	0.00%	1.6%
19-3051	Urban and Regional Planners			
19-4031	Chemical Technicians	3,850	0.19%	6.9%
19-4041	Geological and Petroleum Technicians	8,710	0.44%	65.7%
19-4051	Nuclear Technicians	3,140	0.16%	46.4%
19-4091	Environmental Science and Protection Technicians, Including Health	660	0.03%	3.9%
19-4099	Life, Physical, and Social Science Technicians, All Other	360	0.02%	1.1%
23-1011	Lawyers	2,120	0.11%	0.5%
23-2011	Paralegals and Legal Assistants	410	0.02%	0.2%
23-2093	Title Examiners, Abstractors, and Searchers	1,160	0.06%	2.4%
23-2099	Legal Support Workers, All Other			
25-9021	Farm and Home Management Advisors	40	0.00%	1.5%
25-9031	Instructional Coordinators	30	0.00%	0.1%
27-1021	Commercial and Industrial Designers	40	0.00%	0.1%
27-1024	Graphic Designers	190	0.01%	0.1%
27-3031	Public Relations Specialists	1,570	0.08%	0.8%
27-3041	Editors	40	0.00%	0.0%
27-3042	Technical Writers			
29-1111	Registered Nurses	130	0.01%	0.0%
29-9011	Occupational Health and Safety Specialists	4,790	0.24%	15.2%
29-9012	Occupational Health and Safety Technicians	940	0.05%	13.6%
33-1099	First-Line Supervisors of Protective Service Workers, All Other	310	0.02%	0.8%
33-9021	Private Detectives and Investigators	90	0.00%	0.4%
33-9032	Security Guards	5,100	0.26%	0.6%
33-9091	Crossing Guards	550	0.03%	4.1%
33-9099	Protective Service Workers, All Other	430	0.02%	1.3%
35-2012	Cooks, Institution and Cafeteria	130	0.01%	0.1%
35-2019	Cooks, All Other			
35-3021	Combined Food Preparation and Serving Workers, Including Fast Food			
37-1012	First-Line Supervisors of Landscaping, Lawn Service, and Groundskeeping Workers	320	0.02%	0.4%
37-2011	Janitors and Cleaners, Except Maids and Housekeeping Cleaners	4,270	0.21%	0.3%
37-3011	Landscaping and Groundskeeping Workers	1,670	0.08%	0.2%
37-3013	Tree Trimmers and Pruners	1,260	0.06%	3.7%
41-1011	First-Line Supervisors of Retail Sales Workers	170	0.01%	0.0%
41-1012	First-Line Supervisors of Non-Retail Sales	1,190	0.06%	0.5%

	Workers			
41-2011	Cashiers	1,950	0.10%	0.1%
41-2022	Parts Salespersons	40	0.00%	0.0%
41-2031	Retail Salespersons	300	0.02%	0.0%
41-3031	Securities, Commodities, and Financial Services Sales Agents	590	0.03%	0.2%
41-3099	Sales Representatives, Services, All Other	4,590	0.23%	0.9%
41-4011	Sales Representatives, Wholesale and Manufacturing, Technical and Scientific Products	2,560	0.13%	0.7%
41-4012	Sales Representatives, Wholesale and Manufacturing, Except Technical and Scientific Products	12,120	0.61%	0.9%
41-9021	Real Estate Brokers	60	0.00%	0.1%
41-9022	Real Estate Sales Agents	610	0.03%	0.4%
41-9031	Sales Engineers	240	0.01%	0.4%
41-9799	Sales and Related Workers, All Other	680	0.03%	0.5%
43-1011	First-Line Supervisors of Office and Administrative Support Workers	14,930	0.75%	1.2%
43-2011	Switchboard Operators, Including Answering Service	100	0.01%	0.1%
43-3011	Bill and Account Collectors	2,800	0.14%	0.7%
43-3021	Billing and Posting Clerks	4,730	0.24%	1.0%
43-3031	Bookkeeping, Accounting, and Auditing Clerks	23,240	1.17%	1.6%
43-3051	Payroll and Timekeeping Clerks	4,040	0.20%	2.7%
43-3061	Procurement Clerks	490	0.02%	1.0%
43-4041	Credit Authorizers, Checkers, and Clerks	80	0.00%	0.2%
43-4051	Customer Service Representatives	32,280	1.62%	1.6%
43-4071	File Clerks	620	0.03%	0.4%
43-4151	Order Clerks	350	0.02%	0.2%
43-4161	Human Resources Assistants, Except Payroll and Timekeeping	1,680	0.08%	1.5%
43-4171	Receptionists and Information Clerks	4,260	0.21%	0.5%
43-4199	Information and Record Clerks, All Other	250	0.01%	0.3%
43-5021	Couriers and Messengers	40	0.00%	0.0%
43-5032	Dispatchers, Except Police, Fire, and Ambulance	6,280	0.32%	3.8%
43-5041	Meter Readers, Utilities	15,840	0.80%	68.4%
43-5061	Production, Planning, and Expediting Clerks	9,270	0.47%	3.7%
43-5071	Shipping, Receiving, and Traffic Clerks	6,710	0.34%	1.0%
43-5081	Stock Clerks and Order Fillers	8,090	0.41%	0.5%
43-5111	Weighers, Measurers, Checkers, and Samplers, Recordkeeping	1,860	0.09%	2.9%
43-6011	Executive Secretaries and Executive Administrative Assistants	17,190	0.86%	1.9%
43-6012	Legal Secretaries	120	0.01%	0.1%
43-6014	Secretaries and Administrative Assistants, Except Legal, Medical, and Executive	22,360	1.12%	1.6%
43-9011	Computer Operators	140	0.01%	0.2%
43-9021	Data Entry Keyers	500	0.03%	0.3%

43-9022	Word Processors and Typists	330	0.02%	1.0%
43-9051	Mail Clerks and Mail Machine Operators, Except Postal Service	240	0.01%	0.2%
43-9061	Office Clerks, General	31,250	1.57%	1.4%
43-9071	Office Machine Operators, Except Computer			
43-9799	Office and Administrative Support Workers, All Other	1,400	0.07%	1.0%
45-2093	Farmworkers, Farm, Ranch, and Aquacultural Animals	100	0.01%	0.3%
45-2099	Agricultural Workers, All Other			
47-1011	First-Line Supervisors of Construction Trades and Extraction Workers	56,110	2.82%	13.1%
47-2011	Boilermakers	2,550	0.13%	13.7%
47-2021	Brickmasons and Blockmasons	440	0.02%	0.7%
47-2031	Carpenters	6,870	0.35%	1.1%
47-2051	Cement Masons and Concrete Finishers	2,810	0.14%	2.0%
47-2061	Construction Laborers	87,300	4.39%	11.8%
47-2071	Paving, Surfacing, and Tamping Equipment Operators	1,930	0.10%	5.3%
47-2072	Pile-Driver Operators	530	0.03%	12.9%
47-2073	Operating Engineers and Other Construction Equipment Operators	72,150	3.63%	27.5%
47-2111	Electricians	28,050	1.41%	5.8%
47-2132	Insulation Workers, Mechanical	790	0.04%	2.9%
47-2141	Painters, Construction and Maintenance	1,060	0.05%	0.6%
47-2151	Pipelayers	18,000	0.91%	55.4%
47-2152	Plumbers, Pipefitters, and Steamfitters	24,190	1.22%	7.2%
47-2171	Reinforcing Iron and Rebar Workers	320	0.02%	1.6%
47-2211	Sheet Metal Workers	70	0.00%	0.1%
47-2221	Structural Iron and Steel Workers	2,460	0.12%	4.2%
47-3012	Helpers--Carpenters	660	0.03%	1.4%
47-3013	Helpers--Electricians	680	0.03%	1.0%
47-3014	Helpers--Painters, Paperhangers, Plasterers, and Stucco Masons			
47-3015	Helpers--Pipelayers, Plumbers, Pipefitters, and Steamfitters	5,240	0.26%	9.2%
47-3019	Helpers, Construction Trades, All Other	840	0.04%	4.6%
47-4011	Construction and Building Inspectors	1,350	0.07%	3.6%
47-4041	Hazardous Materials Removal Workers	370	0.02%	1.0%
47-4051	Highway Maintenance Workers	90	0.00%	1.9%
47-4061	Rail-Track Laying and Maintenance Equipment Operators	70	0.00%	0.5%
47-4071	Septic Tank Servicers and Sewer Pipe Cleaners	600	0.03%	3.5%
47-4799	Construction and Related Workers, All Other	870	0.04%	2.5%
47-5011	Derrick Operators, Oil and Gas	16,790	0.84%	99.2%
47-5012	Rotary Drill Operators, Oil and Gas	19,620	0.99%	97.1%
47-5013	Service Unit Operators, Oil, Gas, and Mining	34,650	1.74%	94.6%
47-5021	Earth Drillers, Except Oil and Gas	11,410	0.57%	71.0%

47-5031	Explosives Workers, Ordnance Handling Experts, and Blasters	2,060	0.10%	52.3%
47-5041	Continuous Mining Machine Operators	13,010	0.65%	99.6%
47-5042	Mine Cutting and Channeling Machine Operators	6,240	0.31%	94.1%
47-5049	Mining Machine Operators, All Other	2,620	0.13%	81.9%
47-5051	Rock Splitters, Quarry	2,700	0.14%	79.6%
47-5061	Roof Bolters, Mining	5,560	0.28%	99.1%
47-5071	Roustabouts, Oil and Gas	46,650	2.35%	95.4%
47-5081	Helpers--Extraction Workers	21,930	1.10%	93.9%
47-5099	Extraction Workers, All Other	5,470	0.28%	84.2%
49-1011	First-Line Supervisors of Mechanics, Installers, and Repairers	32,630	1.64%	9.2%
49-2011	Computer, Automated Teller, and Office Machine Repairers			
49-2021	Radio, Cellular, and Tower Equipment Installers and Repairs	110	0.01%	1.3%
49-2022	Telecommunications Equipment Installers and Repairers, Except Line Installers	670	0.03%	0.4%
49-2092	Electric Motor, Power Tool, and Related Repairers	180	0.01%	1.0%
49-2093	Electrical and Electronics Installers and Repairers, Transportation Equipment	50	0.00%	0.5%
49-2094	Electrical and Electronics Repairers, Commercial and Industrial Equipment	2,760	0.14%	5.2%
49-2095	Electrical and Electronics Repairers, Powerhouse, Substation, and Relay	17,970	0.90%	89.2%
49-3011	Aircraft Mechanics and Service Technicians	50	0.00%	0.1%
49-3023	Automotive Service Technicians and Mechanics	3,440	0.17%	0.6%
49-3031	Bus and Truck Mechanics and Diesel Engine Specialists	7,970	0.40%	4.3%
49-3041	Farm Equipment Mechanics and Service Technicians			
49-3042	Mobile Heavy Equipment Mechanics, Except Engines	14,640	0.74%	16.3%
49-3043	Rail Car Repairers	180	0.01%	1.0%
49-3093	Tire Repairers and Changers	150	0.01%	0.2%
49-9012	Control and Valve Installers and Repairers, Except Mechanical Door	22,960	1.16%	65.6%
49-9021	Heating, Air Conditioning, and Refrigeration Mechanics and Installers	1,000	0.05%	0.5%
49-9031	Home Appliance Repairers	1,160	0.06%	3.5%
49-9041	Industrial Machinery Mechanics	39,090	1.97%	15.0%
49-9043	Maintenance Workers, Machinery	7,160	0.36%	11.1%
49-9044	Millwrights	4,520	0.23%	12.4%
49-9045	Refractory Materials Repairers, Except Brickmasons	1,000	0.05%	48.5%
49-9051	Electrical Power-Line Installers and Repairers	81,790	4.11%	90.2%
49-9052	Telecommunications Line Installers and Repairers	16,450	0.83%	10.6%

49-9069	Precision Instrument and Equipment Repairers, All Other	290	0.01%	3.1%
49-9071	Maintenance and Repair Workers, General	38,320	1.93%	3.9%
49-9092	Commercial Divers	630	0.03%	17.2%
49-9096	Riggers	2,880	0.14%	23.6%
49-9098	Helpers--Installation, Maintenance, and Repair Workers	9,000	0.45%	8.2%
49-9799	Installation, Maintenance, and Repair Workers, All Other	4,350	0.22%	4.3%
51-1011	First-Line Supervisors of Production and Operating Workers	39,340	1.98%	7.4%
51-2021	Coil Winders, Tapers, and Finishers	1,340	0.07%	9.0%
51-2022	Electrical and Electronic Equipment Assemblers	120	0.01%	0.1%
51-2023	Electromechanical Equipment Assemblers	50	0.00%	0.1%
51-2041	Structural Metal Fabricators and Fitters	860	0.04%	1.1%
51-2092	Team Assemblers	8,910	0.45%	1.0%
51-2099	Assemblers and Fabricators, All Other	1,500	0.08%	0.6%
51-4011	Computer-Controlled Machine Tool Operators, Metal and Plastic	4,340	0.22%	3.5%
51-4012	Computer Numerically Controlled Machine Tool Programmers, Metal and Plastic	160	0.01%	1.0%
51-4021	Extruding and Drawing Machine Setters, Operators, and Tenders, Metal and Plastic	11,940	0.60%	15.7%
51-4022	Forging Machine Setters, Operators, and Tenders, Metal and Plastic	2,010	0.10%	9.2%
51-4023	Rolling Machine Setters, Operators, and Tenders, Metal and Plastic	16,370	0.82%	51.3%
51-4031	Cutting, Punching, and Press Machine Setters, Operators, and Tenders, Metal and Plastic	11,630	0.59%	6.4%
51-4032	Drilling and Boring Machine Tool Setters, Operators, and Tenders, Metal and Plastic	1,560	0.08%	7.0%
51-4033	Grinding, Lapping, Polishing, and Buffing Machine Tool Setters, Operators, and Tenders, Metal and Plastic	8,410	0.42%	12.0%
51-4034	Lathe and Turning Machine Tool Setters, Operators, and Tenders, Metal and Plastic	1,630	0.08%	4.0%
51-4035	Milling and Planing Machine Setters, Operators, and Tenders, Metal and Plastic	2,250	0.11%	
51-4041	Machinists	8,840	0.44%	2.5%
51-4051	Metal-Refining Furnace Operators and Tenders	13,160	0.66%	86.5%
51-4052	Pourers and Casters, Metal	10,460	0.53%	93.5%
51-4061	Model Makers, Metal and Plastic	190	0.01%	3.2%
51-4062	Patternmakers, Metal and Plastic	1,470	0.07%	33.5%
51-4071	Foundry Mold and Coremakers	7,900	0.40%	78.9%
51-4072	Molding, Coremaking, and Casting Machine Setters, Operators, and Tenders, Metal and Plastic	11,680	0.59%	10.2%
51-4081	Multiple Machine Tool Setters, Operators, and Tenders, Metal and Plastic	3,980	0.20%	5.7%
51-4111	Tool and Die Makers	2,860	0.14%	4.3%

51-4121	Welders, Cutters, Solderers, and Brazers	24,800	1.25%	8.0%
51-4122	Welding, Soldering, and Brazing Machine Setters, Operators, and Tenders	710	0.04%	1.8%
51-4191	Heat Treating Equipment Setters, Operators, and Tenders, Metal and Plastic	4,240	0.21%	23.3%
51-4192	Layout Workers, Metal and Plastic	80	0.00%	1.0%
51-4193	Plating and Coating Machine Setters, Operators, and Tenders, Metal and Plastic	1,260	0.06%	4.2%
51-4194	Tool Grinders, Filers, and Sharpeners	970	0.05%	8.1%
51-4199	Metal Workers and Plastic Workers, All Other	2,570	0.13%	11.2%
51-8011	Nuclear Power Reactor Operators	4,300	0.22%	93.9%
51-8012	Power Distributors and Dispatchers	7,440	0.37%	90.7%
51-8013	Power Plant Operators	30,350	1.53%	92.5%
51-8021	Stationary Engineers and Boiler Operators	2,980	0.15%	13.3%
51-8031	Water and Wastewater Treatment Plant and System Operators	1,440	0.07%	6.8%
51-8091	Chemical Plant and System Operators	3,170	0.16%	7.4%
51-8092	Gas Plant Operators	10,770	0.54%	83.2%
51-8093	Petroleum Pump System Operators, Refinery Operators, and Gaugers	36,690	1.85%	87.3%
51-8099	Plant and System Operators, All Other	2,490	0.13%	
51-9011	Chemical Equipment Operators and Tenders	1,950	0.10%	4.2%
51-9012	Separating, Filtering, Clarifying, Precipitating, and Still Machine Setters, Operators, and Tenders	3,170	0.16%	8.4%
51-9021	Crushing, Grinding, and Polishing Machine Setters, Operators, and Tenders	5,310	0.27%	16.2%
51-9022	Grinding and Polishing Workers, Hand	4,180	0.21%	15.3%
51-9023	Mixing and Blending Machine Setters, Operators, and Tenders	4,780	0.24%	3.9%
51-9032	Cutting and Slicing Machine Setters, Operators, and Tenders	570	0.03%	0.9%
51-9041	Extruding, Forming, Pressing, and Compacting Machine Setters, Operators, and Tenders	840	0.04%	1.3%
51-9051	Furnace, Kiln, Oven, Drier, and Kettle Operators and Tenders	2,870	0.14%	15.6%
51-9061	Inspectors, Testers, Sorters, Samplers, and Weighers	21,060	1.06%	5.2%
51-9071	Jewelers and Precious Stone and Metal Workers	50	0.00%	0.2%
51-9111	Packaging and Filling Machine Operators and Tenders	4,470	0.22%	1.3%
51-9121	Coating, Painting, and Spraying Machine Setters, Operators, and Tenders	1,750	0.09%	2.3%
51-9192	Cleaning, Washing, and Metal Pickling Equipment Operators and Tenders	700	0.04%	3.8%
51-9195	Molders, Shapers, and Casters, Except Metal and Plastic	560	0.03%	1.7%
51-9198	Helpers--Production Workers	17,830	0.90%	4.5%
51-9399	Production Workers, All Other	7,620	0.38%	3.4%

53-1021	First-Line Supervisors of Helpers, Laborers, and Material Movers, Hand	2,450	0.12%	1.5%
53-1031	First-Line Supervisors of Transportation and Material-Moving Machine and Vehicle Operators	5,420	0.27%	3.2%
53-2012	Commercial Pilots	330	0.02%	1.1%
53-3031	Driver/Sales Workers	240	0.01%	0.1%
53-3032	Heavy and Tractor-Trailer Truck Drivers	41,940	2.11%	2.9%
53-3033	Light Truck or Delivery Services Drivers	2,790	0.14%	0.4%
53-3099	Motor Vehicle Operators, All Other	150	0.01%	0.3%
53-4011	Locomotive Engineers	100	0.01%	0.2%
53-4013	Rail Yard Engineers, Dinkey Operators, and Hostlers	360	0.02%	6.5%
53-5011	Sailors and Marine Oilers	270	0.01%	1.0%
53-5021	Captains, Mates, and Pilots of Water Vessels	660	0.03%	2.4%
53-6031	Automotive and Watercraft Service Attendants			
53-6099	Transportation Workers, All Other	40	0.00%	0.1%
53-7011	Conveyor Operators and Tenders	2,290	0.12%	6.2%
53-7021	Crane and Tower Operators	9,500	0.48%	24.9%
53-7031	Dredge Operators	1,110	0.06%	69.8%
53-7032	Excavating and Loading Machine and Dragline Operators	17,390	0.87%	37.0%
53-7033	Loading Machine Operators, Underground Mining	2,910	0.15%	95.4%
53-7041	Hoist and Winch Operators	720	0.04%	26.0%
53-7051	Industrial Truck and Tractor Operators	14,510	0.73%	2.8%
53-7061	Cleaners of Vehicles and Equipment	360	0.02%	0.1%
53-7062	Laborers and Freight, Stock, and Material Movers, Hand	26,960	1.36%	1.4%
53-7063	Machine Feeders and Offbearers	2,680	0.13%	2.2%
53-7064	Packers and Packagers, Hand	2,800	0.14%	0.4%
53-7071	Gas Compressor and Gas Pumping Station Operators	3,110	0.16%	79.3%
53-7072	Pump Operators, Except Wellhead Pumpers	6,010	0.30%	65.5%
53-7073	Wellhead Pumpers	12,820	0.64%	99.0%
53-7111	Mine Shuttle Car Operators	3,060	0.15%	99.4%
53-7121	Tank Car, Truck, and Ship Loaders	1,200	0.06%	11.6%
53-7199	Material Moving Workers, All Other	530	0.03%	2.1%

Notes: The table includes occupations in the following energy and mining NAICS codes: 211, 212, 213, 2211, 2212, 2371, 324, 331, 486 (and excludes 22133, 33313, and 333611 because data by occupation is not available for these NAICS codes). A blank cell indicates information is not available.
Source: BLS 2012e. Additional tabulations by the National Research Council.

TABLE C.7. Education, experience, and training requirements for U.S. energy and mining occupations.

Standard Occupation Code	Standard Occupation Title	Typical education needed for entry	Work experience in a related occupation	Typical on-the-job training needed to attain competency	High Skill?
11-1011	Chief Executives	Bachelor's degree	More than 5 years	None	Yes
11-1021	General and Operations Managers	Associate's degree	1 to 5 years	None	Yes
11-2021	Marketing Managers	Bachelor's degree	1 to 5 years	None	Yes
11-2022	Sales Managers	Bachelor's degree	1 to 5 years	None	Yes
11-2031	Public Relations and Fundraising Managers	Bachelor's degree	1 to 5 years	None	Yes
11-3011	Administrative Services Managers	High school diploma or equivalent	1 to 5 years	None	Yes
11-3021	Computer and Information Systems Managers	Bachelor's degree	More than 5 years	None	Yes
11-3031	Financial Managers	Bachelor's degree	More than 5 years	None	Yes
11-3051	Industrial Production Managers	Bachelor's degree	1 to 5 years	None	Yes
11-3061	Purchasing Managers	Bachelor's degree	More than 5 years	None	Yes
11-3071	Transportation, Storage, and Distribution Managers	High school diploma or equivalent	More than 5 years	None	Yes
11-3111	Compensation and Benefits Managers	Bachelor's degree	1 to 5 years	None	Yes
11-3121	Human Resources Managers	Bachelor's degree	1 to 5 years	None	Yes
11-3131	Training and Development Managers	Bachelor's degree	1 to 5 years	None	Yes
11-9021	Construction Managers	Associate's degree	More than 5 years	None	Yes
11-9041	Architectural and Engineering Managers	Bachelor's degree	More than 5 years	None	Yes
11-9121	Natural Sciences Managers	Bachelor's degree	More than 5 years	None	Yes
11-9141	Property, Real Estate, and Community Association Managers	High school diploma or equivalent	1 to 5 years	None	Yes
11-9161	Emergency Management Directors	Bachelor's degree	1 to 5 years	Long-term on-the-job training	Yes

11-9199	Managers, All Other	High school diploma or equivalent	1 to 5 years	None	Yes
13-1021	Buyers and Purchasing Agents, Farm Products	High school diploma or equivalent	None	Long-term on-the-job training	Yes
13-1022	Wholesale and Retail Buyers, Except Farm Products	High school diploma or equivalent	None	Long-term on-the-job training	Yes
13-1023	Purchasing Agents, Except Wholesale, Retail, and Farm Products	High school diploma or equivalent	None	Long-term on-the-job training	Yes
13-1031	Claims Adjusters, Examiners, and Investigators	High school diploma or equivalent	None	Long-term on-the-job training	Yes
13-1041	Compliance Officers	Bachelor's degree	None	Moderate-term on-the-job training	Yes
13-1051	Cost Estimators	Bachelor's degree	None	None	Yes
13-1078	Human Resources, Training, and Labor Relations Specialists, All Other	Bachelor's degree	None	None	Yes
13-1081	Logisticians	Bachelor's degree	1 to 5 years	None	Yes
13-1111	Management Analysts	Bachelor's degree	1 to 5 years	None	Yes
13-1141	Compensation, Benefits, and Job Analysis Specialists	Bachelor's degree	None	None	Yes
13-1151	Training and Development Specialists	Bachelor's degree	None	None	Yes
13-1161	Market Research Analysts and Marketing Specialists	Bachelor's degree	None	None	Yes
13-1199	Business Operations Specialists, All Other	High school diploma or equivalent	Less than 1 year	Long-term on-the-job training	Yes
13-2011	Accountants and Auditors	Bachelor's degree	None	None	Yes
13-2021	Appraisers and Assessors of Real Estate	High school diploma or equivalent	None	Apprenticeship	Yes
13-2031	Budget Analysts	Bachelor's degree	None	None	Yes
13-2041	Credit Analysts	Bachelor's degree	None	None	Yes
13-2051	Financial Analysts	Bachelor's degree	None	None	Yes
13-2061	Financial Examiners	Bachelor's degree	None	Moderate-term on-the-job training	Yes
13-2099	Financial Specialists, All Other	Bachelor's degree	None	Moderate-term on-the-job training	Yes

15-1111	Computer and Information Research Scientists	Doctoral or professional degree	None	None	Yes
15-1121	Computer Systems Analysts	Bachelor's degree	None	None	Yes
15-1131	Computer Programmers	Bachelor's degree	None	None	Yes
15-1132	Software Developers, Applications	Bachelor's degree	None	None	Yes
15-1133	Software Developers, Systems Software	Bachelor's degree	None	None	Yes
15-1141	Database Administrators	Bachelor's degree	1 to 5 years	None	Yes
15-1142	Network and Computer Systems Administrators	Bachelor's degree	None	None	Yes
15-1150	Computer Support Specialists	Some college, no degree	None	Moderate-term on-the-job training	Yes
15-1179	Information Security Analysts, Web Developers, and Computer Network Architects	Bachelor's degree	1 to 5 years	None	Yes
15-1799	Computer Occupations, All Other	Bachelor's degree	None	None	Yes
15-2031	Operations Research Analysts	Bachelor's degree	None	None	Yes
17-1021	Cartographers and Photogrammetrists	Bachelor's degree	None	None	Yes
17-1022	Surveyors	Bachelor's degree	None	None	Yes
17-2041	Chemical Engineers	Bachelor's degree	None	None	Yes
17-2051	Civil Engineers	Bachelor's degree	None	None	Yes
17-2061	Computer Hardware Engineers	Bachelor's degree	None	None	Yes
17-2071	Electrical Engineers	Bachelor's degree	None	None	Yes
17-2072	Electronics Engineers, Except Computer	Bachelor's degree	None	None	Yes
17-2081	Environmental Engineers	Bachelor's degree	None	None	Yes
17-2111	Health and Safety Engineers, Except Mining Safety Engineers and Inspectors	Bachelor's degree	None	None	Yes
17-2112	Industrial Engineers	Bachelor's degree	None	None	Yes
17-2131	Materials Engineers	Bachelor's degree	None	None	Yes
17-2141	Mechanical Engineers	Bachelor's degree	None	None	Yes
17-2151	Mining and Geological Engineers, Including Mining Safety Engineers	Bachelor's degree	None	None	Yes
17-2161	Nuclear Engineers	Bachelor's degree	None	None	Yes
17-2171	Petroleum Engineers	Bachelor's degree	None	None	Yes
17-2199	Engineers, All Other	Bachelor's degree	None	None	Yes
17-3011	Architectural and Civil Drafters	Associate's degree	None	None	Yes

17-3012	Electrical and Electronics Drafters	Associate's degree	None	None	Yes
17-3013	Mechanical Drafters	Associate's degree	None	None	Yes
17-3019	Drafters, All Other	Associate's degree	None	None	Yes
17-3022	Civil Engineering Technicians	Associate's degree	None	None	Yes
17-3023	Electrical and Electronics Engineering Technicians	Associate's degree	None	None	Yes
17-3024	Electro-Mechanical Technicians	Associate's degree	None	None	Yes
17-3025	Environmental Engineering Technicians	Associate's degree	None	None	Yes
17-3026	Industrial Engineering Technicians	Associate's degree	None	None	Yes
17-3027	Mechanical Engineering Technicians	Associate's degree	None	None	Yes
17-3029	Engineering Technicians, Except Drafters, All Other	Associate's degree	None	None	Yes
17-3031	Surveying and Mapping Technicians	High school diploma or equivalent	None	Moderate-term on-the-job training	No
19-1032	Foresters	Bachelor's degree	None	None	Yes
19-2012	Physicists	Doctoral or professional degree	None	None	Yes
19-2031	Chemists	Bachelor's degree	None	None	Yes
19-2032	Materials Scientists	Bachelor's degree	None	None	Yes
19-2041	Environmental Scientists and Specialists, Including Health	Bachelor's degree	None	None	Yes
19-2042	Geoscientists, Except Hydrologists and Geographers	Bachelor's degree	None	None	Yes
19-2099	Physical Scientists, All Other	Bachelor's degree	None	None	Yes
19-3011	Economists	Bachelor's degree	None	None	Yes
19-3051	Urban and Regional Planners	Master's degree	None	None	Yes
19-4031	Chemical Technicians	Associate's degree	None	Moderate-term on-the-job training	Yes
19-4041	Geological and Petroleum Technicians	Associate's degree	None	Moderate-term on-the-job training	Yes
19-4051	Nuclear Technicians	Associate's degree	None	Moderate-term on-the-job training	Yes
19-4091	Environmental Science and Protection Technicians, Including Health	Associate's degree	None	Moderate-term on-the-job training	Yes

19-4099	Life, Physical, and Social Science Technicians, All Other	Associate's degree	None	Moderate-term on-the-job training	Yes
23-1011	Lawyers	Doctoral or professional degree	None	None	Yes
23-2011	Paralegals and Legal Assistants	Associate's degree	None	None	Yes
23-2093	Title Examiners, Abstractors, and Searchers	High school diploma or equivalent	None	Short-term on-the-job training	No
23-2099	Legal Support Workers, All Other	High school diploma or equivalent	None	Short-term on-the-job training	No
25-9021	Farm and Home Management Advisors	Master's degree	None	None	Yes
25-9031	Instructional Coordinators	Master's degree	More than 5 years	None	Yes
27-1021	Commercial and Industrial Designers	Bachelor's degree	None	None	Yes
27-1024	Graphic Designers	Bachelor's degree	None	None	Yes
27-3031	Public Relations Specialists	Bachelor's degree	None	Moderate-term on-the-job training	Yes
27-3041	Editors	Bachelor's degree	1 to 5 years	None	Yes
27-3042	Technical Writers	Bachelor's degree	1 to 5 years	Short-term on-the-job training	Yes
29-1111	Registered Nurses	Associate's degree	None	None	Yes
29-9011	Occupational Health and Safety Specialists	Bachelor's degree	None	Moderate-term on-the-job training	Yes
29-9012	Occupational Health and Safety Technicians	High school diploma or equivalent	None	Moderate-term on-the-job training	No
33-1099	First-Line Supervisors of Protective Service Workers, All Other	High school diploma or equivalent	1 to 5 years	None	Yes
33-9021	Private Detectives and Investigators	Some college, no degree	1 to 5 years	Moderate-term on-the-job training	Yes
33-9032	Security Guards	High school diploma or equivalent	None	Short-term on-the-job training	No
33-9091	Crossing Guards	High school diploma or equivalent	None	Short-term on-the-job training	No
33-9099	Protective Service Workers, All Other	High school diploma or equivalent	None	Short-term on-the-job training	No

35-2012	Cooks, Institution and Cafeteria	Less than high school	None	Short-term on-the-job training	No
35-2019	Cooks, All Other	Less than high school	None	Moderate-term on-the-job training	No
35-3021	Combined Food Preparation and Serving Workers, Including Fast Food	Less than high school	None	Short-term on-the-job training	No
37-1012	First-Line Supervisors of Landscaping, Lawn Service, and Groundskeeping Workers	High school diploma or equivalent	1 to 5 years	None	Yes
37-2011	Janitors and Cleaners, Except Maids and Housekeeping Cleaners	Less than high school	None	Short-term on-the-job training	No
37-3011	Landscaping and Groundskeeping Workers	Less than high school	None	Short-term on-the-job training	No
37-3013	Tree Trimmers and Pruners	High school diploma or equivalent	None	Short-term on-the-job training	No
41-1011	First-Line Supervisors of Retail Sales Workers	High school diploma or equivalent	1 to 5 years	None	Yes
41-1012	First-Line Supervisors of Non-Retail Sales Workers	High school diploma or equivalent	More than 5 years	None	Yes
41-2011	Cashiers	Less than high school	None	Short-term on-the-job training	No
41-2022	Parts Salespersons	Less than high school	None	Moderate-term on-the-job training	No
41-2031	Retail Salespersons	Less than high school	None	Short-term on-the-job training	No
41-3031	Securities, Commodities, and Financial Services Sales Agents	Bachelor's degree	None	Moderate-term on-the-job training	Yes
41-3099	Sales Representatives, Services, All Other	High school diploma or equivalent	None	Short-term on-the-job training	No
41-4011	Sales Representatives, Wholesale and Manufacturing, Technical and Scientific Products	Bachelor's degree	None	Moderate-term on-the-job training	Yes
41-4012	Sales Representatives, Wholesale and Manufacturing, Except Technical and Scientific Products	High school diploma or equivalent	None	Moderate-term on-the-job training	No

41-9021	Real Estate Brokers	High school diploma or equivalent	1 to 5 years	None	Yes
41-9022	Real Estate Sales Agents	High school diploma or equivalent	None	Long-term on-the-job training	Yes
41-9031	Sales Engineers	Bachelor's degree	None	Moderate-term on-the-job training	Yes
41-9799	Sales and Related Workers, All Other	High school diploma or equivalent	None	Moderate-term on-the-job training	No
43-1011	First-Line Supervisors of Office and Administrative Support Workers	High school diploma or equivalent	1 to 5 years	None	Yes
43-2011	Switchboard Operators, Including Answering Service	High school diploma or equivalent	None	Short-term on-the-job training	No
43-3011	Bill and Account Collectors	High school diploma or equivalent	None	Moderate-term on-the-job training	No
43-3021	Billing and Posting Clerks	High school diploma or equivalent	None	Short-term on-the-job training	No
43-3031	Bookkeeping, Accounting, and Auditing Clerks	High school diploma or equivalent	None	Moderate-term on-the-job training	No
43-3051	Payroll and Timekeeping Clerks	High school diploma or equivalent	None	Moderate-term on-the-job training	No
43-3061	Procurement Clerks	High school diploma or equivalent	None	Moderate-term on-the-job training	No
43-4041	Credit Authorizers, Checkers, and Clerks	High school diploma or equivalent	None	Short-term on-the-job training	No
43-4051	Customer Service Representatives	High school diploma or equivalent	None	Short-term on-the-job training	No
43-4071	File Clerks	High school diploma or equivalent	None	Short-term on-the-job training	No
43-4151	Order Clerks	High school diploma or equivalent	None	Short-term on-the-job training	No
43-4161	Human Resources Assistants, Except Payroll and Timekeeping	High school diploma or equivalent	None	Short-term on-the-job training	No
43-4171	Receptionists and Information Clerks	High school diploma or equivalent	None	Short-term on-the-job training	No
43-4199	Information and Record Clerks, All Other	High school diploma or equivalent	None	Short-term on-the-job training	No

43-5021	Couriers and Messengers	High school diploma or equivalent	None	Short-term on-the-job training	No
43-5032	Dispatchers, Except Police, Fire, and Ambulance	High school diploma or equivalent	None	Moderate-term on-the-job training	No
43-5041	Meter Readers, Utilities	High school diploma or equivalent	None	Short-term on-the-job training	No
43-5061	Production, Planning, and Expediting Clerks	High school diploma or equivalent	None	Moderate-term on-the-job training	No
43-5071	Shipping, Receiving, and Traffic Clerks	High school diploma or equivalent	None	Short-term on-the-job training	No
43-5081	Stock Clerks and Order Fillers	Less than high school	None	Short-term on-the-job training	No
43-5111	Weighers, Measurers, Checkers, and Samplers, Recordkeeping	High school diploma or equivalent	None	Short-term on-the-job training	No
43-6011	Executive Secretaries and Executive Administrative Assistants	High school diploma or equivalent	1 to 5 years	None	Yes
43-6012	Legal Secretaries	High school diploma or equivalent	None	Moderate-term on-the-job training	No
43-6014	Secretaries and Administrative Assistants, Except Legal, Medical, and Executive	High school diploma or equivalent	None	Short-term on-the-job training	No
43-9011	Computer Operators	High school diploma or equivalent	None	Moderate-term on-the-job training	No
43-9021	Data Entry Keyers	High school diploma or equivalent	None	Moderate-term on-the-job training	No
43-9022	Word Processors and Typists	High school diploma or equivalent	None	Short-term on-the-job training	No
43-9051	Mail Clerks and Mail Machine Operators, Except Postal Service	High school diploma or equivalent	None	Short-term on-the-job training	No
43-9061	Office Clerks, General	High school diploma or equivalent	None	Short-term on-the-job training	No
43-9071	Office Machine Operators, Except Computer	High school diploma or equivalent	None	Short-term on-the-job training	No
43-9799	Office and Administrative Support Workers, All Other	High school diploma or equivalent	None	Short-term on-the-job training	No

45-2093	Farmworkers, Farm, Ranch, and Aquacultural Animals				
45-2099	Agricultural Workers, All Other				
47-1011	First-Line Supervisors of Construction Trades and Extraction Workers	High school diploma or equivalent	More than 5 years	None	Yes
47-2011	Boilermakers	High school diploma or equivalent	None	Apprenticeship	Yes
47-2021	Brickmasons and Blockmasons	High school diploma or equivalent	None	Apprenticeship	Yes
47-2031	Carpenters	High school diploma or equivalent	None	Apprenticeship	Yes
47-2051	Cement Masons and Concrete Finishers	Less than high school	None	Moderate-term on-the-job training	No
47-2061	Construction Laborers	Less than high school	None	Short-term on-the-job training	No
47-2071	Paving, Surfacing, and Tamping Equipment Operators	High school diploma or equivalent	None	Moderate-term on-the-job training	No
47-2072	Pile-Driver Operators	High school diploma or equivalent	None	Moderate-term on-the-job training	No
47-2073	Operating Engineers and Other Construction Equipment Operators	High school diploma or equivalent	None	Moderate-term on-the-job training	No
47-2111	Electricians	High school diploma or equivalent	None	Apprenticeship	Yes
47-2132	Insulation Workers, Mechanical	High school diploma or equivalent	None	Apprenticeship	Yes
47-2141	Painters, Construction and Maintenance	Less than high school	None	Moderate-term on-the-job training	No
47-2151	Pipelayers	High school diploma or equivalent	None	Short-term on-the-job training	No
47-2152	Plumbers, Pipefitters, and Steamfitters	High school diploma or equivalent	None	Apprenticeship	Yes
47-2171	Reinforcing Iron and Rebar Workers	High school diploma or equivalent	None	Apprenticeship	Yes
47-2211	Sheet Metal Workers	High school diploma or equivalent	None	Apprenticeship	Yes

47-2221	Structural Iron and Steel Workers	High school diploma or equivalent	None	Apprenticeship	Yes
47-3012	Helpers--Carpenters	Less than high school	None	Short-term on-the-job training	No
47-3013	Helpers--Electricians	High school diploma or equivalent	None	Short-term on-the-job training	No
47-3014	Helpers--Painters, Paperhangers, Plasterers, and Stucco Masons	Less than high school	None	Short-term on-the-job training	No
47-3015	Helpers--Pipelayers, Plumbers, Pipefitters, and Steamfitters	High school diploma or equivalent	None	Short-term on-the-job training	No
47-3019	Helpers, Construction Trades, All Other	Less than high school	None	Short-term on-the-job training	No
47-4011	Construction and Building Inspectors	High school diploma or equivalent	More than 5 years	Moderate-term on-the-job training	Yes
47-4041	Hazardous Materials Removal Workers	High school diploma or equivalent	None	Moderate-term on-the-job training	No
47-4051	Highway Maintenance Workers	High school diploma or equivalent	None	Moderate-term on-the-job training	No
47-4061	Rail-Track Laying and Maintenance Equipment Operators	High school diploma or equivalent	None	Moderate-term on-the-job training	No
47-4071	Septic Tank Servicers and Sewer Pipe Cleaners	Less than high school	None	Moderate-term on-the-job training	No
47-4799	Construction and Related Workers, All Other	High school diploma or equivalent	None	Moderate-term on-the-job training	No
47-5011	Derrick Operators, Oil and Gas	Less than high school	None	Short-term on-the-job training	No
47-5012	Rotary Drill Operators, Oil and Gas	Less than high school	None	Moderate-term on-the-job training	No
47-5013	Service Unit Operators, Oil, Gas, and Mining	Less than high school	None	Moderate-term on-the-job training	No
47-5021	Earth Drillers, Except Oil and Gas	High school diploma or equivalent	None	Moderate-term on-the-job training	No
47-5031	Explosives Workers, Ordnance Handling Experts, and Blasters	High school diploma or equivalent	None	Moderate-term on-the-job training	No
47-5041	Continuous Mining Machine Operators	High school diploma or equivalent	None	Moderate-term on-the-job training	No

47-5042	Mine Cutting and Channeling Machine Operators	High school diploma or equivalent	None	Moderate-term on-the-job training	No
47-5049	Mining Machine Operators, All Other	High school diploma or equivalent	None	Moderate-term on-the-job training	No
47-5051	Rock Splitters, Quarry	High school diploma or equivalent	None	Moderate-term on-the-job training	No
47-5061	Roof Bolters, Mining	High school diploma or equivalent	None	Moderate-term on-the-job training	No
47-5071	Roustabouts, Oil and Gas	Less than high school	None	Moderate-term on-the-job training	No
47-5081	Helpers--Extraction Workers	High school diploma or equivalent	None	Short-term on-the-job training	No
47-5099	Extraction Workers, All Other	High school diploma or equivalent	None	Moderate-term on-the-job training	No
49-1011	First-Line Supervisors of Mechanics, Installers, and Repairers	High school diploma or equivalent	1 to 5 years	None	Yes
49-2011	Computer, Automated Teller, and Office Machine Repairers	Postsecondary non-degree award	None	None	Yes
49-2021	Radio, Cellular, and Tower Equipment Installers and Repairs	Associate's degree	None	Moderate-term on-the-job training	Yes
49-2022	Telecommunications Equipment Installers and Repairers, Except Line Installers	Postsecondary non-degree award	None	Moderate-term on-the-job training	Yes
49-2092	Electric Motor, Power Tool, and Related Repairers	Postsecondary non-degree award	None	Long-term on-the-job training	Yes
49-2093	Electrical and Electronics Installers and Repairers, Transportation Equipment	Postsecondary non-degree award	None	Long-term on-the-job training	Yes
49-2094	Electrical and Electronics Repairers, Commercial and Industrial Equipment	Postsecondary non-degree award	None	Long-term on-the-job training	Yes
49-2095	Electrical and Electronics Repairers, Powerhouse, Substation, and Relay	Postsecondary non-degree award	None	Long-term on-the-job training	Yes
49-3011	Aircraft Mechanics and Service Technicians	Postsecondary non-degree award	None	None	Yes
49-3023	Automotive Service Technicians and Mechanics	High school diploma or equivalent	None	Long-term on-the-job training	Yes

49-3031	Bus and Truck Mechanics and Diesel Engine Specialists	High school diploma or equivalent	None	Long-term on-the-job training	Yes
49-3041	Farm Equipment Mechanics and Service Technicians	High school diploma or equivalent	None	Long-term on-the-job training	Yes
49-3042	Mobile Heavy Equipment Mechanics, Except Engines	High school diploma or equivalent	None	Long-term on-the-job training	Yes
49-3043	Rail Car Repairers	High school diploma or equivalent	None	Long-term on-the-job training	Yes
49-3093	Tire Repairers and Changers	High school diploma or equivalent	None	Moderate-term on-the-job training	No
49-9012	Control and Valve Installers and Repairers, Except Mechanical Door	High school diploma or equivalent	None	Moderate-term on-the-job training	No
49-9021	Heating, Air Conditioning, and Refrigeration Mechanics and Installers	Postsecondary non-degree award	None	Long-term on-the-job training	Yes
49-9031	Home Appliance Repairers	High school diploma or equivalent	None	Moderate-term on-the-job training	No
49-9041	Industrial Machinery Mechanics	High school diploma or equivalent	None	Long-term on-the-job training	Yes
49-9043	Maintenance Workers, Machinery	High school diploma or equivalent	None	Moderate-term on-the-job training	No
49-9044	Millwrights	High school diploma or equivalent	None	Long-term on-the-job training	Yes
49-9045	Refractory Materials Repairers, Except Brickmasons	Postsecondary non-degree award	None	Moderate-term on-the-job training	Yes
49-9051	Electrical Power-Line Installers and Repairers	High school diploma or equivalent	None	Long-term on-the-job training	Yes
49-9052	Telecommunications Line Installers and Repairers	High school diploma or equivalent	None	Long-term on-the-job training	Yes
49-9069	Precision Instrument and Equipment Repairers, All Other	Associate's degree	None	Long-term on-the-job training	Yes
49-9071	Maintenance and Repair Workers, General	High school diploma or equivalent	None	Moderate-term on-the-job training	No
49-9092	Commercial Divers	Postsecondary non-degree award	None	Moderate-term on-the-job training	Yes
49-9096	Riggers	High school diploma or equivalent	None	Short-term on-the-job training	No

49-9098	Helpers--Installation, Maintenance, and Repair Workers	High school diploma or equivalent	None	Moderate-term on-the-job training	No
49-9799	Installation, Maintenance, and Repair Workers, All Other	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-1011	First-Line Supervisors of Production and Operating Workers	Postsecondary non-degree award	1 to 5 years	None	Yes
51-2021	Coil Winders, Tapers, and Finishers	High school diploma or equivalent	None	Short-term on-the-job training	No
51-2022	Electrical and Electronic Equipment Assemblers	High school diploma or equivalent	None	Short-term on-the-job training	No
51-2023	Electromechanical Equipment Assemblers	High school diploma or equivalent	None	Short-term on-the-job training	No
51-2041	Structural Metal Fabricators and Fitters	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-2092	Team Assemblers	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-2099	Assemblers and Fabricators, All Other	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4011	Computer-Controlled Machine Tool Operators, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4012	Computer Numerically Controlled Machine Tool Programmers, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4021	Extruding and Drawing Machine Setters, Operators, and Tenders, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4022	Forging Machine Setters, Operators, and Tenders, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4023	Rolling Machine Setters, Operators, and Tenders, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4031	Cutting, Punching, and Press Machine Setters, Operators, and Tenders, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4032	Drilling and Boring Machine Tool Setters, Operators, and Tenders, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No

51-4033	Grinding, Lapping, Polishing, and Buffing Machine Tool Setters, Operators, and Tenders, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4034	Lathe and Turning Machine Tool Setters, Operators, and Tenders, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4035	Milling and Planing Machine Setters, Operators, and Tenders, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4041	Machinists	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-4051	Metal-Refining Furnace Operators and Tenders	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4052	Pourers and Casters, Metal	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4061	Model Makers, Metal and Plastic	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-4062	Patternmakers, Metal and Plastic	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-4071	Foundry Mold and Coremakers	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4072	Molding, Coremaking, and Casting Machine Setters, Operators, and Tenders, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4081	Multiple Machine Tool Setters, Operators, and Tenders, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4111	Tool and Die Makers	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-4121	Welders, Cutters, Solderers, and Brazers	High school diploma or equivalent	Less than 1 year	Moderate-term on-the-job training	No
51-4122	Welding, Soldering, and Brazing Machine Setters, Operators, and Tenders	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4191	Heat Treating Equipment Setters, Operators, and Tenders, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No

51-4192	Layout Workers, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4193	Plating and Coating Machine Setters, Operators, and Tenders, Metal and Plastic	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4194	Tool Grinders, Filers, and Sharpeners	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-4199	Metal Workers and Plastic Workers, All Other	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-8011	Nuclear Power Reactor Operators	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-8012	Power Distributors and Dispatchers	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-8013	Power Plant Operators	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-8021	Stationary Engineers and Boiler Operators	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-8031	Water and Wastewater Treatment Plant and System Operators	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-8091	Chemical Plant and System Operators	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-8092	Gas Plant Operators	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-8093	Petroleum Pump System Operators, Refinery Operators, and Gaugers	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-8099	Plant and System Operators, All Other	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-9011	Chemical Equipment Operators and Tenders	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-9012	Separating, Filtering, Clarifying, Precipitating, and Still Machine Setters, Operators, and Tenders	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-9021	Crushing, Grinding, and Polishing Machine Setters, Operators, and Tenders	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-9022	Grinding and Polishing Workers, Hand	Less than high school	None	Moderate-term on-the-job training	No

51-9023	Mixing and Blending Machine Setters, Operators, and Tenders	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-9032	Cutting and Slicing Machine Setters, Operators, and Tenders	High school diploma or equivalent	None	Short-term on-the-job training	No
51-9041	Extruding, Forming, Pressing, and Compacting Machine Setters, Operators, and Tenders	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-9051	Furnace, Kiln, Oven, Drier, and Kettle Operators and Tenders	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-9061	Inspectors, Testers, Sorters, Samplers, and Weighers	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-9071	Jewelers and Precious Stone and Metal Workers	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-9111	Packaging and Filling Machine Operators and Tenders	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-9121	Coating, Painting, and Spraying Machine Setters, Operators, and Tenders	High school diploma or equivalent	None	Moderate-term on-the-job training	No
51-9192	Cleaning, Washing, and Metal Pickling Equipment Operators and Tenders	Less than high school	None	Moderate-term on-the-job training	No
51-9195	Molders, Shapers, and Casters, Except Metal and Plastic	High school diploma or equivalent	None	Long-term on-the-job training	Yes
51-9198	Helpers--Production Workers	Less than high school	None	Short-term on-the-job training	No
51-9399	Production Workers, All Other	High school diploma or equivalent	None	Moderate-term on-the-job training	No
53-1021	First-Line Supervisors of Helpers, Laborers, and Material Movers, Hand	High school diploma or equivalent	1 to 5 years	None	Yes
53-1031	First-Line Supervisors of Transportation and Material-Moving Machine and Vehicle Operators	High school diploma or equivalent	1 to 5 years	None	Yes
53-2012	Commercial Pilots	High school diploma or equivalent	None	Long-term on-the-job training	Yes
53-3031	Driver/Sales Workers	High school diploma or equivalent	None	Short-term on-the-job training	No
53-3032	Heavy and Tractor-Trailer Truck Drivers	High school diploma or equivalent	1 to 5 years	Short-term on-the-job training	Yes

53-3033	Light Truck or Delivery Services Drivers	High school diploma or equivalent	None	Short-term on-the-job training	No
53-3099	Motor Vehicle Operators, All Other	High school diploma or equivalent	None	Short-term on-the-job training	No
53-4011	Locomotive Engineers	High school diploma or equivalent	1 to 5 years	Moderate-term on-the-job training	Yes
53-4013	Rail Yard Engineers, Dinkey Operators, and Hostlers	High school diploma or equivalent	None	Moderate-term on-the-job training	No
53-5011	Sailors and Marine Oilers	Less than high school	None	Short-term on-the-job training	No
53-5021	Captains, Mates, and Pilots of Water Vessels	Bachelor's degree	None	None	Yes
53-6031	Automotive and Watercraft Service Attendants	Less than high school	None	Short-term on-the-job training	No
53-6099	Transportation Workers, All Other	High school diploma or equivalent	None	Short-term on-the-job training	No
53-7011	Conveyor Operators and Tenders	Less than high school	None	Short-term on-the-job training	No
53-7021	Crane and Tower Operators	Less than high school	1 to 5 years	Long-term on-the-job training	Yes
53-7031	Dredge Operators	Less than high school	None	Short-term on-the-job training	No
53-7032	Excavating and Loading Machine and Dragline Operators	Less than high school	1 to 5 years	Moderate-term on-the-job training	Yes
53-7033	Loading Machine Operators, Underground Mining	Less than high school	None	Short-term on-the-job training	No
53-7041	Hoist and Winch Operators	Less than high school	None	Moderate-term on-the-job training	No
53-7051	Industrial Truck and Tractor Operators	Less than high school	Less than 1 year	Short-term on-the-job training	No
53-7061	Cleaners of Vehicles and Equipment	Less than high school	None	Short-term on-the-job training	No
53-7062	Laborers and Freight, Stock, and Material Movers, Hand	Less than high school	None	Short-term on-the-job training	No
53-7063	Machine Feeders and Offbearers	Less than high school	None	Short-term on-the-job training	No

53-7064	Packers and Packagers, Hand	Less than high school	None	Short-term on-the-job training	No
53-7071	Gas Compressor and Gas Pumping Station Operators	Less than high school	None	Moderate-term on-the-job training	No
53-7072	Pump Operators, Except Wellhead Pumpers	Less than high school	None	Moderate-term on-the-job training	No
53-7073	Wellhead Pumpers	Less than high school	Less than 1 year	Moderate-term on-the-job training	No
53-7111	Mine Shuttle Car Operators	Less than high school	None	Short-term on-the-job training	No
53-7121	Tank Car, Truck, and Ship Loaders	Less than high school	None	Short-term on-the-job training	No
53-7199	Material Moving Workers, All Other	Less than high school	None	Short-term on-the-job training	No

Notes: The table above includes occupations in the following energy and mining NAICS codes: 211, 212, 213, 2211, 2212, 2371, 324, 331, 486 (and excludes 22133, 33313, and 333611 because data by occupation is not available for these NAICS codes). A blank cell indicates data is not available. A high skill occupation is one that requires any of the following: (1) post-secondary education, (2) a year or more of experience in a related occupation, or (3) long-term on the job training or apprenticeship.
Source: BLS 2012f. Additional tabulations by the National Research Council.

TABLE C.8. Instructional programs that feed into key U.S. energy and mining occupations that require post-secondary education.

Standard Occupation Code	Standard Occupation Title	CIP Code	CIP Title
17-2071	Electrical Engineers	14.1001	Electrical and Electronics Engineering
		14.1099	Electrical, Electronics and Communications Engineering, Other.
17-2111	Health and Safety Engineers, Except Mining Safety Engineers and Inspectors	14.1401	Environmental/Environmental Health Engineering.
17-2131	Materials Engineers	14.0601	Ceramic Sciences and Engineering.
		14.1801	Materials Engineering.
		14.2001	Metallurgical Engineering.
		14.2801	Textile Sciences and Engineering.
		14.3201	Polymer/Plastics Engineering.
17-2151	Mining and Geological Engineers, Including Mining Safety Engineers	14.0802	Geotechnical and Geoenvironmental Engineering.
		14.2101	Mining and Mineral Engineering.
		14.3901	Geological/Geophysical Engineering.
17-2161	Nuclear Engineers	14.2301	Nuclear Engineering.
17-2171	Petroleum Engineers	14.0802	Geotechnical and Geoenvironmental Engineering.
		14.2501	Petroleum Engineering.
17-3029	Engineering Technicians, Except Drafters, All Other	15.0101	Architectural Engineering Technology/Technician.
		15.0304	Laser and Optical Technology/Technician.
		15.0401	Biomedical Technology/Technician.
		15.0501	Heating, Ventilation, Air Conditioning and Refrigeration Engineering Technology/Technician.
		15.0503	Energy Management and Systems Technology/Technician.
		15.0505	Solar Energy Technology/Technician.
		15.0599	Environmental Control Technologies/Technicians, Other.
		15.0607	Plastics and Polymer Engineering Technology/Technician.
		15.0611	Metallurgical Technology/Technician.
		15.0614	Welding Engineering Technology/Technician.
		15.0615	Chemical Engineering Technology/Technician.

		15.0901	Mining Technology/Technician.
		15.1103	Hydraulics and Fluid Power Technology/Technician.
		15.1203	Computer Hardware Technology/Technician.
		15.1503	Packaging Science.
19-2042	Geoscientists, Except Hydrologists and Geographers	30.3201	Marine Sciences.
		40.0601	Geology/Earth Science, General.
		40.0602	Geochemistry.
		40.0603	Geophysics and Seismology.
		40.0604	Paleontology.
		40.0606	Geochemistry and Petrology.
		40.0607	Oceanography, Chemical and Physical.
		40.0699	Geological and Earth Sciences/Geosciences, Other.
19-4041	Geological and Petroleum Technicians	15.0903	Petroleum Technology/Technician.
		15.0999	Mining and Petroleum Technologies/Technicians, Other.
19-4051	Nuclear Technicians	15.1401	Nuclear Engineering Technology/Technician.
		41.0204	Industrial Radiologic Technology/Technician.
		41.0205	Nuclear/Nuclear Power Technology/Technician.
		41.0299	Nuclear and Industrial Radiologic Technologies/Technicians, Other.
		51.0916	Radiation Protection/Health Physics Technician.
29-9011	Occupational Health and Safety Specialists	15.0701	Occupational Safety and Health Technology/Technician.
	Occupational Health and Safety Specialists	15.0703	Industrial Safety Technology/Technician.
	Occupational Health and Safety Specialists	51.2202	Environmental Health.
	Occupational Health and Safety Specialists	51.2206	Occupational Health and Industrial Hygiene.
49-2095	Electrical and Electronics Repairers, Powerhouse, Substation, and Relay	NO MATCH	NO MATCH

Source: NCES, 2010, BLS, 2012g.

TABLE C.9. Number of U.S. degrees and certificates conferred across instructional programs related to key U.S. energy and mining occupations that require post-secondary education, 2005-2009.

Standard Occupation Code	**Standard Occupation Title**	**Degree Level**	**2005**	**2006**	**2007**	**2008**	**2009**
17-2071	Electrical Engineers	Doctorate degrees	1,567	1,863	2,048	2,006	1,819
		Master's degrees	9,107	8,265	7,828	8,719	9,281
		Bachelor's degrees	14,453	14,225	13,376	12,618	11,862
		Associate's degrees	219	178	157	163	180
		Post-master's certificates	63	67	68	77	78
		Post-baccalaureate certificates	13	6	3	9	33
		1 but less than 2 year certificates	6	8	3	9	2
		Less than 1 year certificates	.	.	.	.	11
17-2111	Health and Safety Engineers, Except Mining Safety Engineers and Inspectors	Doctorate degrees	111	107	121	144	134
		Master's degrees	642	589	539	555	560
		Bachelor's degrees	468	432	441	504	570
		Associate's degrees	14	10	6	5	7
		Post-master's certificates	11	7	4	5	7
		Post-baccalaureate certificates	13	27	11	8	14
17-2131	Materials Engineers	Doctorate degrees	449	519	540	534	542
		Master's degrees	755	726	699	694	719
		Bachelor's degrees	929	954	1,007	1,122	1,096
		Associate's degrees	2	2	.	2	1
		Post-master's certificates	4	3	5	12	1
		Post-baccalaureate certificates	.	.	.	2	1
		1 but less than 2 year certificates	1	.	.	2	1
		Less than 1 year certificates	.	.	1	.	1
17-2151	Mining and Geological Engineers, Including Mining Safety Engineers	Doctorate degrees	15	19	25	15	14
		Master's degrees	83	86	97	118	131
		Bachelor's degrees	198	214	248	260	309
		Post-master's certificates	.	1	.	.	.
		Post-baccalaureate certificates	.	.	.	2	5
		1 but less than 2 year certificates	.	.	.	3	2
		Less than 1 year certificates	1	.	1	.	.
17-2161	Nuclear Engineers	Doctorate degrees	78	80	84	100	81

		Master's degrees	160	221	227	249	252
		Bachelor's degrees	264	360	384	430	373
		Post-master's certificates	.	.	2	.	3
		Post-baccalaureate certificates	4	2	2	5	5
		Less than 1 year certificates	.	.	.	11	25
17-2171	Petroleum Engineers	Doctorate degrees	49	45	37	48	52
		Master's degrees	248	253	225	242	251
		Bachelor's degrees	322	353	450	521	690
		Associate's degrees	.	1	3	.	1
		Post-master's certificates	1	.	1	2	2
		Post-baccalaureate certificates	.	1	1	6	12
		1 but less than 2 year certificates	.	.	.	3	3
		Less than 1 year certificates	2	4	6	.	1
17-3029	*Engineering Technicians, Except Drafters, All Other*	*Doctorate degrees*	*5*	*10*	*3*	*6*	*8*
		Master's degrees	*78*	*80*	*88*	*82*	*101*
		Bachelor's degrees	*645*	*692*	*840*	*832*	*819*
		Associate's degrees	*2,908*	*2,776*	*2,898*	*2,860*	*2,992*
		Post-baccalaureate certificates	*1*	.	.	.	.
		2 but less than 4 year certificates	*119*	*51*	*59*	*13*	*16*
		1 but less than 2 year certificates	*1,048*	*996*	*899*	*860*	*1,049*
		Less than 1 year certificates	*803*	*691*	*727*	*930*	*1,135*
19-2042	Geoscientists, Except Hydrologists and Geographers	Doctorate degrees	463	500	633	573	611
		Master's degrees	1,412	1,471	1,411	1,330	1,315
		Bachelor's degrees	3,262	3,300	3,304	3,548	3,801
		Associate's degrees	43	57	56	59	92
		Post-master's certificates	38	24	20	34	19
		Post-baccalaureate certificates	11	18	6	12	20
		Less than 1 year certificates	7	8	5	7	11
19-4041	*Geological and Petroleum Technicians*	*Master's degrees*	*1*	*3*	*1*	.	*1*
		Bachelor's degrees	*12*	*12*	*16*	*13*	*11*
		Associate's degrees	*46*	*38*	*58*	*73*	*101*
		1 but less than 2 year certificates	*9*	.	.	.	*29*
		Less than 1 year certificates	*15*	*13*	*15*	*26*	*19*
19-4051	*Nuclear Technicians*	*Master's degrees*	*10*	*10*	*24*	*33*	*23*
		Bachelor's degrees	*27*	*45*	*107*	*109*	*121*

		Associate's degrees	*80*	*55*	*77*	*110*	*109*
		1 but less than 2 year certificates	*.*	*7*	*6*	*15*	*21*
		Less than 1 year certificates	*6*	*8*	*5*	*7*	*18*
29-9011	Occupational Health and Safety Specialists	Doctorate degrees	61	61	75	88	67
		Master's degrees	510	508	515	487	551
		Bachelor's degrees	692	724	781	816	812
		Associate's degrees	281	286	295	297	372
		Post-master's certificates	7	.	11	14	8
		Post-baccalaureate certificates	14	7	6	16	23
		2 but less than 4 year certificates	2	2	8	6	3
		1 but less than 2 year certificates	49	63	122	88	91
		Less than 1 year certificates	42	48	61	35	68

Note: The occupations in *italics* typically require an associate's degree or higher upon entry; the remaining occupations typically require a bachelor's degree or higher upon entry.
Source: WebCASPAR, 2012. Additional tabulations by the National Research Council.

TABLE C.10. Number of U.S. degrees and certificates conferred in 2009 for each instructional program related to key U.S. energy and mining occupations that require post-secondary education.

Standard Occupation Code	Standard Occupation Title	CIP Code	CIP Title	Degree Level	Degrees/Certificates Conferred (2009)
17-2071	Electrical Engineers	14.1001	Electrical and Electronics Engineering	Doctorate degrees	1,819
				Master's degrees	9,281
				Bachelor's degrees	11,862
				Associate's degrees	180
				Post-master's certificates	78
				Post-baccalaureate certificates	33
				1 but less than 2 year certificates	2
				Less than 1 year certificates	11
17-2111	Health and Safety Engineers, Except Mining Safety Engineers and Inspectors	14.1401	Environmental/Environmental Health Engineering.	Doctorate degrees	134
				Master's degrees	560
				Bachelor's degrees	570
				Associate's degrees	7
				Post-master's certificates	7
				Post-baccalaureate certificates	14
17-2131	Materials Engineers	14.0601	Ceramic Sciences and Engineering.	Doctorate degrees	7
				Master's degrees	8
				Bachelor's degrees	69
		14.1801	Materials Engineering.	Doctorate degrees	434
				Master's degrees	572
				Bachelor's degrees	679
				Associate's degrees	1
				Post-baccalaureate certificates	1
		14.2001	Metallurgical Engineering.	Doctorate degrees	31
				Master's degrees	52
				Bachelor's degrees	100
		14.2801	Textile Sciences and Engineering.	Doctorate degrees	33
				Master's degrees	49
				Bachelor's degrees	181
		14.3201	Polymer/Plastics Engineering.	Doctorate degrees	37
				Master's degrees	38

				Bachelor's degrees	67
				Post-master's certificates	1
				1 but less than 2 year certificates	1
				Less than 1 year certificates	1
17-2151	Mining and Geological Engineers, Including Mining Safety Engineers	14.0802	Geotechnical and Geoenvironmental Engineering.	Master's degrees	5
		14.2101	Mining and Mineral Engineering.	Doctorate degrees	10
				Master's degrees	48
				Bachelor's degrees	176
				Post-baccalaureate certificates	1
				1 but less than 2 year certificates	2
		14.3901	Geological/Geophysical Engineering.	Doctorate degrees	4
				Master's degrees	78
				Bachelor's degrees	133
				Post-baccalaureate certificates	4
17-2161	Nuclear Engineers	14.2301	Nuclear Engineering.	Doctorate degrees	81
				Master's degrees	252
				Bachelor's degrees	373
				Post-master's certificates	3
				Post-baccalaureate certificates	5
				Less than 1 year certificates	25
17-2171	Petroleum Engineers	14.0802	Geotechnical and Geoenvironmental Engineering.	Post-baccalaureate certificates	7
				1 but less than 2 year certificates	3
				Less than 1 year certificates	1
		14.2501	Petroleum Engineering.	Doctorate degrees	52
				Master's degrees	251
				Bachelor's degrees	690
				Associate's degrees	1
				Post-master's certificates	2
				Post-baccalaureate certificates	5
17-3029	*Engineering Technicians, Except Drafters, All Other*	*15.0101*	*Architectural Engineering Technology/Technician.*	*Bachelor's degrees*	*552*
				Associate's degrees	*929*
				1 but less than 2 year certificates	*39*
				Less than 1 year certificates	*343*

		15.0304	*Laser and Optical Technology/Technician.*	*Associate's degrees*	*80*
				1 but less than 2 year certificates	*36*
				Less than 1 year certificates	*31*
		15.0401	*Biomedical Technology/Technician.*	*Doctorate degrees*	*8*
				Master's degrees	*20*
				Bachelor's degrees	*79*
				Associate's degrees	*388*
				2 but less than 4 year certificates	*1*
				1 but less than 2 year certificates	*41*
				Less than 1 year certificates	*59*
		15.0501	*Heating, Ventilation, Air Conditioning and Refrigeration Engineering Technology/Technician.*	*Bachelor's degrees*	*14*
				Associate's degrees	*787*
				1 but less than 2 year certificates	*855*
				Less than 1 year certificates	*572*
		15.0503	*Energy Management and Systems Technology/Technician.*	*Master's degrees*	*25*
				Bachelor's degrees	*50*
				Associate's degrees	*113*
				1 but less than 2 year certificates	*26*
				Less than 1 year certificates	*60*
		15.0505	*Solar Energy Technology/Technician.*	*Bachelor's degrees*	*21*
				Associate's degrees	*5*
				1 but less than 2 year certificates	*6*
		15.0599	*Environmental Control Technologies/Technicians, Other.*	*Master's degrees*	*46*
				Bachelor's degrees	*11*
				Associate's degrees	*471*
				1 but less than 2 year certificates	*7*
				Less than 1 year certificates	*27*
		15.0607	*Plastics and Polymer Engineering Technology/Technician.*	*Master's degrees*	*9*
				Bachelor's degrees	*85*
				Associate's degrees	*75*
				1 but less than 2 year certificates	*15*
				Less than 1 year certificates	*13*
		15.0611	*Metallurgical Technology/Technician.*	*Bachelor's degrees*	*4*
				Associate's degrees	*71*
				1 but less than 2 year certificates	*14*

Prepublication Version

				Less than 1 year certificates	*14*
		15.0901	*Mining Technology/Technician.*	*Bachelor's degrees*	*2*
				Associate's degrees	*40*
				1 but less than 2 year certificates	*2*
		15.1103	*Hydraulics and Fluid Power Technology/Technician.*	*Associate's degrees*	*29*
				2 but less than 4 year certificates	*15*
				1 but less than 2 year certificates	*4*
				Less than 1 year certificates	*8*
		15.1203	*Computer Hardware Technology/Technician.*	*Master's degrees*	*1*
				Bachelor's degrees	*1*
				Associate's degrees	*4*
				1 but less than 2 year certificates	*4*
				Less than 1 year certificates	*8*
19-2042	Geoscientists, Except Hydrologists and Geographers	40.0601	Geology/Earth Science, General.	Doctorate degrees	396
				Master's degrees	1,017
				Bachelor's degrees	3,268
				Associate's degrees	51
				Post-master's certificates	17
				Post-baccalaureate certificates	13
				Less than 1 year certificates	1
		40.0602	Geochemistry.	Doctorate degrees	3
				Master's degrees	13
				Bachelor's degrees	10
				Post-master's certificates	2
		40.0603	Geophysics and Seismology.	Doctorate degrees	50
				Master's degrees	77
				Bachelor's degrees	86
		40.0604	Paleontology.	Master's degrees	4
		40.0607	Oceanography, Chemical and Physical.	Doctorate degrees	111
				Master's degrees	137
				Bachelor's degrees	142
				Associate's degrees	35
				Less than 1 year certificates	6
		40.0699	Geological and Earth Sciences/Geosciences, Other.	Doctorate degrees	51
				Master's degrees	67

				Bachelor's degrees	295
				Associate's degrees	6
				Post-baccalaureate certificates	7
				Less than 1 year certificates	4
19-4041	*Geological and Petroleum Technicians*	*15.0903*	*Petroleum Technology/Technician.*	*Bachelor's degrees*	*9*
				Associate's degrees	*85*
				1 but less than 2 year certificates	*29*
				Less than 1 year certificates	*19*
		15.0999	*Mining and Petroleum Technologies/Technicians, Other.*	*Master's degrees*	*1*
				Bachelor's degrees	*2*
				Associate's degrees	*16*
19-4051	*Nuclear Technicians*	*15.1401*	*Nuclear Engineering Technology/Technician.*	*Bachelor's degrees*	*108*
				Associate's degrees	*39*
				1 but less than 2 year certificates	*17*
		41.0204	*Industrial Radiologic Technology/Technician.*	*Associate's degrees*	*39*
				Less than 1 year certificates	*1*
		41.0205	*Nuclear/Nuclear Power Technology/Technician.*	*Master's degrees*	*2*
				Bachelor's degrees	*2*
				Associate's degrees	*31*
				1 but less than 2 year certificates	*4*
				Less than 1 year certificates	*4*
		51.0916	*Radiation Protection/Health Physics Technician.*	*Master's degrees*	*21*
				Bachelor's degrees	*11*
				Less than 1 year certificates	*13*
29-9011	Occupational Health and Safety Specialists	15.0701	Occupational Safety and Health Technology/Technician.	Master's degrees	79
				Bachelor's degrees	449
				Associate's degrees	267
				Post-master's certificates	2
				1 but less than 2 year certificates	81
				Less than 1 year certificates	53
		15.0703	Industrial Safety Technology/Technician.	Master's degrees	13
				Bachelor's degrees	74
				Associate's degrees	9
				1 but less than 2 year certificates	8
				Less than 1 year certificates	15

		51.2202	Environmental Health.	Doctorate degrees	59
				Master's degrees	374
				Bachelor's degrees	239
				Associate's degrees	16
				Post-master's certificates	1
				Post-baccalaureate certificates	23
				2 but less than 4 year certificates	3
				1 but less than 2 year certificates	2
		51.2206	Occupational Health and Industrial Hygiene.	Doctorate degrees	8
				Master's degrees	85
				Bachelor's degrees	50
				Associate's degrees	80
				Post-master's certificates	5

Note: The occupations in *italics* typically require an associate's degree or higher upon entry; the remaining occupations typically require a bachelor's degree or higher upon entry.
Source: WebCASPAR, 2012.

TABLE C.11. Average annual U.S. oil and gas private sector employment, by NAICS code (2005-2010).

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
211	Oil and Gas Extraction	125,818	134,858	146,081	160,081	160,688	158,423
213111	Drilling Oil and Gas Wells	66,691	79,818	84,525	92,640	67,756	74,491
213112	Support Activities for Oil and Gas Operations	145,725	171,127	197,100	223,635	193,589	201,685
2212	Natural Gas Distribution	106,478	106,351	106,287	107,988	108,915	108,605
23712	Oil and Gas Pipeline and Related Structures Construction	71,826	83,379	97,095	110,975	98,214	92,039
32411	Petroleum Refineries	68,427	69,124	72,337	75,099	75,588	72,689
333132	Oil and Gas Field Machinery and Equipment Manufacturing	45,293	52,382	60,045	63,827	60,360	59,602
486	Pipeline Transportation	37,910	38,676	40,303	41,116	41,384	42,265
TOTAL		**668,168**	**735,715**	**803,773**	**875,361**	**806,494**	**809,799**

Source: BLS 2011d.

TABLE C.12. Average annual U.S. oil and gas local government employment, by NAICS code (2005-2010).

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
211	Oil and Gas Extraction						
213111	Drilling Oil and Gas Wells						
213112	Support Activities for Oil and Gas Operations						
2212	Natural Gas Distribution	8,916	8,819	8,654	7,872	7,870	6,533
23712	Oil and Gas Pipeline and Related Structures Construction	23	29	19	279	287	280
32411	Petroleum Refineries						
333132	Oil and Gas Field Machinery and Equipment Manufacturing						
486	Pipeline Transportation	1,718	1,687	913	926	901	886
TOTAL		**10,657**	**10,535**	**9,586**	**9,077**	**9,058**	**7,699**

Note: A blank cell indicates data is not disclosable or is not applicable.
Source: BLS 2011d.

TABLE C.13. Demographic information for the U.S. oil and gas workforce by Census industry, 2010.

Census industry	Women	Black or African Amr	Asian	Hispanic or Latino	16-19 years	20-24 years	25-34 years	35-44 years	45-54 years	55-64 years	65 years and over	Median age
U.S. WORKFORCE, 16 YRS+	**47.2%**	**10.8%**	**4.8%**	**14.3%**	**3.1%**	**9.1%**	**21.7%**	**22.0%**	**23.9%**	**15.6%**	**4.5%**	**42.0**
0370: Oil and Gas Extraction	18.0%	5.9%	3.5%	12.8%		6.7%	28.0%	17.3%	29.3%	17.3%	1.3%	45.1
0580: Natural Gas Distribution	28.4%	13.7%	3.1%	18.8%		1.0%	19.6%	19.6%	37.1%	19.6%	3.1%	47.6
2070: Petroleum refining	19.9%	11.6%	5.5%	12.2%	1.2%	2.4%	17.1%	27.1%	35.3%	15.3%	2.4%	46.0
6270: Pipeline Transportation	16.9%	3.0%		14.9%	1.8%	3.6%	14.3%	25.0%	33.9%	19.6%	1.8%	45.3

Notes: A blank cell indicates data is not available or is not applicable. Age distribution figures may not add up to 100% due to rounding. Industries are based on the 2007 Census industry classification.
Source: BLS, 2011e.

Prepublication Version

TABLE C.14. Mapping of U.S. oil and gas NAICS industries to Census industries.

NAICS Code	NAICS Title	Census Code	Census Title
211	Oil and Gas Extraction	0370	Oil and gas extraction
213111	Drilling Oil and Gas Wells	N/A	N/A
213112	Support Activities for Oil and Gas Operations	N/A	N/A
2212	Natural Gas Distribution	0580	Natural gas distribution
23712	Oil and Gas Pipeline and Related Structures Construction	N/A	N/A
32411	Petroleum Refineries	2070	Petroleum refining
333132	Oil and Gas Field Machinery and Equipment Manufacturing	N/A	N/A
486	Pipeline Transportation	6270	Pipeline transportation

TABLE C.15. Employment estimates for the 20 largest U.S. private sector oil and gas extraction (NAICS 211) occupations, 2010.

NAICS 211 (Oil and Gas Extraction)			
Standard Occupation Code	**Standard Occupation Title**	**2010 Employment**	**Percent of Industry Employment**
17-2171	Petroleum Engineers	13,270	8.56%
47-5071	Roustabouts, Oil and Gas	9,680	6.24%
53-7073	Wellhead Pumpers	8,020	5.17%
51-8093	Petroleum Pump System Operators, Refinery Operators, and Gaugers	6,450	4.16%
19-2042	Geoscientists, Except Hydrologists and Geographers	6,390	4.12%
13-2011	Accountants and Auditors	5,260	3.40%
47-5013	Service Unit Operators, Oil, Gas, and Mining	5,160	3.33%
11-1021	General and Operations Managers	4,910	3.17%
47-1011	First-Line Supervisors of Construction Trades and Extraction Workers	4,310	2.78%
43-9061	Office Clerks, General	4,060	2.62%
17-2199	Engineers, All Other	3,960	2.56%
43-3031	Bookkeeping, Accounting, and Auditing Clerks	3,780	2.44%
19-4041	Geological and Petroleum Technicians	3,730	2.40%
43-6014	Secretaries and Administrative Assistants, Except Legal, Medical, and Executive	3,690	2.38%
47-5081	Helpers--Extraction Workers	3,240	2.09%
47-5012	Rotary Drill Operators, Oil and Gas	3,170	2.05%
43-6011	Executive Secretaries and Executive Administrative Assistants	2,820	1.82%
13-1199	Business Operations Specialists, All Other	2,190	1.41%
47-5011	Derrick Operators, Oil and Gas	2,050	1.32%
49-9041	Industrial Machinery Mechanics	2,000	1.29%

Source: BLS, 2012e

TABLE C.16. Employment estimates for the 20 largest U.S. private sector natural gas distribution (NAICS 2212) occupations.

NAICS 2212 (Natural Gas Distribution)			
Standard Occupation Code	**Standard Occupation Title**	**2010 Employment**	**Percent of Industry Employment**
43-4051	Customer Service Representatives	9,530	8.81%
49-9012	Control and Valve Installers and Repairers, Except Mechanical Door	8,330	7.70%
47-2152	Plumbers, Pipefitters, and Steamfitters	5,600	5.18%
43-5041	Meter Readers, Utilities	5,510	5.09%
51-8092	Gas Plant Operators	4,220	3.90%
49-9051	Electrical Power-Line Installers and Repairers	2,730	2.52%
43-9061	Office Clerks, General	2,540	2.35%
49-1011	First-Line Supervisors of Mechanics, Installers, and Repairers	2,400	2.22%
13-1199	Business Operations Specialists, All Other	2,190	2.02%
47-2061	Construction Laborers	1,950	1.80%
49-9041	Industrial Machinery Mechanics	1,940	1.79%
43-1011	First-Line Supervisors of Office and Administrative Support Workers	1,890	1.75%
11-1021	General and Operations Managers	1,880	1.74%
13-2011	Accountants and Auditors	1,650	1.52%
51-1011	First-Line Supervisors of Production and Operating Workers	1,620	1.50%
49-9071	Maintenance and Repair Workers, General	1,460	1.35%
43-6011	Executive Secretaries and Executive Administrative Assistants	1,410	1.30%
47-1011	First-Line Supervisors of Construction Trades and Extraction Workers	1,380	1.28%
13-1111	Management Analysts	1,370	1.27%
15-1121	Computer Systems Analysts	1,300	1.20%

Source: BLS, 2012e.

TABLE C.17. Employment estimates for the 20 largest U.S. private sector pipeline transportation (NAICS 486) occupations, 2010.

NAICS 486 (Pipeline Transportation)

Standard Occupation Code	Standard Occupation Title	2010 Employment	Percent of Industry Employment
51-8093	Petroleum Pump System Operators, Refinery Operators, and Gaugers	6,680	15.90%
51-8092	Gas Plant Operators	3,560	8.46%
49-9041	Industrial Machinery Mechanics	2,330	5.55%
53-7071	Gas Compressor and Gas Pumping Station Operators	1,460	3.48%
51-1011	First-Line Supervisors of Production and Operating Workers	1,270	3.02%
53-3032	Heavy and Tractor-Trailer Truck Drivers	1,120	2.67%
11-1021	General and Operations Managers	1,050	2.50%
13-1199	Business Operations Specialists, All Other	1,010	2.39%
49-9012	Control and Valve Installers and Repairers, Except Mechanical Door	970	2.32%
13-2011	Accountants and Auditors	850	2.03%
43-6011	Executive Secretaries and Executive Administrative Assistants	750	1.79%
47-2152	Plumbers, Pipefitters, and Steamfitters	740	1.76%
17-2051	Civil Engineers	710	1.70%
43-4051	Customer Service Representatives	680	1.62%
49-9799	Installation, Maintenance, and Repair Workers, All Other	640	1.52%
49-9071	Maintenance and Repair Workers, General	630	1.49%
43-9061	Office Clerks, General	530	1.26%
49-1011	First-Line Supervisors of Mechanics, Installers, and Repairers	490	1.16%
17-3029	Engineering Technicians, Except Drafters, All Other	450	1.07%
17-3023	Electrical and Electronics Engineering Technicians	440	1.06%

Source: BLS, 2012e.

TABLE C.18. Average annual U.S. nuclear energy private sector employment, by NAICS code (2005-2010).

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
221113	Nuclear Electric Power Generation	52,331	53,396	52,968	51,479	53,080	52,582
TOTAL		**52,331**	**53,396**	**52,968**	**51,479**	**53,080**	**52,582**

Source: BLS, 2011d..

TABLE C.19. Average annual U.S. nuclear energy federal government employment, by NAICS code (2005-2010).

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
221113	Nuclear Electric Power Generation	1,036	1,126	1,150	1,119	1,271	1,381
TOTAL		**1,036**	**1,126**	**1,150**	**1,119**	**1,271**	**1,381**

Source: BLS, 2011d.

TABLE C.20. Average annual U.S. nuclear energy local government employment, by NAICS code (2005-2010).

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
221113	Nuclear Electric Power Generation	7,253	7,224	7,316	7,461	7,606	2,815
TOTAL		**7,253**	**7,224**	**7,316**	**7,461**	**7,606**	**2,815**

Source: BLS, 2011d.

TABLE C.21. Average annual U.S. nonfuel mining private sector employment, by NAICS code (2005-2010).

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
2122	Metal Ore Mining	29,250	31,883	35,901	40,156	34,100	35,953
2123	Nonmetallic Mineral Mining and Quarrying	107,621	108,712	107,428	101,899	90,669	86,419
213114	Support Activities for Metal Mining	2,315	2,582	2,896	3,357	2,538	3,118
213115	Support Activities for Nonmetal Minerals (except Fuels) Mining	1,773	1,888	2,216	2,428	2,064	2,290
331	Primary Metal Manufacturing	464,836	463,139	455,683	443,867	363,744	361,211
TOTAL		**605,795**	**608,204**	**604,124**	**591,707**	**493,115**	**488,991**

Source: BLS, 2011d.

TABLE C.22. Average annual U.S. nonfuel mining local government employment, by NAICS code (2005-2010).

NAICS Code	NAICS Title	2005	2006	2007	2008	2009	2010
2122	Metal Ore Mining						
2123	Nonmetallic Mineral Mining and Quarrying	559	448			349	268
213114	Support Activities for Metal Mining						
213115	Support Activities for Nonmetal Minerals (except Fuels) Mining						
331	Primary Metal Manufacturing						
TOTAL		**559**	**448**			**349**	**268**

Note: A blank cell indicates data is not disclosable or is not applicable.
Source: BLS, 2011d.

TABLE C.23. Demographic information for the U.S. nonfuel mining workforce by Census industry, 2010.

Census industry	Women	Black or African Amr	Asian	Hispanic or Latino	16-19 years	20-24 years	25-34 years	35-44 years	45-54 years	55-64 years	65 years and over	Median age
U.S. WORKFORCE, 16 YRS+	**47.2%**	**10.8%**	**4.8%**	**14.3%**	**3.1%**	**9.1%**	**21.7%**	**22.0%**	**23.9%**	**15.6%**	**4.5%**	**42.0**
0390: Metal Ore Mining						2.9%	25.7%	22.9%	25.7%	20.0%	5.7%	43.4
0470: Nonmetallic Mineral Mining and Quarrying	7.9%	0.1%	0.8%	12.5%		5.3%	21.3%	16.0%	32.0%	20.0%	5.3%	47.8
2670: Iron and steel mills and steel product manufacturing	10.7%	8.2%	0.6%	15.3%	1.2%	4.3%	22.7%	25.0%	28.1%	17.2%	2.0%	43.6
2680: Aluminum production and processing	9.9%	5.4%	2.5%	22.8%		3.9%	11.8%	23.5%	39.2%	15.7%	3.9%	48.2
2690: Nonferrous metal (except aluminum) production and processing	15.2%	7.9%	2.6%	5.3%		10.9%	9.1%	25.5%	32.7%	20.0%	1.8%	45.8
2770: Foundries	16.3%	9.1%	0.4%	14.0%		2.5%	19.8%	23.5%	30.9%	17.3%	6.2%	47.2

Notes: A blank cell indicates data is not available or is not applicable. Age distribution figures may not add up to 100% due to rounding. Industries are based on the 2007 Census industry classification.
Source: BLS, 2011e. Additional tabulations by the National Research Council.

TABLE C.24. Mapping of U.S. nonfuel mining NAICS industries to Census industries.

NAICS Code	NAICS Title	Census Code	Census Title
2122	Metal Ore Mining	0390	Metal Ore Mining
2123	Nonmetallic Mineral Mining and Quarrying	0470	Nonmetallic Mineral Mining and Quarrying
213114	Support Activities for Metal Mining	N/A	N/A
213115	Support Activities for Nonmetal Minerals (except Fuels) Mining	N/A	N/A
331	Primary Metal Manufacturing	2670	Iron and steel mills and steel product manufacturing
		2680	Aluminum production and processing
		2690	Nonferrous metal (except aluminum) production and processing
		2770	Foundries

TABLE C.25. Employment estimates for the 20 largest U.S. private sector metal ore mining (NAICS 2112) occupations, 2010.

Standard Occupation Code	Standard Occupation Title	2010 Employment	Percent of Industry Employment
47-2073	Operating Engineers and Other Construction Equipment Operators	3,040	8.92%
49-3042	Mobile Heavy Equipment Mechanics, Except Engines	2,860	8.40%
53-3032	Heavy and Tractor-Trailer Truck Drivers	1,970	5.78%
47-5041	Continuous Mining Machine Operators	1,960	5.75%
49-9041	Industrial Machinery Mechanics	1,450	4.26%
47-2111	Electricians	1,130	3.32%
47-5042	Mine Cutting and Channeling Machine Operators	1,110	3.26%
51-9012	Separating, Filtering, Clarifying, Precipitating, and Still Machine Setters, Operators, and Tenders	900	2.64%
17-2151	Mining and Geological Engineers, Including Mining Safety Engineers	860	2.52%
49-9071	Maintenance and Repair Workers, General	840	2.47%
51-9021	Crushing, Grinding, and Polishing Machine Setters, Operators, and Tenders	790	2.32%
47-1011	First-Line Supervisors of Construction Trades and Extraction Workers	780	2.29%
47-5021	Earth Drillers, Except Oil and Gas	780	2.29%
49-1011	First-Line Supervisors of Mechanics, Installers, and Repairers	720	2.11%
51-1011	First-Line Supervisors of Production and Operating Workers	560	1.64%
47-5031	Explosives Workers, Ordnance Handling Experts, and Blasters	530	1.56%
47-5081	Helpers--Extraction Workers	530	1.56%
47-5049	Mining Machine Operators, All Other	470	1.38%
19-2042	Geoscientists, Except Hydrologists and Geographers	460	1.35%
53-7062	Laborers and Freight, Stock, and Material Movers, Hand	420	1.23%

Source: BLS, 2012e.

TABLE C.26. Employment estimates for the 20 largest U.S. private sector nonmetal mining (NAICS 2123) occupations, 2010.

Standard Occupation Code	Standard Occupation Title	2010 Employment	Percent of Industry Employment
51-8093	Petroleum Pump System Operators, Refinery Operators, and Gaugers	6,680	15.90%
51-8092	Gas Plant Operators	3,560	8.46%
49-9041	Industrial Machinery Mechanics	2,330	5.55%
53-7071	Gas Compressor and Gas Pumping Station Operators	1,460	3.48%
51-1011	First-Line Supervisors of Production and Operating Workers	1,270	3.02%
53-3032	Heavy and Tractor-Trailer Truck Drivers	1,120	2.67%
11-1021	General and Operations Managers	1,050	2.50%
13-1199	Business Operations Specialists, All Other	1,010	2.39%
49-9012	Control and Valve Installers and Repairers, Except Mechanical Door	970	2.32%
13-2011	Accountants and Auditors	850	2.03%
43-6011	Executive Secretaries and Executive Administrative Assistants	750	1.79%
47-2152	Plumbers, Pipefitters, and Steamfitters	740	1.76%
17-2051	Civil Engineers	710	1.70%
43-4051	Customer Service Representatives	680	1.62%
49-9799	Installation, Maintenance, and Repair Workers, All Other	640	1.52%
49-9071	Maintenance and Repair Workers, General	630	1.49%
43-9061	Office Clerks, General	530	1.26%
49-1011	First-Line Supervisors of Mechanics, Installers, and Repairers	490	1.16%
17-3029	Engineering Technicians, Except Drafters, All Other	450	1.07%
17-3023	Electrical and Electronics Engineering Technicians	440	1.06%

Source: BLS, 2012e.

TABLE C.27. Employment estimates for the 20 largest U.S. private sector primary metal manufacturing (NAICS 331) occupations, 2010.

Standard Occupation Code	Standard Occupation Title	2010 Employment	Percent of Industry Employment
51-1011	First-Line Supervisors of Production and Operating Workers	16,860	4.75%
51-4023	Rolling Machine Setters, Operators, and Tenders, Metal and Plastic	16,370	4.61%
49-9071	Maintenance and Repair Workers, General	14,850	4.18%
51-4051	Metal-Refining Furnace Operators and Tenders	12,820	3.61%
51-9061	Inspectors, Testers, Sorters, Samplers, and Weighers	12,290	3.46%
49-9041	Industrial Machinery Mechanics	12,090	3.40%
51-4021	Extruding and Drawing Machine Setters, Operators, and Tenders, Metal and Plastic	11,940	3.36%
51-9198	Helpers--Production Workers	11,770	3.31%
51-4072	Molding, Coremaking, and Casting Machine Setters, Operators, and Tenders, Metal and Plastic	11,680	3.29%
51-4031	Cutting, Punching, and Press Machine Setters, Operators, and Tenders, Metal and Plastic	11,630	3.27%
51-4052	Pourers and Casters, Metal	10,460	2.95%
53-7062	Laborers and Freight, Stock, and Material Movers, Hand	8,680	2.44%
51-4033	Grinding, Lapping, Polishing, and Buffing Machine Tool Setters, Operators, and Tenders, Metal and Plastic	8,410	2.37%
51-4071	Foundry Mold and Coremakers	7,900	2.22%
53-7051	Industrial Truck and Tractor Operators	7,890	2.22%
51-4121	Welders, Cutters, Solderers, and Brazers	6,960	1.96%
51-2092	Team Assemblers	6,230	1.76%
51-4041	Machinists	5,860	1.65%
53-7021	Crane and Tower Operators	5,670	1.60%
47-2111	Electricians	5,190	1.46%

Source: BLS, 2012e.

TABLE C.28. Demographic information for the U.S. coal mining workforce by Census industry, 2010.

Census industry	Women	Black or African Amr	Asian	Hispanic or Latino	16-19 years	20-24 years	25-34 years	35-44 years	45-54 years	55-64 years	65 years and over	Median age
U.S. WORKFORCE, 16 YRS+	**47.2%**	**10.8%**	**4.8%**	**14.3%**	**3.1%**	**9.1%**	**21.7%**	**22.0%**	**23.9%**	**15.6%**	**4.5%**	**42.0**
0380: Coal Mining	6.0%	0.4%		0.4%		7.4%	17.0%	23.4%	29.8%	20.2%	1.1%	46.4

Notes: A blank cell indicates data is not available or is not applicable. Age distribution figures may not add up to 100% due to rounding. Industries are based on the 2007 Census industry classification.
Source: BLS, 2011e. Additional calculations by the National Research Council.

TABLE C.29. Mapping of U.S. coal mining NAICS industries to Census industries.

NAICS Code	NAICS Title	Census Code	Census Title
2121	Coal Mining	0380	Coal Mining
213113	Support Activities for Coal Mining	N/A	N/A

TABLE C.30. Employment estimates for the 20 largest U.S. private sector coal mining (NAICS 2121) occupations, 2010.

Standard Occupation Code	Standard Occupation Title	2010 Employment	Percent of Industry Employment
47-2073	Operating Engineers and Other Construction Equipment Operators	8,660	10.89%
47-5041	Continuous Mining Machine Operators	8,480	10.67%
47-5061	Roof Bolters, Mining	5,320	6.69%
47-1011	First-Line Supervisors of Construction Trades and Extraction Workers	4,530	5.70%
47-5081	Helpers--Extraction Workers	3,830	4.82%
47-2111	Electricians	3,490	4.39%
53-7032	Excavating and Loading Machine and Dragline Operators	3,290	4.14%
53-7111	Mine Shuttle Car Operators	2,930	3.69%
47-5042	Mine Cutting and Channeling Machine Operators	2,790	3.51%
49-3042	Mobile Heavy Equipment Mechanics, Except Engines	2,700	3.40%
53-7033	Loading Machine Operators, Underground Mining	2,130	2.68%
53-3032	Heavy and Tractor-Trailer Truck Drivers	2,110	2.65%
49-9041	Industrial Machinery Mechanics	2,000	2.52%
49-9071	Maintenance and Repair Workers, General	1,910	2.40%
47-5099	Extraction Workers, All Other	1,450	1.82%
53-7062	Laborers and Freight, Stock, and Material Movers, Hand	1,380	1.74%
49-9043	Maintenance Workers, Machinery	1,230	1.55%
49-1011	First-Line Supervisors of Mechanics, Installers, and Repairers	1,080	1.36%
53-7011	Conveyor Operators and Tenders	1,050	1.32%
47-2061	Construction Laborers	1,020	1.28%
51-4121	Welders, Cutters, Solderers, and Brazers	1,020	1.28%

Source: BLS, 2012e.

TABLE C.31. Distribution of employment across occupational groups at key federal agencies responsible for management and oversight of energy and mining, 2011.

Occupational Group / Job Family	BIA	BLM	BOEMRE	DOE	FERC	MSHA	NRC	OSHA	OSM	PHMSA	USGS
00xx-MISCELLANEOUS OCCUPATIONS	5.6%	5.3%	3.0%	5.9%	2.0%	0.2%	3.3%	40.4%	2.5%	0.2%	0.4%
01xx-SOCIAL SCIENCE, PSYCHOLOGY, AND WELFARE	2.1%	3.5%	3.0%	2.5%	4.4%	0.3%	1.0%	0.6%	1.5%	0.2%	2.7%
02xx-PERSONNEL MGMT & INDUSTRIAL RELATIONS	0.9%	1.8%	5.5%	2.7%	1.9%	0.9%	1.8%	0.7%	3.1%	2.7%	1.0%
03xx-GENERAL ADMIN, CLERICAL, & OFFICE SVCS	14.9%	19.2%	26.6%	23.9%	16.3%	11.1%	22.5%	16.8%	39.9%	16.7%	11.2%
04xx-NATURAL RESOURCES MGMT & BIO SCI GROUP	10.5%	33.4%	4.2%	0.6%	4.6%	0.0%	0.2%	0.0%	3.7%	0.0%	16.2%
05xx-ACCOUNTING AND BUDGET	2.2%	1.8%	2.8%	6.3%	5.1%	0.7%	2.3%	1.5%	13.5%	1.8%	2.7%
06xx-MEDICAL, HOSPITAL, DENTAL & PUB HEALTH	0.2%	0.0%	0.0%	0.3%	0.0%	0.6%	0.2%	20.3%	0.0%	0.0%	0.0%
07xx-VETERINARY MEDICAL SCIENCE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
08xx-ENGINEERING AND ARCHITECTURE	4.1%	5.9%	16.5%	19.5%	19.1%	8.7%	45.2%	5.8%	4.0%	30.4%	1.7%
09xx-LEGAL AND KINDRED	3.5%	3.3%	0.6%	2.6%	21.2%	0.0%	3.2%	0.0%	0.0%	7.0%	0.0%
10xx-INFORMATION AND ARTS	0.1%	1.7%	2.3%	0.8%	0.5%	0.3%	0.6%	0.9%	0.8%	2.0%	1.9%
11xx-BUSINESS AND INDUSTRY	7.0%	4.5%	3.1%	11.9%	21.4%	1.2%	2.1%	0.3%	2.1%	2.3%	1.4%
12xx-COPYRIGHT, PATENT, AND TRADE-MARK	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
13xx-PHYSICAL SCIENCES	0.4%	6.3%	18.6%	5.8%	0.5%	2.3%	10.8%	1.7%	11.0%	2.5%	50.7%
14xx-LIBRARY AND ARCHIVES	0.1%	0.0%	0.6%	0.1%	0.1%	0.2%	0.3%	0.4%	0.2%	0.0%	0.8%
15xx-MATHEMATICS AND STATISTICS	0.0%	0.0%	0.3%	1.4%	0.3%	0.0%	0.1%	0.1%	0.0%	0.7%	1.3%
16xx-EQUIPMENT, FACILITIES, AND SERVICES	0.7%	0.3%	0.0%	0.9%	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.1%
17xx-EDUCATION	27.9%	0.4%	0.0%	0.3%	0.0%	1.1%	0.4%	0.6%	1.2%	0.2%	0.1%

Prepublication Version

18xx-INVESTIGATION	1.6%	3.2%	6.9%	0.8%	0.2%	68.8%	1.1%	8.1%	10.8%	12.6%	0.0%
19xx-QUALITY ASSURANCE, INSPECTION, & GRADING	0.0%	0.0%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
20xx-SUPPLY	0.6%	0.4%	0.0%	0.3%	0.0%	0.2%	0.2%	0.0%	0.0%	0.0%	0.2%
21xx-TRANSPORTATION	0.1%	0.9%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%	0.0%	17.8%	0.0%
22xx-INFORMATION TECHNOLOGY	1.3%	3.5%	6.0%	4.1%	1.9%	3.1%	4.6%	1.7%	5.8%	2.9%	6.3%
25xx-WIRE COMM. EQUIP. INSTALLTN & MAINTNCE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
26xx-ELECTRONIC EQUIP. INSTALLTN & MAINTNCE	0.0%	0.1%	0.0%	1.5%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
28xx-ELECTRICAL INSTALLATION AND MAINTENANCE	0.6%	0.0%	0.0%	4.7%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
31xx-FABRIC AND LEATHER WORK	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
33xx-INSTRUMENT WORK	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
34xx-MACHINE TOOL WORK	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
35xx-GENERAL SERVICES AND SUPPORT WORK	3.3%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
36xx-STRUCTURAL AND FINISHING WORK	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
37xx-METAL PROCESSING	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
38xx-METAL WORK	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
39xx-MOVIE, RADIO, TV & SOUND EQUIP OPERATING	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
40xx-LENS AND CRYSTAL WORK	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
41xx-PAINTING AND PAPERHANGING	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
42xx-PLUMBING AND PIPEFITTING	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
43xx-PLIABLE MATERIALS WORK	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
44xx-PRINTING	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%

46xx-WOOD WORK	0.0%	0.0%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
47xx-GENERAL MAINTENANCE AND OPERATIONS WORK	3.5%	1.2%	0.0%	0.2%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.4%
48xx-GENERAL EQUIPMENT MAINTENANCE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
50xx-PLANT AND ANIMAL WORK	0.1%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
52xx-MISCELLANEOUS OCCUPATIONS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
53xx-INDUSTRIAL EQUIPMENT MAINTENANCE	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%
54xx-INDUSTRIAL EQUIPMENT OPERATION	0.1%	0.3%	0.0%	1.4%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
57xx-TRANSPORT/MOBILE EQUIPMENT OPERATION	4.5%	1.6%	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.2%
58xx-TRANSPORT/MOBILE EQUIPMENT MAINTENANCE	0.4%	0.1%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
65xx-AMMO, EXPLOSIVES, &TOXIC MATERIALS WORK	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
66xx-ARMAMENT WORK	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
69xx-WAREHOUSING AND STOCK HANDLING	0.2%	0.4%	0.0%	0.2%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
70xx-PACKING AND PROCESSING	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
73xx-LAUNDRY, DRY CLEANING, AND PRESSING	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
74xx-FOOD PREPARATION AND SERVING	3.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
76xx-PERSONAL SERVICES	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
82xx-FLUID SYSTEMS MAINTENANCE	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
86xx-ENGINE OVERHAUL	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
88xx-AIRCRAFT OVERHAUL	0.0%	0.1%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
99xx-VESSEL JOBS EXCLUDED FROM FED WAGE SYS	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
UNSPECIFIED	0.2%	0.0%	0.0%	0.0%	0.3%	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%

TOTAL	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Note: Information is as of the fiscal year-end 2011 (September 30). Occupational group refers to white collar occupational groups represented by 00xx-MISCELLANEOUS OCCUPATIONS through 22xx-INFORMATION TECHNOLOGY. Job family refers to trade, craft, or labor job families represented by 25xx-WIRE COMM. EQUIP. INSTALLTN & MAINTNCE through 88xx-AIRCRAFT OVERHAUL. Occupational groups or job families with 5 percent or more of total agency employment are highlighted.

Legend:
BIA = Bureau of Indian Affairs
BLM = Bureau of Land Management
BOEMRE = Bureau of Ocean Energy Management, Regulation and Enforcement
DOE = Department of Energy
FERC = Federal Energy Regulatory Commission
MSHA = Mine Safety and Health Administration
NRC = Nuclear Regulatory Commission
OSHA = Occupational Safety and Health Administration
OSM = Office of Surface Mining Reclamation and Enforcement
PHMSA = Pipeline and Hazardous Materials Safety Administration
USGS = U.S. Geological Survey

Source: FedScope, 2012. Additional tabulations by the National Research Council.

TABLE C.32. Employment counts for the 20 largest occupations within the Bureau of Indian Affairs, 2011.

Occupation	Employment	Percent of agency employment
1710-EDUCATION AND VOCATIONAL TRAINING	1,347	14.7%
1702-EDUCATION AND TRAINING TECHNICIAN	982	10.7%
0303-MISCELLANEOUS CLERK AND ASSISTANT	421	4.6%
0462-FORESTRY TECHNICIAN	409	4.5%
1170-REALTY	330	3.6%
0301-MISCELLANEOUS ADMINISTRATION AND PROGRAM	295	3.2%
4749-MAINTENANCE MECHANIC	267	2.9%
5703-MOTOR VEHICLE OPERATING	256	2.8%
7404-COOKING	250	2.7%
1101-GENERAL BUSINESS AND INDUSTRY	221	2.4%
3566-CUSTODIAL WORKING	211	2.3%
0083-POLICE	200	2.2%
0318-SECRETARY	188	2.1%
0802-ENGINEERING TECHNICAL	181	2.0%
0007-CORRECTIONAL OFFICER	169	1.8%
0340-PROGRAM MANAGEMENT	157	1.7%
5716-ENGINEERING EQUIPMENT OPERATING	151	1.7%
1811-CRIMINAL INVESTIGATION	143	1.6%
0401-GENERAL NATURAL RESOURCES MANAGEMENT AND BIOLOGICAL SCIENCES	137	1.5%
0460-FORESTRY	136	1.5%

Note: Employment is as of September 30, 2011
Source: FedScope, 2012. Additional tabulations by the National Research Council.

TABLE C.33. Employment counts for the 20 largest occupations within the Bureau of Land Management, 2011.

Occupation	Employment	Percent of agency employment
0455-RANGE TECHNICIAN	1,480	12.9%
0301-MISCELLANEOUS ADMINISTRATION AND PROGRAM	818	7.1%
0401-GENERAL NATURAL RESOURCES MANAGEMENT AND BIOLOGICAL SCIENCES	772	6.7%
0303-MISCELLANEOUS CLERK AND ASSISTANT	424	3.7%
0462-FORESTRY TECHNICIAN	421	3.7%
2210-INFORMATION TECHNOLOGY MANAGEMENT	396	3.5%
0340-PROGRAM MANAGEMENT	386	3.4%
0454-RANGELAND MANAGEMENT	302	2.6%
0802-ENGINEERING TECHNICAL	286	2.5%
1170-REALTY	278	2.4%
0025-PARK RANGER	245	2.1%
0023-OUTDOOR RECREATION PLANNING	227	2.0%
1373-LAND SURVEYING	226	2.0%
0486-WILDLIFE BIOLOGY	225	2.0%
1801-GENERAL INSPECTION, INVESTIGATION, ENFORCEMENT, AND COMPLIANCE SERIES	220	1.9%
0193-ARCHEOLOGY	206	1.8%
0404-BIOLOGICAL SCIENCE TECHNICIAN	202	1.8%
0965-LAND LAW EXAMINING	196	1.7%
1350-GEOLOGY	196	1.7%
0460-FORESTRY	173	1.5%

Note: Employment is as of September 30, 2011
Source: FedScope, 2012. Additional tabulations by the National Research Council.

TABLE C.34. Employment counts for the 20 largest occupations within the Bureau of Ocean Energy Management, Regulation and Enforcement, 2011.

Occupation	Employment	Percent of agency employment
0881-PETROLEUM ENGINEERING	161	13.6%
0301-MISCELLANEOUS ADMINISTRATION AND PROGRAM	95	8.0%
1350-GEOLOGY	95	8.0%
1801-GENERAL INSPECTION, INVESTIGATION, ENFORCEMENT, AND COMPLIANCE SERIES	81	6.9%
2210-INFORMATION TECHNOLOGY MANAGEMENT	70	5.9%
0343-MANAGEMENT AND PROGRAM ANALYSIS	67	5.7%
0303-MISCELLANEOUS CLERK AND ASSISTANT	53	4.5%
1313-GEOPHYSICS	52	4.4%
0318-SECRETARY	51	4.3%
0201-HUMAN RESOURCES MANAGEMENT	48	4.1%
0401-GENERAL NATURAL RESOURCES MANAGEMENT AND BIOLOGICAL SCIENCES	40	3.4%
1301-GENERAL PHYSICAL SCIENCE	30	2.5%
1102-CONTRACTING	27	2.3%
0028-ENVIRONMENTAL PROTECTION SPECIALIST	25	2.1%
0340-PROGRAM MANAGEMENT	22	1.9%
1360-OCEANOGRAPHY	22	1.9%
0802-ENGINEERING TECHNICAL	21	1.8%
0560-BUDGET ANALYSIS	14	1.2%
1035-PUBLIC AFFAIRS	14	1.2%
0110-ECONOMIST	13	1.1%

Note: Employment is as of September 30, 2011.
Source: FedScope, 2012. Additional tabulations by the National Research Council.

TABLE C.35. Employment counts for the 20 largest occupations within the Department of Energy, 2011.

Occupation	Employment	Percent of agency employment
0801-GENERAL ENGINEERING	1,631	11.0%
0301-MISCELLANEOUS ADMINISTRATION AND PROGRAM	1,576	10.6%
0343-MANAGEMENT AND PROGRAM ANALYSIS	908	6.1%
1301-GENERAL PHYSICAL SCIENCE	655	4.4%
1102-CONTRACTING	641	4.3%
2210-INFORMATION TECHNOLOGY MANAGEMENT	603	4.0%
2810-HIGH VOLTAGE ELECTRICIAN	542	3.6%
1130-PUBLIC UTILITIES SPECIALIST	440	3.0%
0850-ELECTRICAL ENGINEERING	436	2.9%
1101-GENERAL BUSINESS AND INDUSTRY	429	2.9%
0340-PROGRAM MANAGEMENT	406	2.7%
0303-MISCELLANEOUS CLERK AND ASSISTANT	377	2.5%
0084-NUCLEAR MATERIALS COURIER	338	2.3%
0905-GENERAL ATTORNEY	338	2.3%
0510-ACCOUNTING	334	2.2%
0080-SECURITY ADMINISTRATION	330	2.2%
0201-HUMAN RESOURCES MANAGEMENT	320	2.1%
0560-BUDGET ANALYSIS	252	1.7%
0840-NUCLEAR ENGINEERING	249	1.7%
5407-ELECTRICAL POWER CONTROLLING	204	1.4%

Note: Employment is as of September 30, 2011.
Source: FedScope, 2012. Additional tabulations by the National Research Council.

TABLE C.36. Employment counts for the 20 largest occupations within the Federal Energy Regulatory Commission, 2011.

Occupation	Employment	Percent of agency employment
1101-GENERAL BUSINESS AND INDUSTRY	302	20.3%
0905-GENERAL ATTORNEY	266	17.9%
0810-CIVIL ENGINEERING	139	9.3%
0850-ELECTRICAL ENGINEERING	100	6.7%
0301-MISCELLANEOUS ADMINISTRATION AND PROGRAM	66	4.4%
0343-MANAGEMENT AND PROGRAM ANALYSIS	65	4.4%
0110-ECONOMIST	56	3.8%
0511-AUDITING	39	2.6%
0340-PROGRAM MANAGEMENT	29	1.9%
2210-INFORMATION TECHNOLOGY MANAGEMENT	29	1.9%
0318-SECRETARY	27	1.8%
0303-MISCELLANEOUS CLERK AND ASSISTANT	26	1.7%
0401-GENERAL NATURAL RESOURCES MANAGEMENT AND BIOLOGICAL SCIENCES	25	1.7%
0201-HUMAN RESOURCES MANAGEMENT	23	1.5%
0510-ACCOUNTING	23	1.5%
0482-FISH BIOLOGY	21	1.4%
0028-ENVIRONMENTAL PROTECTION SPECIALIST	16	1.1%
0935-ADMINISTRATIVE LAW JUDGE	15	1.0%
0950-PARALEGAL SPECIALIST	14	0.9%
0986-LEGAL ASSISTANCE	14	0.9%

Note: Employment is as of September 30, 2011.
Source: FedScope, 2012. Additional tabulations by the National Research Council.

TABLE C.37. Employment counts for the 20 largest occupations within the Mine Safety and Health Administration, 2011.

Occupation	Employment	Percent of agency employment
1822-MINE SAFETY AND HEALTH INSPECTION SERIES	1,404	60.3%
1802-COMPLIANCE INSPECTION AND SUPPORT	182	7.8%
2210-INFORMATION TECHNOLOGY MANAGEMENT	73	3.1%
0343-MANAGEMENT AND PROGRAM ANALYSIS	68	2.9%
0880-MINING ENGINEERING	58	2.5%
0318-SECRETARY	55	2.4%
0301-MISCELLANEOUS ADMINISTRATION AND PROGRAM	54	2.3%
0801-GENERAL ENGINEERING	38	1.6%
0810-CIVIL ENGINEERING	34	1.5%
0850-ELECTRICAL ENGINEERING	33	1.4%
1311-PHYSICAL SCIENCE TECHNICIAN	29	1.2%
0326-OFFICE AUTOMATION CLERICAL AND ASSISTANCE	25	1.1%
1712-TRAINING INSTRUCTION	23	1.0%
0303-MISCELLANEOUS CLERK AND ASSISTANT	17	0.7%
0830-MECHANICAL ENGINEERING	16	0.7%
1801-GENERAL INSPECTION, INVESTIGATION, ENFORCEMENT, AND COMPLIANCE SERIES	16	0.7%
0690-INDUSTRIAL HYGIENE	15	0.6%
0802-ENGINEERING TECHNICAL	15	0.6%
0201-HUMAN RESOURCES MANAGEMENT	14	0.6%
1301-GENERAL PHYSICAL SCIENCE	13	0.6%

Note: Employment is as of September 30, 2011.
Source: FedScope, 2012. Additional tabulations by the National Research Council.

TABLE C.38. Employment counts for the 20 largest occupations within the Nuclear Regulatory Commission, 2011.

Occupation	Employment	Percent of agency employment
0801-GENERAL ENGINEERING	1,160	28.2%
0840-NUCLEAR ENGINEERING	434	10.6%
0343-MANAGEMENT AND PROGRAM ANALYSIS	310	7.5%
0318-SECRETARY	238	5.8%
1301-GENERAL PHYSICAL SCIENCE	209	5.1%
2210-INFORMATION TECHNOLOGY MANAGEMENT	186	4.5%
1306-HEALTH PHYSICS	184	4.5%
0301-MISCELLANEOUS ADMINISTRATION AND PROGRAM	181	4.4%
0080-SECURITY ADMINISTRATION	129	3.1%
0905-GENERAL ATTORNEY	114	2.8%
0303-MISCELLANEOUS CLERK AND ASSISTANT	106	2.6%
0806-MATERIALS ENGINEERING	64	1.6%
0201-HUMAN RESOURCES MANAGEMENT	51	1.2%
0810-CIVIL ENGINEERING	49	1.2%
1102-CONTRACTING	49	1.2%
0340-PROGRAM MANAGEMENT	48	1.2%
0830-MECHANICAL ENGINEERING	47	1.1%
1811-CRIMINAL INVESTIGATION	44	1.1%
0850-ELECTRICAL ENGINEERING	42	1.0%
0510-ACCOUNTING	34	0.8%

Note: Employment is as of September 30, 2011.
Source: FedScope, 2012. Additional tabulations by the National Research Council.

TABLE C.39. Employment counts for the 20 largest occupations within the Occupational Safety and Health Administration, 2011.

Occupation	Employment	Percent of agency employment
0018-SAFETY AND OCCUPATIONAL HEALTH MANAGEMENT	915	40.3%
0690-INDUSTRIAL HYGIENE	425	18.7%
0343-MANAGEMENT AND PROGRAM ANALYSIS	156	6.9%
1801-GENERAL INSPECTION, INVESTIGATION, ENFORCEMENT, AND COMPLIANCE SERIES	103	4.5%
0303-MISCELLANEOUS CLERK AND ASSISTANT	92	4.0%
0803-SAFETY ENGINEERING	92	4.0%
1802-COMPLIANCE INSPECTION AND SUPPORT	81	3.6%
0301-MISCELLANEOUS ADMINISTRATION AND PROGRAM	41	1.8%
2210-INFORMATION TECHNOLOGY MANAGEMENT	39	1.7%
1320-CHEMISTRY	32	1.4%
0344-MANAGEMENT AND PROGRAM CLERICAL AND ASSISTANCE	30	1.3%
0601-GENERAL HEALTH SCIENCE	28	1.2%
0326-OFFICE AUTOMATION CLERICAL AND ASSISTANCE	23	1.0%
0318-SECRETARY	20	0.9%
0110-ECONOMIST	14	0.6%
0201-HUMAN RESOURCES MANAGEMENT	13	0.6%
0501-FINANCIAL ADMINISTRATION AND PROGRAM	13	0.6%
0341-ADMINISTRATIVE OFFICER	12	0.5%
1712-TRAINING INSTRUCTION	10	0.4%
0560-BUDGET ANALYSIS	9	0.4%
0893-CHEMICAL ENGINEERING	9	0.4%
1083-TECHNICAL WRITING AND EDITING	9	0.4%

Note: Employment is as of September 30, 2011
Source: FedScope, 2012. Additional tabulations by the National Research Council.

TABLE C.40. Employment counts for the 20 largest occupations within the Office of Surface Mining Reclamation and Enforcement, 2011.

Occupation	Employment	Percent of agency employment
0301-MISCELLANEOUS ADMINISTRATION AND PROGRAM	79	15.2%
1801-GENERAL INSPECTION, INVESTIGATION, ENFORCEMENT, AND COMPLIANCE SERIES	52	10.0%
0303-MISCELLANEOUS CLERK AND ASSISTANT	43	8.3%
0343-MANAGEMENT AND PROGRAM ANALYSIS	37	7.1%
2210-INFORMATION TECHNOLOGY MANAGEMENT	30	5.8%
0511-AUDITING	29	5.6%
1301-GENERAL PHYSICAL SCIENCE	27	5.2%
0340-PROGRAM MANAGEMENT	22	4.2%
0510-ACCOUNTING	19	3.7%
1315-HYDROLOGY	18	3.5%
0028-ENVIRONMENTAL PROTECTION SPECIALIST	12	2.3%
0810-CIVIL ENGINEERING	12	2.3%
0501-FINANCIAL ADMINISTRATION AND PROGRAM	10	1.9%
0201-HUMAN RESOURCES MANAGEMENT	9	1.7%
0401-GENERAL NATURAL RESOURCES MANAGEMENT AND BIOLOGICAL SCIENCES	9	1.7%
0318-SECRETARY	8	1.5%
0880-MINING ENGINEERING	7	1.3%
0260-EQUAL EMPLOYMENT OPPORTUNITY	6	1.2%
1311-PHYSICAL SCIENCE TECHNICIAN	6	1.2%
1350-GEOLOGY	6	1.2%

Note: Employment is as of September 30, 2011
Source: FedScope, 2012. Additional tabulations by the National Research Council.

TABLE C.41. Employment counts for the 20 largest occupations within the Pipeline and Hazardous Materials Safety Administration, 2011.

Occupation	Employment	Percent of agency employment
0801-GENERAL ENGINEERING	134	30.2%
2101-TRANSPORTATION SPECIALIST	73	16.4%
1801-GENERAL INSPECTION, INVESTIGATION, ENFORCEMENT, AND COMPLIANCE SERIES	54	12.2%
0905-GENERAL ATTORNEY	29	6.5%
0343-MANAGEMENT AND PROGRAM ANALYSIS	21	4.7%
0301-MISCELLANEOUS ADMINISTRATION AND PROGRAM	19	4.3%
0303-MISCELLANEOUS CLERK AND ASSISTANT	16	3.6%
2210-INFORMATION TECHNOLOGY MANAGEMENT	12	2.7%
0201-HUMAN RESOURCES MANAGEMENT	9	2.0%
0340-PROGRAM MANAGEMENT	9	2.0%
1102-CONTRACTING	9	2.0%
1001-GENERAL ARTS AND INFORMATION	6	1.4%
1320-CHEMISTRY	6	1.4%
0399-ADMINISTRATION AND OFFICE SUPPORT STUDENT TRAINEE	4	0.9%
0560-BUDGET ANALYSIS	4	0.9%
1301-GENERAL PHYSICAL SCIENCE	4	0.9%
0203-HUMAN RESOURCES ASSISTANCE	3	0.7%
2102-TRANSPORTATION CLERK AND ASSISTANT	3	0.7%
2199-TRANSPORTATION STUDENT TRAINEE	3	0.7%
0341-ADMINISTRATIVE OFFICER	2	0.5%
0360-EQUAL OPPORTUNITY COMPLIANCE	2	0.5%
0510-ACCOUNTING	2	0.5%
1035-PUBLIC AFFAIRS	2	0.5%
1515-OPERATIONS RESEARCH	2	0.5%
1899-INVESTIGATION STUDENT TRAINEE	2	0.5%

Note: Employment is as of September 30, 2011
Source: FedScope, 2012. Additional tabulations by the National Research Council.

TABLE C.42. Employment counts for the 20 largest occupations within the U.S. Geological Survey, 2011.

Occupation	Employment	Percent of agency employment
1315-HYDROLOGY	1,398	15.4%
1316-HYDROLOGIC TECHNICIAN	1,252	13.8%
1350-GEOLOGY	576	6.3%
2210-INFORMATION TECHNOLOGY MANAGEMENT	542	6.0%
1301-GENERAL PHYSICAL SCIENCE	385	4.2%
0404-BIOLOGICAL SCIENCE TECHNICIAN	379	4.2%
0401-GENERAL NATURAL RESOURCES MANAGEMENT AND BIOLOGICAL SCIENCES	298	3.3%
0303-MISCELLANEOUS CLERK AND ASSISTANT	275	3.0%
0408-ECOLOGY	265	2.9%
1313-GEOPHYSICS	247	2.7%
0150-GEOGRAPHY	204	2.2%
0482-FISH BIOLOGY	201	2.2%
0486-WILDLIFE BIOLOGY	192	2.1%
1311-PHYSICAL SCIENCE TECHNICIAN	187	2.1%
1370-CARTOGRAPHY	174	1.9%
0301-MISCELLANEOUS ADMINISTRATION AND PROGRAM	158	1.7%
1320-CHEMISTRY	150	1.7%
1399-PHYSICAL SCIENCE STUDENT TRAINEE	139	1.5%
0343-MANAGEMENT AND PROGRAM ANALYSIS	130	1.4%
0326-OFFICE AUTOMATION CLERICAL AND ASSISTANCE	115	1.3%

Note: Employment is as of September 30, 2011
Source: FedScope, 2012. Additional tabulations by the National Research Council.

D

List of Acronyms and Abbreviations

AAPG	American Association of Petroleum Geologists
ac	alternating current
ACS	American Chemical Society
ACT	American College Testing
AGI	American Geological Institute
AGU	American Geophysical Union
ANSI	American National Standards Institute
ARRA	American Recovery and Reinvestment Act of 2009
ATE	Advanced Technological Education
ATEEC	Advanced Technology Environmental and Energy Center
AWEA	American Wind Energy Association
bbl	barrel
BEA	U.S. Bureau of Economic Analysis
BET	Bachelor of Science in Engineering Technology
BHEF	Business Higher Education Forum
BLM	U.S. Bureau of Land Management
BLS	U.S. Bureau of Labor Statistics
BOEM	Bureau of Ocean Energy Management
BRC	Blue Ribbon Commission
BSEE	Bureau of Safety and Environmental Enforcement
BSET	Bachelor of Science in Engineering Technology
Btu	British thermal unit
CCS	carbon capture and storage
CCUS	carbon capture, use, and storage
CDC	Centers for Disease Control and Prevention
CDEP	Cooperative Development Energy Program
CEWD	Center for Energy Workforce Development
CIP	Classification of Instructional Programs
CO_2	carbon dioxide
CPI	Consumer Price Index
CREATE	California Regional Consortium for Engineering Advances in Technological Education
CREZ	Competitive Renewable Energy Zone
CSP	concentrating solar power
CSR	corporate social responsibility

DACUM	*D*eveloping *a Cu*rriculu*m*
dc	direct current
DOE	U.S. Department of Energy
E&P	exploration and production
EEI	Edison Electric Institute
EERE	energy efficiency and renewable energy
EGS	enhanced or engineered geothermal system
EIA	U.S. Energy Information Administration
EOR	enhanced oil recovery
EPC	engineering, procurement, and construction
ETA	Employment and Training Administration
ETAI	Electronics Technicians Association International
FLATE	Florida Advanced Technological Education Center
FTE	full-time-equivalent
FVSU	Fort Valley State University
GAO	U.S. Government Accountability Office
GDP	gross domestic product
GEA	Geothermal Energy Association
GHP	geothermal heat pump
GIS	geographic information system
GNF	Global Nuclear Fuel
GSFC	Goddard Space Flight Center
GWe	gigawatt electric
GWhe	gigawatt-hour electric
H&S	health and safety
HBCU	Historically Black Colleges and Universities
HVAC	heating, ventilation, and air-conditioning
IAEA	International Atomic Energy Agency
IBEW	International Brotherhood of Electrical Workers
IEC	independent electrical contractor
IEEE PES	Institute of Electrical and Electronics Engineers Power and Energy Society
IMA	International Maritime Associates
IMA-NA	Industrial Minerals Association–North America
IMF	International Monetary Fund
INPO	Institute of Nuclear Power Operations
IOM	Institute of Medicine
IPEDS	Integrated Postsecondary Education Data System
IREC	Interstate Renewable Energy Council
ISPQ	Institute for Sustainable Power Quality
ITC	investment tax credit

JIP	Joint-Industry Project
KSA	knowledge, skills, and abilities
kW	kilowatt
kWe	kilowatt electric
MBA	Master's of Business Administration
MCA	Minerals Council of Australia
MIT	Massachusetts Institute of Technology
MPa/km	megapascals per kilometer
MSHA	Mine Safety and Health Administration
MW	megawatt
MWt	megawatt thermal
NABCEP	North American Board of Certified Energy Practitioners
NAE	National Academy of Engineering
NAICS	North American Industry Classification System
NAM	National Association of Manufacturers
NANT	National Academy for Nuclear Training
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NCEP	National Commission on Energy Policy
NCRC	National Career Readiness Certificate
NDBC	National Data Buoy Center
NECA	National Electrical Contractors Association
NEED	National Energy Education Development
NEI	Nuclear Energy Institute
NEORI	National Enhanced Oil Recovery Institute
NETL	National Energy Technology Laboratory
NGA	National Geothermal Academy
NIOSH	National Institute for Occupational Safety and Health
NJATC	National Joint Apprenticeship and Training Committee
NMA	National Mining Association
NMOC	Naval Meteorology and Oceanography Command
NMSI	National Math and Science Initiative
NNSA	National Nuclear Security Administration
NOAA	National Oceanic and Atmospheric Administration
NOS	National Ocean Service
NRC	National Research Council
NRCA	National Roofing Contractors Association
NREC	North American Electric Reliability Corporation
NREL	National Renewable Energy Laboratory
NSF	National Science Foundation
NSSGA	National Stone, Sand and Gravel Association
NUCP	Nuclear Uniform Curriculum Program

O&M	operating and maintenance
O*NET	Occupational Information Network
OEM	original equipment manufacturer
OMSHR	Office of Mine Safety and Health Research
OPEC	Organization of Petroleum Exporting Countries
OPM	Office of Personnel Management
OSHA	Occupational Safety and Health Administration
OSM	Office of Surface Mining, Reclamation and Enforcement
PCA	planned capacity addition
PPA	purchase power agreement
PSM	Professional Science Master's
PTC	production tax credit
PTP	petrotechnical professional
PV	photovoltaic
R&D	research and development
RCNET	Regional Center for Nuclear Education and Training
REC	renewable energy certificate
RECS	research experience in carbon sequestration
REE	rare earth element
RISE CSRP	Roof Integrated Solar Energy, Inc. Certified Solar Roofing Professional
RPS	renewable portfolio standard
RRTT	rapid response team for transmission
RTP	regional training provider
SACS	Sleipner Saline Aquifer Storage
SAT	Scholastic Aptitude Test
SBC	Schlumberger Business Consulting
SHC	solar heating and cooling
SIC	Standard Industrial Classification System
SITN	Solar Instructor Training Network
SME	Society of Mining, Metallurgy and Exploration
SMR	small modular reactor
SOC	Standard Occupation Code
SPE	Society of Petroleum Engineers
SSE	short-service employee
STEM	science, technology, engineering, and mathematics
THMC	thermo-hydro-mechanical-chemical
TJ/yr	terrajoules per year
TL	transmission line
TMCC	Truckee Meadows Community College
UAF	University of Alaska Fairbanks
UBB	Upper Big Branch

USBM	U.S. Bureau of Mines
ULU	Underwriters Laboratories University
USEC	United States Enrichment Corporation
USFS	U.S. Forest Service
USGS	U.S. Geological Survey
USNRC	U.S. Nuclear Regulatory Commission
UT	University of Texas
VET	vocational education and training
WAG	water-alternating-gas
WGA	Western Governors' Association

E

Committee and Staff Biographies

ELAINE T. CULLEN (*Cochair*) is the vice president of Safety Solutions International Northwest Operations. She has over 38 years of experience working to improve safety and health in mining, beginning her career with the U.S. Bureau of Mines. She was a principal investigator for the National Institute for Occupational Safety and Health (NIOSH) Spokane Research Lab, where she led a research team to develop and evaluate effective safety training for miners. Dr. Cullen has created 12 safety training videos, 9 for the mining industry, 2 for oil and gas production, and 1 for commercial salmon fishing. Dr. Cullen has won numerous national and international awards for her work, including a Telly Award for her documentary on the Sunshine Mine fire that killed 91 miners. She is particularly interested in the power that stories have to connect to trainees and convince them to work more safely. Dr. Cullen is a member of the American Society of Safety Engineers, Women in Safety Engineering, the Society for Mining, Metallurgy, and Exploration, the National Safety Council, and the International Society for Mine Safety Professionals, and is a Certified Mine Safety Professional as well as a Mine Safety and Health Administration certified safety trainer for both surface and underground. She is currently working on assessing safety cultures on mine sites and on an occupational ethnography of land-based oil and gas workers, and is using the findings of her study to create training materials for those working on drill and service rigs. Dr. Cullen is also member of the National Research Council Committee on Earth Resources. She earned a B.A., M.B.A., and Ph.D. from Gonzaga University.

CHARLES FAIRHURST (NAE) (*Cochair*) is professor emeritus from the University of Minnesota and senior consulting engineer for Itasca Consulting Group, Inc. His leadership in rock mechanics has led to numerous innovations in the field. He is the author of more than 100 publications that span nearly all aspects of rock mechanics and rock engineering. His primary professional interests are rock mechanics and its application to problems in civil, mining, petroleum engineering, engineered geothermal systems (EGSs) and the geological isolation of nuclear waste. His current interests include the integration of analytical and numerical modeling procedures with field observations, to guide practical design in rock engineering. Dr. Fairhurst is a former president of the International Society for Rock Mechanics; fellow of the American Rock Mechanics Association; and member of the American Institute of Mining Engineers; American Society of Civil Engineers, and Sigma Xi. He is a member of the Royal Swedish Academy of Engineering Sciences and has been awarded honorary doctorate degrees by the University of Nancy, France; Techical University, St. Petersburg, Russia; University of Sheffield, England; and University of Minnesota. He is advisory professor of Tongji Univeristy, China. Dr. Fairhurst received a Ph.D. in mining engineering from Sheffield University.

KATHLEEN A. ALFANO is the director and principal investigator of the National Science Foundation (NSF) Advanced Technological Education (ATE) CREATE Renewable Energy Center of Excellence. Since 1996, she has led a community college consortium (CREATE) focused on addressing emerging engineering technology curriculum needs through education–industry partnerships. As Director of NSF's Renewable Energy Center of Excellence, she is involved in efforts across the United States to define and implement credit technician curricula in many areas of renewable energy, including wind, solar, geothermal, and energy efficiency. She served as a program director and colead for the ATE Program at the NSF in 2007-2008, and previously as dean of Academic Computing and Professional Programs, and she continues to be a faculty member at the College of the Canyons. She has over 30 years of successful faculty leadership, administration of technical departments, and leadership and evaluation of state and federal curriculum projects, especially in the areas of technical education. Dr. Alfano has a B.S. in chemistry, and M.S. in education/counseling, and a Ph.D. from UCLA in higher education, work, and adult development.

BURT S. BARNOW is the Amsterdam Professor of Public Service and Economics in the Trachtenberg School of Public Policy and Public Administration at George Washington University. Dr. Barnow has over 30 years of experience as an economist and manager of research projects in the fields of workforce development, program evaluation, performance analysis, labor economics, welfare, poverty, child support, and fatherhood initiatives. He has extensive experience conducting research on implementation and effectiveness of large government programs. His current and recent research includes a project to develop and evaluate demonstrations that test innovative strategies to promote self-sufficiency for low-income families for the U.S. Department of Health and Human Services and an assessment of the implementation of the workforce provisions of the American Recovery and Reinvestment Act. Prior to coming to George Washington University, Dr. Barnow was associate director for research at Johns Hopkins University Institute for Policy Studies, where he worked for 18 years. Dr. Barnow has also worked for the Lewin Group, U.S. Department of Labor (including 4 years as director of the Office of Research and Evaluation in the Employment and Training Administration), and the University of Pittsburgh. Dr. Barnow has served on nine other National Research Council committees. He has a B.S. degree in economics from the Massachusetts Institute of Technology and M.S. and Ph.D. degrees in economics from the University of Wisconsin at Madison.

SALLY M. BENSON is the director of Stanford University's Global Climate and Energy Project (GCEP) and a research professor in the Department of Energy Resources Engineering (ERE), in the School of Earth Sciences. The ERE research group investigates fundamental characteristics of carbon dioxide storage in geological formations as a means of climate change mitigation. Prior to joining GCEP, Dr. Benson worked at Lawrence Berkeley National Laboratory, serving in a number of capacities, including division director for Earth Sciences, associate laboratory director for Energy Sciences, and deputy director for Operations. She is the author and coauthor of over 160 scientific publications. Dr. Benson received a B.S. degree in geology from Barnard

College at Columbia University and an M.S. and Ph.D. in materials science and mineral engineering from the University of California, Berkeley.

EMILY DeROCCO is the principal of E3, a Washington, D.C.-based strategic consulting practice focused on linking education, workforce, and economic development assets for competitive advantage. Dr. DeRocco is the immediate past president of The Manufacturing Institute where she launched and implemented a strategic national agenda focused on education reform and workforce development, innovation support and services, and research on behalf of U.S. manufacturers. Under her leadership, the Institute developed and deployed a system of nationally portable, industry-recognized manufacturing skills certifications now influencing secondary and postsecondary education reform efforts in 36 states; chaired the National Thought Leaders Forum on linking the nation's high-performance supercomputing capacity to manufacturers; and released leading-edge research including *The Facts About Modern Manufacturing*; *The Innovation Imperative: How U.S. Manufacturing Can Restore Its Edge*; *The Manufacturing Industry's Structural Cost Study*; *People & Profitability*; and *The Annual Index of the Public Perception About Modern Manufacturing*. Prior to her leadership in U.S. manufacturing, Dr. DeRocco was nominated by President Bush and confirmed by the U.S. Senate as the Assistant Secretary of Labor in 2001. She currently serves on the Board of Directors of Western Governors University and the Harrisburg University of Science and Technology as well as the Board of Advisors to the University of Mississippi's Center for Manufacturing Excellence. Dr. DeRocco is a proud graduate of The Pennsylvania State University and received her Juris Doctorate from the Georgetown Law Center.

LEIGH FREEMAN is the principal and general manager of Downing Teal, Inc. He has over 30 years of domestic and international experience in the resource industries. Early in his career, Mr. Freeman served in technical, management, and executive positions with large and small resource companies, including 10 years with Placer Dome. He cofounded Orvana Minerals, where he served on its board of directors as well as serving as president. Mr. Freeman is a regular speaker at international mining and investment conferences on the topics of talent, minerals education, innovation, sustainable development, and the business of mining. He is a recognized advocate of the junior mining sector. He serves in leadership roles for the Society of Mining Engineers, Society of Economic Geologists, Industrial Minerals Association, International Center for Appropriate and Sustainable Technologies, as well as Montana Tech, South Dakota School of Mines, University of Arizona, and Queen's University. Mr. Freeman received his B.S. in geological engineering from Montana Tech of the University of Montana.

JOHN A. PAPPAS is the director of the Texas A&M Wind Energy Center, the associate director of the Texas A&M Energy Engineering Institute and the academic cochair of The Wind Alliance Technical Committee. He previously was part of the executive management team of the Center for Electromechanics, one of the largest research institutes at the University of Texas. Mr. Pappas served as the program manager and director of business development as well as principal investigator on numerous projects, including multigigawatt generators for electric accelerators, novel high-power converter systems, controls and measurement systems for high-voltage power supplies, and advanced manufacturing processes for the oil and specialty materials industries. Mr. Pappas is a member of the American Wind Energy Association and the Institute of Electrical and Electronics Engineers and is the author of 25 refereed papers in IEEE publications. Mr. Pappas is a registered professional engineer. He holds a BSEE from the New Jersey Institute of Technology and an M.S. in engineering from the University of Texas at Austin.

ROY RADNER (NAS) is Leonard N. Stern School Professor of Business at New York University (NYU). He is also a professor of economics and information systems at the Stern School, and professor of environmental studies at NYU. Prior to joining NYU, he was a distinguished member of technical staff at AT&T Bell Laboratories, and professor of economics and statistics at the University of California, Berkeley. Dr. Radner's research interests include bounded rationality in decision making, self-enforcing global climate change treaties, strategic analyses of petty corruption in developing countries, theories of information processing and decentralization within firms, and pricing of information technology. He is a member of the National Academy of Sciences, a fellow of the American Academy of Arts and Sciences, a distinguished fellow of the American Association for the Advancement of Science and of the American Economic Association, a past president of the Econometric Society, an overseas fellow of Churchill College, Cambridge, and a past recipient of a Guggenheim Foundation Fellowship. Dr. Radner received his Ph.B. (with Honors), his B.S. and M.S. in mathematics, and Ph.D. in mathematical statistics from the University of Chicago.

JOEL L. RENNER is a geothermal consultant with over 30 years of research and management experience related to mineral and energy resources. His experience includes management of multidisciplinary research groups, business development, resource assessment, and independent research. Mr. Renner is an internationally recognized expert on geothermal energy. Prior to becoming an independent consultant, Mr. Renner worked for over 20 years with the Idaho National Laboratory, where he was a principal investigator and manager of the Geothermal Program. Mr. Renner has provided technical expertise on geothermal resources to the Department of Energy. He received a B.A. in mathematics from Carleton College and an M.S. in geology from the University of Minnesota, and he had a Ph.D. candidacy in applied earth science at Stanford University. He is a member of the Geothermal Resources Council, a former member of its board of directors and recipient of its Joseph W. Aidlin award. Mr. Renner is also a member of the American Association of Petroleum Geologists, American Geophysical Union, and the Geological Society of Minnesota.

STERLING J. RIDEOUT, JR. is the assistant director of program support in the Office of Surface Mining of the U.S. Department of the Interior. He is responsible for developing and implementing national policies, guidelines, and technical guidance for active and abandoned mine land reclamation in order to implement the Surface Mining Control and Reclamation Act. He also oversees policy direction on state, federal, and Indian regulatory as well as abandoned mine lands programs, grants administration, reclamation technology programs, bonding and the Applicant/Violator System and technical training program. Mr. Rideout received a B.S. degree in chemistry from Morehouse College, and an M.S. in technology management and an M.B.A. from the University of Maryland.

KENNETH C. ROGERS is a retired commissioner of the U.S. Nuclear Regulatory Commission, to which he was appointed in 1987. Prior to his appointment to the Nuclear Regulatory Commission, Dr. Rogers was the president of Stevens Institute of Technology, where he had also served as acting provost/dean of faculty. His expertise includes particle-accelerator, plasma, and high-energy particle physics and physical electronics, as well as nuclear facility operations. He is a fellow of the American Association for the Advancement of Science and the American Nuclear Society, and he is a recipient of the Institute of Electrical and Electronics Engineers Millennium Award Medal. Dr. Rogers received a B.S. in physics from St. Lawrence University and an M.A. and a Ph.D. in physics from Columbia University.

REGINAL SPILLER is the chief executive officer of Azimuth. Previously he was the chief operating officer for Allied Energy and cofounder of Frontera Resources, and served as executive advisor, Exploration and Technology. Mr. Spiller was an executive vice president at Frontera and in charge of the company's exploration and production activities from May 1996 to March 2009. Mr. Spiller has over 25 years of experience in the international oil and gas industry. He was deputy assistant secretary for gas and petroleum technologies at the U.S. Department of Energy, and served as the international exploration manager for Maxus Energy Corporation. Mr. Spiller is an active member of the American Association of Petroleum Geologists and the National Association of Black Geologists and Geophysicists. He is currently a member of the Board on Earth Sciences and Resources and has previously served on the NRC Committee on Earth Resources and two National Research Council ad hoc study committees. Mr. Spiller holds an M.S. degree in hydrogeology from The Pennsylvania State University and a B.S. in geology from the State University of New York.

GERARD ("JERRY") VENTRE is a consultant in photovoltaic (PV) systems engineering, specializing in workforce development, system design, and product assurance. He has over 35 years of experience in research, development, design, systems analysis, and education. For 20 of those years, he led the PV and distributed power programs at the Florida Solar Energy Center, a research institute of the University of Central Florida. During that time he also managed the U.S. DOE's Photovoltaic Southeast Regional Experiment Station, with emphasis on test, evaluation, and application of PV and advanced technologies. He developed the Florida Photovoltaic Buildings Program, including the most comprehensive PV quality assurance program in the United States. Workforce activities have included a survey of workforce needs for the PV industry; task analyses, curriculum and training program development for both practitioners and trainers; chair of a national committee on PV entry-level learning objectives for the North American Board of Certified Energy Practitioners; senior advisor to the national administrator for the Solar Instructor Training Network; consultant and advisor to the Interstate Renewable Energy Council (IREC) and the Institute for Sustainable Power Quality accreditation and certification programs; and contributing author of IREC's document on best practices and recommended guidelines for renewable energy training. He has taught at the graduate and undergraduate levels, including PV systems, has over 150 technical publications, and is coauthor with Roger Messenger of the highly regarded text entitled *Photovoltaic Systems Engineering*. Dr. Ventre received his B.S. degree in aerospace engineering, and his M.S. and Ph.D. degrees in aerospace engineering and applied mechanics from the University of Cincinnati.

National Research Council Staff

CY BUTNER is a senior program officer with the Board on Earth Sciences and Resources of the National Academies' National Research Council (NRC). He has been with the NRC for 15 years, during which time he has served with several boards on programs including the U.S. Energy and Mining Industries Workforce Study, and the National Institute of Standards and Technology and Army Research Laboratory Peer Assessment Programs. He also has participated in a number of ad hoc studies, covering a range of topics. Before joining the NRC, Mr. Butner worked with two aerospace consulting firms, supporting space and aeronautics technology development programs at NASA Headquarters. Before that, he worked for RCA as a satellite solar array engineer, for NASA at the Goddard Space Flight Center as a science co-op student and a materials engineer, and for the New Mexico Environmental Improvement Agency as a statistician. Mr. Butner has B.S. and M.S. degrees in physics from the American University and a B.S. degree in mathematics from the University of New Mexico.

ELIZABETH A. EIDE is director of the Board on Earth Sciences and Resources at the National Research Council (NRC). Prior to joining the NRC as a staff officer in 2005, she served as a researcher, team leader, and laboratory manager for 12 years at the Geological Survey of Norway in Trondheim. While in Norway her research included basic and applied projects related to isotope geochronology, mineralogy and petrology, and crustal processes. Her publications include more than 40 journal articles and book chapters, and 10 Geological Survey reports. She has overseen 10 NRC studies. She completed a Ph.D. in geology at Stanford University and received a B.A. in geology from Franklin and Marshall College.

GAIL GREENFIELD is a senior program officer with the Board on Higher Education and Workforce at the National Research Council (NRC). Recent studies in which she has been involved include: Future U.S. Workforce for Geospatial Intelligence; Science, Technology, Engineering and Mathematics Workforce Needs for the U.S. Department of Defense and the U.S. Defense Industrial Base; and Emerging Workforce Trends in the U.S. Energy and Mining Industries. Prior to joining NRC, Gail was an assistant professor of economics at the College of Wooster and, more recently, a consultant at Mercer in Washington, D.C. Gail received her Ph.D. in economics from Claremont Graduate University and her bachelor's degree in business economics from the University of California, Santa Barbara.

NICHOLAS D. ROGERS is a financial and research associate with the Board on Earth Sciences and Resources, National Research Council. He received a B.A. in history, with a focus on the history of science and early American history, from Western Connecticut

State University in 2004. He began working for the National Academies in 2006 and supports the Board on Earth Sciences and Resources on a wide range of areas from earth resources to geographical and mapping sciences.

COURTNEY GIBBS is a program associate with the National Research Council Board on Earth Sciences and Resources. She received her degree in graphic design from the Pittsburgh Technical Institute in 2000 and began working for the National Academies in 2004. Prior to her work with the board, Ms. Gibbs supported the Nuclear and Radiation Studies Board and the former Board on Radiation Effects Research.

JASON R. ORTEGO is a research associate with the Board on Earth Sciences and Resources at the National Academies. He received a B.A. in English from Louisiana State University in 2004 and an M.A. in international affairs from George Washington University in 2008. He began working for the National Academies in 2008 with the Board on Energy and Environmental Systems, and in 2009 he joined the Board on Earth Sciences and Resources.

CHANDA T. IJAMES is a senior program assistant with the Board on Earth Sciences and Resources at the National Academies. She received a B.S. in psychology from the University of Maryland University College and is pursuing an M.Ed. in instructional technology from the University of Maryland University College. She began working for the National Research Council Board on Earth Sciences and Resources in 2011.