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U.S. Geological Survey Energy and Minerals Science Strategy—Public Review Release

By Richard C. Ferrero, Jonathan J. Kolak, Donald J. Bills, Zachary H. Bowen, Daniel J. Cordier, Tanya J. Gallegos, James R. Hein, Karen D. Kelley, Philip H. Nelson, Vito F. Nuccio, Jeanine M. Schmidt, and Robert R. Seal

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Foreword

In 2007, the U.S. Geological Survey (USGS) published a Bureau Science Strategy *Facing Tomorrow's Challenges—U.S. Geological Survey Science in the Decade 2007–2017*. It provided a view of the future, establishing science goals that reflected the USGS's fundamental mission in areas of societal impact such as energy and minerals, climate and land use change, ecosystems, natural hazards, environmental health, and water. Intended to inform long-term program planning, the strategy emphasizes how USGS science can make substantial contributions to the well-being of the Nation and the world.

In 2010, I realigned the USGS management and budget structure, changing it from a structure associated with scientific disciplines—Geography, Geology, Biology and Hydrology—to an issue-based organization along the lines of the Science Strategy. My aim was to align our management structure with our mission, our science priorities, our metrics for success, and our budget. An added benefit was that the USGS immediately appeared relevant to more Americans and it became easier for those outside the agency to navigate our organizational structure to find where within the USGS they would find the solution to their problem. External partners rarely approached us with a problem in "geology," but they might need help with an issue in climate change or energy research.

The new organization is focused on seven science mission areas:

- Climate and Land Use Change
- Core Science Systems
- Ecosystems
- Energy and Minerals
- Environmental Health
- Natural Hazards
- Water

The scope of each of these new mission areas is broader than the science directions outlined in the USGS Science Strategy and together cover the scope of USGS science activities.

In 2010, I also commissioned seven Strategic Science Planning Teams (SSPTs) to draft science strategies for each USGS mission area. Although the existing Bureau Science Strategy could be a starting point for this exercise, the SSPTs had to go well beyond the scope of the existing document. What is of value and enduring from the work of the programs that existed under the former science disciplines needed to be reframed and reinterpreted under the new organization of the science mission areas. In addition, new opportunities for research directions have emerged in the five years since the Bureau Science Strategy was drafted, and exciting possibilities for cooperating and collaborating in new ways are enabled by the new mission focus of the organization.

Scientists from across the Bureau were selected for these SSPTs for their experience in strategic planning, broad range of experience and expertise, and knowledge of stakeholder needs and relationships. Each SSPT was charged with developing a long-term (10-year) science strategy that encompasses the portfolio of USGS science in the respective mission area. Each science strategy will reinforce others because scientific knowledge inherently has significance to multiple issues. Leadership of the USGS and the Department of the Interior will use the science vision and priorities developed in these strategies for program guidance, implementation planning, accountability reporting, and resource allocation. These strategies will guide science and technology investment and workforce and human capital strategies. They will inform our partners regarding opportunities for communication, collaboration, and coordination.

The USGS has taken a significant step toward demonstrating that we are ready to collaborate on the most pressing natural science issues of our day and the future. I believe a leadership aligned to support these issue-based science directions and equipped with the guidance provided in these new science strategies in the capable hands of our scientists will create a new era for USGS of which we can all be proud.

Marcia McNutt
Director

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Mission and Vision

Reflected by and consistent with the 2010 realignment of the U.S. Geological Survey, the energy and mineral resources mission is to provide impartial science and information for understanding the occurrence and distribution of national and global energy and mineral resources that may contribute to supplies, the potential environmental and other effects stemming from resource use, and the global supply and flow of non-fuel mineral commodities. A more integrated, unified approach to energy and mineral resource issues will enhance the Nation's ability to consider viable resource options and better make informed decisions.

Executive Summary

The economy, national security, and standard of living of the United States depend heavily on adequate and reliable supplies of energy and mineral resources. Based on current population and consumption trends, the Nation's use of energy and minerals can be expected to grow, driving the demand for ever broader scientific understanding of resource formation, location, and availability. In addition, the increasing importance of environmental stewardship, human health, and sustainable growth place further emphasis on energy and mineral resources research and understanding. Collectively, these trends in resource demand and the interconnectedness among resources will lead to new challenges and, in turn, require cutting-edge science for the next generation of societal decisions.

The contributions of the U.S. Geological Survey to energy and minerals research are well established. Based on five interrelated goals, this plan establishes a comprehensive science strategy. It provides a structure that identifies the most critical aspects of energy and mineral resources for the coming decade.

- **Goal 1.**—Understand fundamental Earth processes that form energy and mineral resources.
- **Goal 2.**—Understand the environmental behavior of energy and mineral resources and their waste products.
- **Goal 3.**—Provide inventories and assessments of energy and mineral resources.
- **Goal 4.**—Understand the effects of energy and mineral development on natural resources.
- **Goal 5.**—Understand the availability and reliability of energy and mineral resource supplies.

Within each goal, multiple, scalable actions are identified. The level of specificity and complexity of these actions varies, consistent with the reality that even a modest refocus can yield large payoffs in the near term whereas more ambitious plans may take years to reach fruition. As such, prioritization of actions is largely dependent on policy direction, available resources, and the sequencing of prerequisite steps that will lead up to the most visionary directions. The science strategy stresses early planning and places an emphasis on interdisciplinary collaboration and leveraging of expertise across the U.S. Geological Survey.

Introduction

Energy and mineral resources are essential to society. The U.S. Geological Survey (USGS), as the Nation's principal natural science agency, advances the science of energy and mineral resources and provides statistical information and analysis on the global flow of minerals and mineral materials. The Organic Act of 1879 (20 Stat. 394; 43 U.S.C. 31) defines the role of the USGS as "… the classification of the public lands and examination of the geological structure, mineral resources, and products of the national domain." Understanding the science, quality, and spatial distribution of energy and mineral resources has thus been a core function of the USGS since its inception. Today, the USGS is recognized by industry, nongovernmental organizations, and international, Federal, State, and local governments for its reliable, high-quality energy and minerals science, information, fundamental research, and expertise. This plan describes the USGS role and suggests steps that can be taken in the next 10 years to provide the Nation with energy and minerals science and information on both current and emerging issues. Collectively, the understanding gained from these activities provides a basis for informing decision-making with respect to such issues as economic vitality, environmental health, national security, and responsible resource management and protection on U.S. Department of the Interior (DOI) and other lands.

The United States uses substantial amounts of energy and mineral resources each year. In 2011, industries that consumed processed mineral materials added about $2,230 billion to the U.S. gross domestic product (fig. 1*A*), and the Nation's mines and quarries produced raw materials with an estimated value of $74 billion (U.S. Geological Survey, 2012, p. 5; fig. 1*B*). Domestic energy resource production activities also occur across the Nation (such as oil and gas production, fig. 2). In 2010, the United States consumed 7 billion barrels of oil, 24 trillion cubic feet of natural gas, and 1 billion short tons of coal (U.S. Energy Information Administration, 2011). To meet these needs, energy and (or) mineral resource production (extraction) occurs in every State, with significant additional amounts imported from other countries.

The United States faces challenges in meeting its current and future energy and minerals needs. These challenges range in scale from global competition for resources to local decisionmaking about the appropriate use of individual land parcels. Decisions on every scale may affect the availability of energy and minerals and have far-reaching economic, geopolitical, and social consequences. For example, the increasing demand for both traditional and emerging energy and mineral resources is driving exploration and production into geological settings for which there may be relatively little data available, such as in the Arctic, deeper in the Earth's crust, and beneath deeper regions of the oceans, and which may pose considerable technical and engineering challenges or be co-located with sensitive environments or other natural resources of importance. At the same time, consideration of alternative sources of energy and minerals is increasing, which may involve mining of deposits of lower concentration, recovering resources from waste and recycling streams, and sourcing

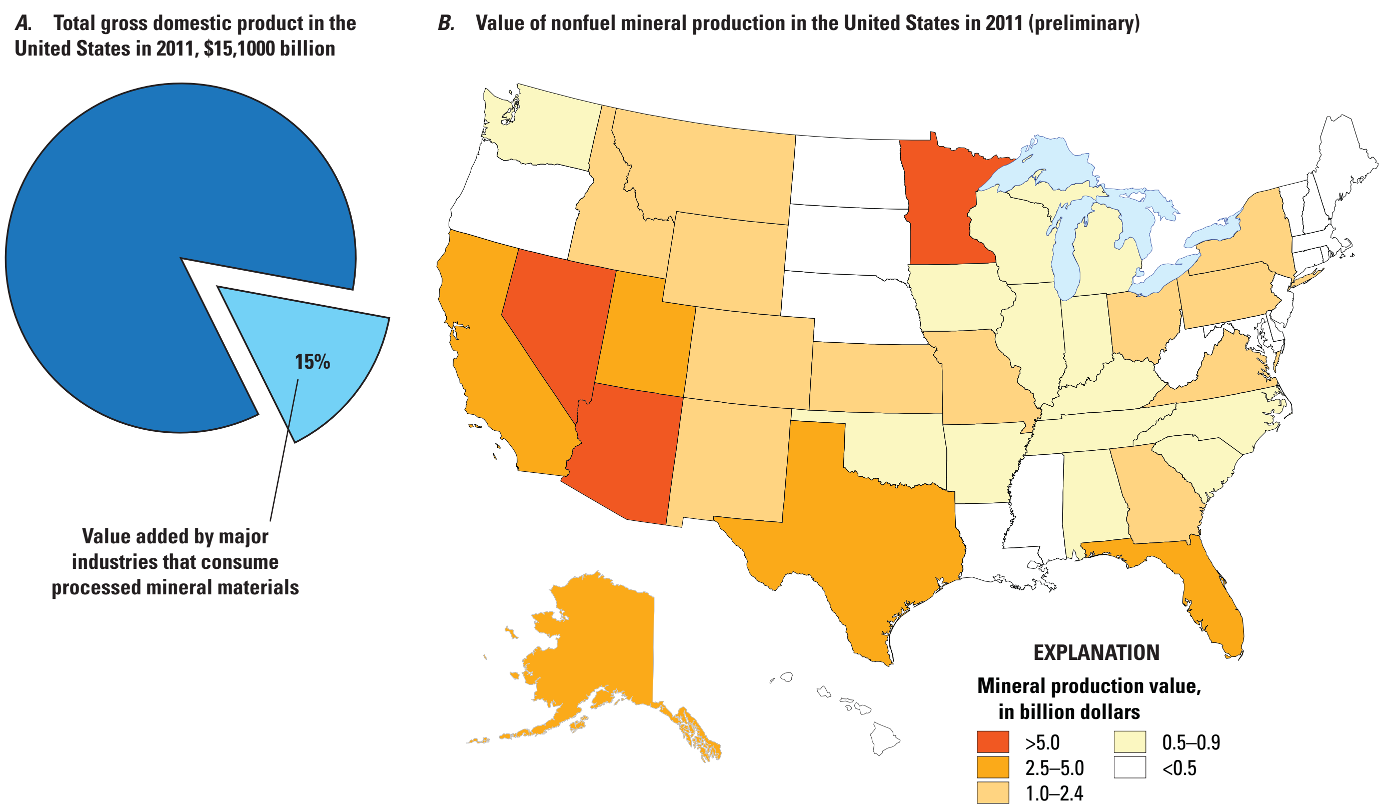


Figure 1. Magnitude and distribution of mineral resource production activities across the Nation. *A*, Pie chart depicting the estimated value added to the U.S. gross domestic product by major industries that consume processed mineral materials; major consuming industries of processed mineral materials are construction, durable goods manufacturers, and some nondurable goods manufacturers. *B*, Map showing the [preliminary] value of nonfuel mineral production (raw materials from mining) in the United States in 2011. Data are from the U.S. Geological Survey (2012).

from countries with political systems and environmental sensitivities dissimilar from our own. The USGS serves the national interest by providing impartial information across this range of scales and about alternatives, thereby enabling decisionmakers and society at large to make informed decisions and better understand the potential outcomes of those decisions.

An additional challenge facing the Nation is the need to balance the availability and reliability of energy and mineral supplies with other considerations, including the availability of other natural resources, the viability of energy and mineral development amidst changes in climate, natural hazards, and demand, and the need to prevent or mitigate environmental degradation (Gundersen and others, 2011). This challenge is especially noteworthy given the long-term nature of resource development and associated infrastructure and the comparable or longer recovery times stemming from any adverse effects. The concept of sustainability, defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations World Commission on Environment and Development, 1987, p. 54), underpins many land-use and environmental policies that address this challenge. From the perspective of nonrenewable energy and mineral resources, sustainability focuses on the stewardship of lands and protection of the environment and on identification of alternative sources.

To provide society with the knowledge needed to consider these factors, there is growing recognition that it is incumbent on "earth scientists to redirect their scientific research, to assemble data that are usable in policy analysis and decisionmaking, and ultimately transmit their findings more clearly to policymakers and the public" (National Research Council, 1996, p. 5). The USGS conducts research and monitoring studies to address these challenges and provide a scientific foundation for decisionmaking with respect to sustainable resource use, protection, and adaptive management. In this strategy, we identified a set of overarching questions that drive the science needed to address energy and minerals resource use issues during the coming decade. All parts of this strategic plan are designed to reflect one or more of these challenges:

- How or where might we obtain the energy and mineral commodities to meet present and future needs?
- What economic, environmental, geopolitical, and health consequences must also be considered in both the short- and the long-term?
- How can decisions more effectively incorporate the scientific complexity and uncertainty associated with these issues?
- What science is needed to anticipate and respond to future challenges?

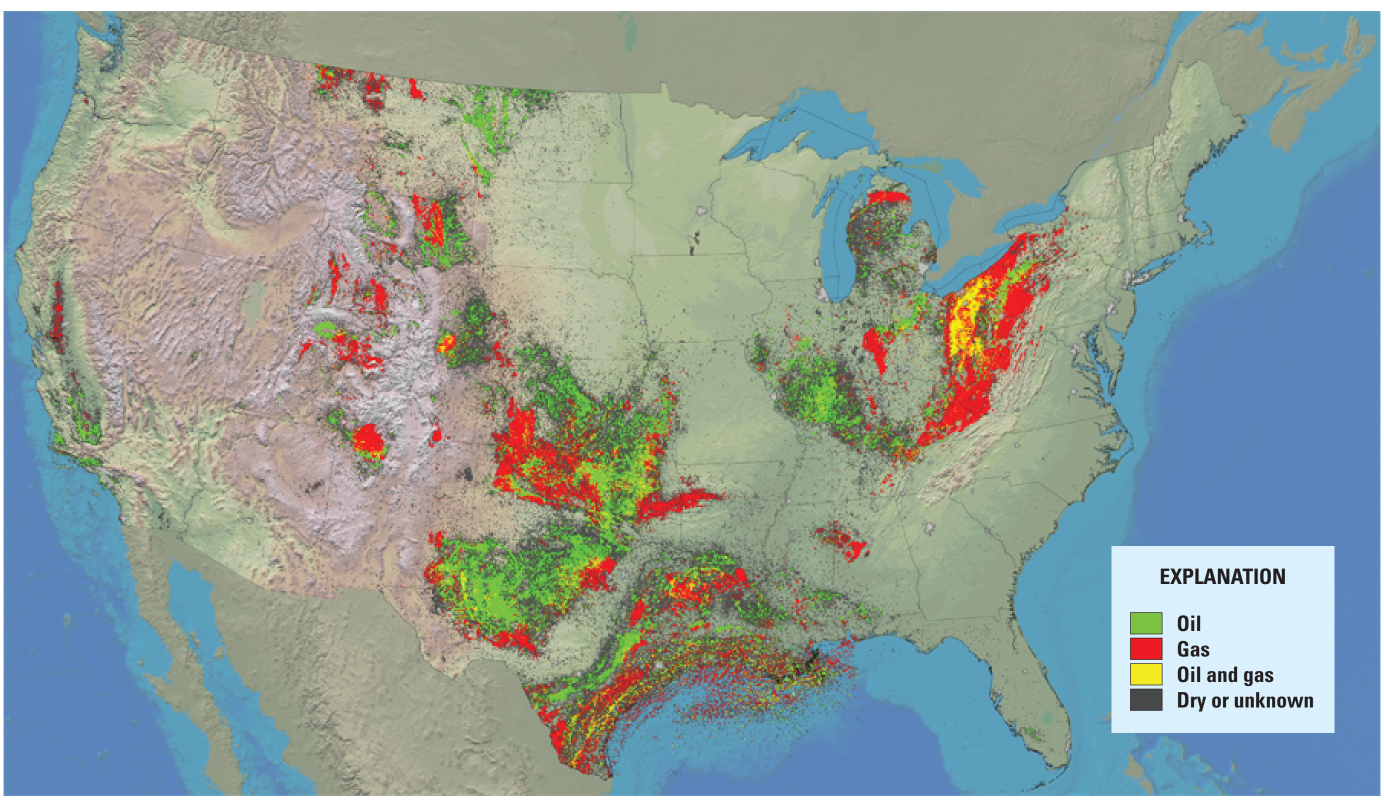


Figure 2. Areas of historical oil and gas exploration and production in the conterminous United States through 2006; from Biewick (2008).

Using these questions as a guide, we constructed five interdependent goals that collectively provide the needed scientific research, information, and analysis:

- **Goal 1.**—Understand fundamental Earth processes that form energy and mineral resources.
- **Goal 2.**—Understand the environmental behavior of energy and mineral resources and their waste products.
- **Goal 3.**—Provide inventories and assessments of energy and mineral resources.
- **Goal 4.**—Understand the effects of energy and mineral development on natural resources.
- **Goal 5.**—Understand the availability and reliability of energy and mineral resource supplies.

The overarching concept for these goals is a resource lifecycle for energy and minerals (fig. 3), which traces the flow of these resources from generation and occurrence through interaction with society and the environment and ultimate disposition and disposal.

Each goal addresses one or more stages of the resource lifecycle. Through targeted research, the first two goals expand our basic knowledge of the formation of energy and mineral deposits and their interaction with the atmosphere, biosphere, and hydrosphere. The next two goals build on this research foundation and develop additional science and information products. The final goal extends beyond current concerns to focus and deliver science on emerging issues and unanticipated events affecting energy and mineral resource supplies.

Together, these goals form a dynamic science strategy for advancing USGS science to a new level of understanding and effectiveness in the next 10 years (table 1). Each goal presents several specific “actions,” intended to fill the highest priority needs and address key gaps in data and understanding. Actions range from those that incrementally build on existing USGS capabilities and core strengths to new, ambitious efforts. In the majority of cases, successful achievement of these actions cannot be accomplished solely within the energy and minerals mission area but rather depends on collaboration and leveraging of expertise and capabilities across the USGS and among stakeholders and partners.

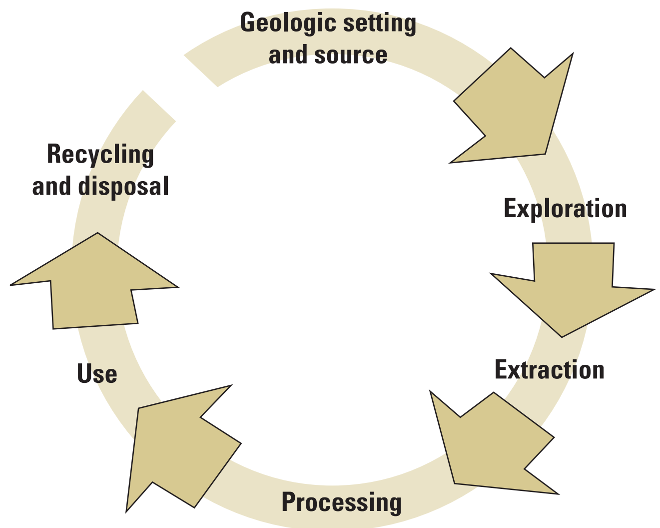


Figure 3. Conceptual diagram that depicts a resource lifecycle for energy and minerals. Society faces key questions within each stage of the resource lifecycle. Scientific understanding is essential to providing information for these decisions.

Core Strengths

As an agency without regulatory or resource stewardship responsibilities, the USGS is able to provide essential science products that complement the missions of other Federal agencies. The USGS performs research ranging from microscopic to global scales and collects and maintains long-term monitoring data that enable study of how systems change over time as well as facilitate construction of predictive models. Having an impartial, global perspective, the USGS can work across agency and jurisdictional boundaries to collect and interpret disparate information.

USGS scientists working on energy and minerals collectively have broad experience in energy and minerals research, resource assessment, environmental characterization, data collection, and analysis. A wide variety of customers and stakeholders, each with unique demands for information—from the Secretary of the Interior requesting scientific evaluation for decision support on uranium mining issues to resource evaluations for Congress, Federal agencies, and others—all rely on the vast breadth and quality of information USGS scientists provide, underscoring the importance of maintaining a robust foundation of scientific expertise.

Geologists, geophysicists, geochemists, physical scientists, and economists at science centers are conducting energy and minerals research and analysis in such areas as igneous and metamorphic petrology, isotopic and organic geochemistry, marine and economic geology, mineralogy, mineral commodity analysis and materials flow studies, sedimentology, sequence stratigraphy, and tectonics and structural geology. This research is applied to the understanding and assessment of fossil fuels and selected nonhydrocarbon energy sources and mineral deposits. Specific examples of energy and minerals research include development of new assessment methodologies; geochemical and mineralogical analyses; geophysical data acquisition and interpretation; minerals information collection, synthesis, and delivery, including development and maintenance of online databases; and dissemination, education, and outreach. In addition, working across the USGS, scientists conduct research on the potential environmental and

Table 1. Summary of goals and actions for the U.S. Geological Survey energy and minerals science strategy.

	Focus area	Actions
Goal 1: Understand fundamental earth processes that form energy and mineral resources		
1–1	Geologic and tectonic framework studies	1–1a; 1–1b; 1–1c
1–2	Evolution of energy and mineral systems	1–2a; 1–2b; 1–2c; 1–2d; 1–2e
1–3	Frontier studies	1–3a; 1–3b; 1–3c
Goal 2: Understand the environmental behavior of energy and mineral resources and their waste products		
2–1	Fundamental studies	2–1a; 2–1b; 2–1c
2–2	Applied investigations	2–2a; 2–2b; 2–2c; 2–2d
2–3	Synthesis activities	2–3a; 2–3b
Goal 3: provide inventories and assessments of energy and mineral resources		
3–1	Undiscovered geologically based energy resources	3–1a; 3–1b
3–2	Discovered nonfuel mineral resources	3–2a; 3–2b; 3-2c; 3-2d; 3-2e
3–3	Undiscovered nonfuel mineral resources	3–3a; 3–3b
Goal 4: Understand the effects of energy and mineral development on natural resources		
4–1	Spatial analysis of energy and mineral resource occurrence and development	4–1a; 4-1b; 4-1c
4–2	Exploration of interdisciplinary approaches	4–2a; 4–2b; 4-2c; 4-2d; 4-2e; 4-2f
Goal 5: Understand the availability and reliability of energy and mineral resource supplies		
5–1	Emerging or longer term issues affecting resource availability	5–1a; 5–1b; 5-1c; 5-1d; 5-1e
5–2	Short-term fluctuations affecting reliability of resource supplies	5–2a; 5–2b

human health effects of energy and mineral resource utilization. With a solid foundation in basic research and a recognized flexibility to apply that understanding to contemporary issues, the USGS is well positioned to provide cutting-edge energy and mineral resources and environmental research on current and future issues.

Mandates and Authorizations

The USGS was established on March 3, 1879, under the Organic Act of March 3, 1879 (20 Stat. 394; 43 U.S.C. 31), for “classification of the public lands, and examination of the geological structure, mineral resources, and products of the national domain.” This legislation stemmed from a report of the National Academy of Sciences, which had been tasked by Congress in June 1878 to provide a plan to secure the most cost-efficient surveying of the territories of the United States. The USGS component stemmed from the need to survey the mineral and water resources of the United States. The USGS responsibility and core capabilities for energy and minerals research and information have evolved considerably since the original legislation as the Nation’s information and resource needs have increased. Today, the United States is the world’s largest user of energy and mineral commodities. Further, with globalization and international demand for energy and minerals, the USGS works outside the borders of the United States as well.

Numerous congressional mandates and authorizations and presidential proclamations that required action by the USGS relative to energy and mineral resources have been enacted (table 2). Many of these mandates and authorizations recognize, support, and encourage research and assessments developed by the USGS and around which the current USGS workforce is formed. For example, the Energy Independence and Security Act of 2007 authorized the USGS to conduct storage capacity assessments of carbon dioxide (CO_2) for the purposes of evaluating geologic sequestration potential. This authorization is a recognition of USGS experience in conducting oil and gas resource assessments and established expertise in Earth sciences, methodologies, and unbiased assessments.

The USGS also operates under a number of memorandums of understanding (MOU) and interagency agreements that specify roles and responsibilities. Based on an MOU that provided the guidelines for coordinating geoscience studies among USGS, the Bureau of Land Management (BLM), and the U.S. Forest Service (USFS), the USGS was deemed responsible for providing resource assessments and inventories, identifying environmental attributes and hazards associated with resources, and conducting studies and research on energy and mineral resources and reserves for the USFS.

Table 2. Principal mandates and authorizations related to U.S. Geological Survey energy and minerals activities and their intersection with each of the five goals in the energy and minerals science strategy.

Legislation or presidential action providing authority	Goal 1	Goal 2	Goal 3	Goal 4	Goal 5
Organic Act of 1879	*	*	*	*	*
Strategic and Critical Materials Stock Piling Act of 1946	†		†		†
Department of Agriculture Organic Act of 1956			†	†	
Wilderness Act of 1964			*	*	
National Environmental Policy Act of 1969		**	**	**	**
Mining and Minerals Policy Act of 1970	†	†	†		
Forest and Rangeland Renewable Resources Planning Act of 1974			**	**	
Geothermal Energy Research, Development, and Demonstration Act of 1974	*		*		
Federal Coal Leasing Amendments Act of 1976			*	*	
Federal Land Policy and Management Act of 1976			*	*	
National Materials and Minerals Policy, Research, and Development Act of 1980	*	*	*	*	*
Alaska National Interest Lands Conservation Act of 1980			*	*	
Deep Seabed Hard Minerals Resources Act of 1980		**	**		
Nuclear Waste Repository Act of 1982			‡	‡	
Geothermal Steam Act Amendments of 1988			*	*	
Executive Order 12656—Assignment of Emergency Preparedness Responsibilities					†
Energy Policy Act of 1992			*		
[Transfer of functions from U.S Bureau of Mines, 1996 (Public Law 104–3019)]			*	*	*
Energy Policy and Conservation Act Amendments of 2000			*	*	
Methane Hydrate Research and Development Act of 2000	*				
Energy Policy Act of 2005	*		*	*	
Energy Independence and Security Act of 2007		*	*		
Executive Order 13603—National Defense Resources Preparedness					†

[*]Specifically mentions the U.S. Geological Survey (USGS) and (or) the U.S. Bureau of Mines, whose functions were partially transferred to the USGS in 1996.

[**]Does not specifically mention the USGS; responsibility for tasks is derived from the Organic Act of March 3, 1879.

[†]Authority is to Secretary of the Interior, not specifically to the USGS.

[‡]The USGS is to be consulted by the U.S. Department of Energy.

Goals for Energy and Mineral Resources Science

Goal 1.—Understand Fundamental Earth Processes That Form Energy and Mineral Resources

Introduction

From the Earth's crust, we extract the energy and mineral resources that are needed for use in our daily lives and that support our economy and national security. Comprehensive studies of the Earth's fundamental processes are necessary to understand the formation and distribution of energy and mineral resources from the surface of the Earth to depths of many kilometers. To achieve this understanding, future research efforts under goal 1 are grouped into three areas:

- Geologic and tectonic framework studies.
- The evolution of energy and mineral systems.
- New research in frontier areas.

The following sections present key scientific questions for each of these three areas and strategic actions to address these questions. These targeted research actions, which illuminate the conditions under which reservoirs and deposits form and where they occur, also lead to clearer identification of those aspects of formation and accumulation that may cause problems when exposed at the Earth surface or extracted (goal 2) and allow clearer delineation of the amount, location, and character of resources potentially available (goal 3).

1–1. Geologic and Tectonic Framework Studies

Regional-scale geologic studies integrate the tectonic and thermal evolution of basement and basin terranes, the occurrence and flow of subsurface fluids, and the fluid-rock interactions. Regional-scale geologic studies provide the geologic framework that will improve our understanding of the formation of oil and gas accumulations and mineral deposits at smaller spatial scales. Outcomes from these studies provide the scientific basis and guidelines for energy and mineral resource mapping and assessments (goal 3). The research activities on geologic processes expressed here and the assessment research activities considered in goal 3 are strongly interrelated because the outcomes of geologic research may alter assessment methodology, and questions uncovered during assessment work may spawn new geologic research activities.

Regional-scale geologic framework studies at the USGS have been limited by incomplete spatial coverage of seismic reflection, gravity, and magnetic data, which provide images of the subsurface and are a prerequisite to conducting structural analyses at the regional scale. With a few important exceptions, the seismic reflection data that the USGS has acquired are sparse and outdated and do not reflect the technological improvements of the past 30 years. Existing national gravity and magnetic datasets are composites of surveys acquired over many years at different scales of spatial coverage with consequent gaps in coverage. For example, in the oil and gas province of the Williston Basin in the northern Great Plains, which hosts one of the largest oil accumulations in the conterminous United States, no regional seismic lines are available for study, and widely spaced magnetic and gravity coverage data were acquired more than 40 years ago. Currently, new data are acquired by topical studies without a plan of systematic acquisition. While the main barrier to acquisition is cost (seismic data are usually purchased from vendors; augmentation of magnetic and gravity data requires new surveys), other avenues could be pursued to acquire data. Having access to a suite of deep-penetrating, crustal-scale geophysical data would improve views of the subsurface, and research based on these data will better reflect the "state-of-the-art" technologies than current efforts. Merging this new information with stratigraphic, structural, and other geophysical studies would support more accurate basin histories and better understanding of the formation of energy and mineral deposits.

The high data densities produced by studies on selected areas require new means of integrating multidisciplinary datasets. Interpretations of different datasets from separate analyses can produce incompatible results when viewed together. Thus, the attainment of consistent geological results benefits from mutual usage of a shared interpretive platform. Collaborative work is done more easily when viewed on interactive three-dimensional (3D) systems that provide the ability to slice and section 3D models at varying elevations and azimuths, complementing and gradually superseding the traditional presentations of selected map and cross sections (highlight 1). Incorporating a wide range of subsurface information, 3D models facilitate improved understanding of geologic processes. Such software systems will continue to evolve and provide improved capability for multidisciplinary collaboration.

Major Questions

- How does the thermal, magmatic, tectonic, and fluid-flow history of the Earth lead to the formation and later modification of energy and mineral deposits?
- What enhancements to geophysical and geochemical data are required to support crustal- and deposit-scale geological interpretations?
- How can multidisciplinary studies of a region or terrane be consistently interpreted and presented to users?

Strategic Actions

- *Action 1–1a.*—Map regional-scale geologic features that control the timing and location of energy and mineral resources. Identify key areas for regional-scale structural and geologic mapping, and use geophysical, geochemical, and isotopic studies to determine areas with resource potential. This action will result in improved geologic models, maps, and cross sections, revealing those areas where energy and mineral resources are most likely to be found in the United States.
- *Action 1–1b.*—Acquire geophysical datasets at the regional scale. Such an effort would require a systematic, multiyear program to facilitate the acquisition of seismic data in sedimentary basins and upgrade the existing national magnetic and gravity datasets. The increased wealth of high-quality geophysical images of the Earth's crust will extend and enhance geological interpretations.
- *Action 1–1c.*—Apply 3D models to areas of high potential for energy and mineral resources, incorporating geologic mapping, thermotectonic, fluid-flow, and geophysical interpretations. Such models will ensure compatibility of data and interpretations from multiple disciplines and broaden the user base because geological and geophysical interpretations may become more readily available in a user-friendly format.

1–2. Evolution of Energy and Mineral Systems

Energy and mineral resources are usually, but not always, located in different geologic settings. The following background paragraphs, questions, and actions sequentially address research issues dealing with energy systems, mineral systems, and areas where energy and mineral systems are coupled.

Highlight 1

The Advantages of Three-Dimensional Models and Visualization

Traditional U.S. Geological Survey (USGS) geoscience products have been generated and distributed primarily through the medium of two-dimensional reports, maps, and cross-sections, limiting the ability to characterize and understand three-dimensional (3D) systems and how they change over time (4D). And yet, the intrinsic 3D and 4D nature of the interpreted results increases the need for the USGS to generate and distribute scientific information using 3D and 4D visualization frameworks. In addition, Web-based delivery in 3D and 4D frameworks could open a new era in USGS publications.

Today, USGS scientists use 3D and 4D tools to visualize and interpret geologic information and to check the data, interpretations, and models (Jacobsen and others, 2011). 3D and 4D visualization can be a powerful quality control tool in the analysis of large, multidimensional datasets. Examples of geologic mapping in 3D include aquifer characterization, the interpretation of geophysical data with geological constraints, subsurface characterization of mineral systems, and oil and gas investigations. For example, a 3D geologic model served as input to a 4D computation of heating and oil generation during subsidence of the Anadarko Basin of Oklahoma (fig. 4). The transformation of kerogen to oil was computed as a function of geologic time and displayed on cross sections (at 300 million years ago (Ma) and 0 Ma). The transformation ratio was also color-contoured on the 3D surface of the source rock (Woodford Shale). Other useful displays (not depicted in figure 4) reveal the migration of oil and gas at different geologic times from the deep basin to reservoirs on the flanks of the basin.

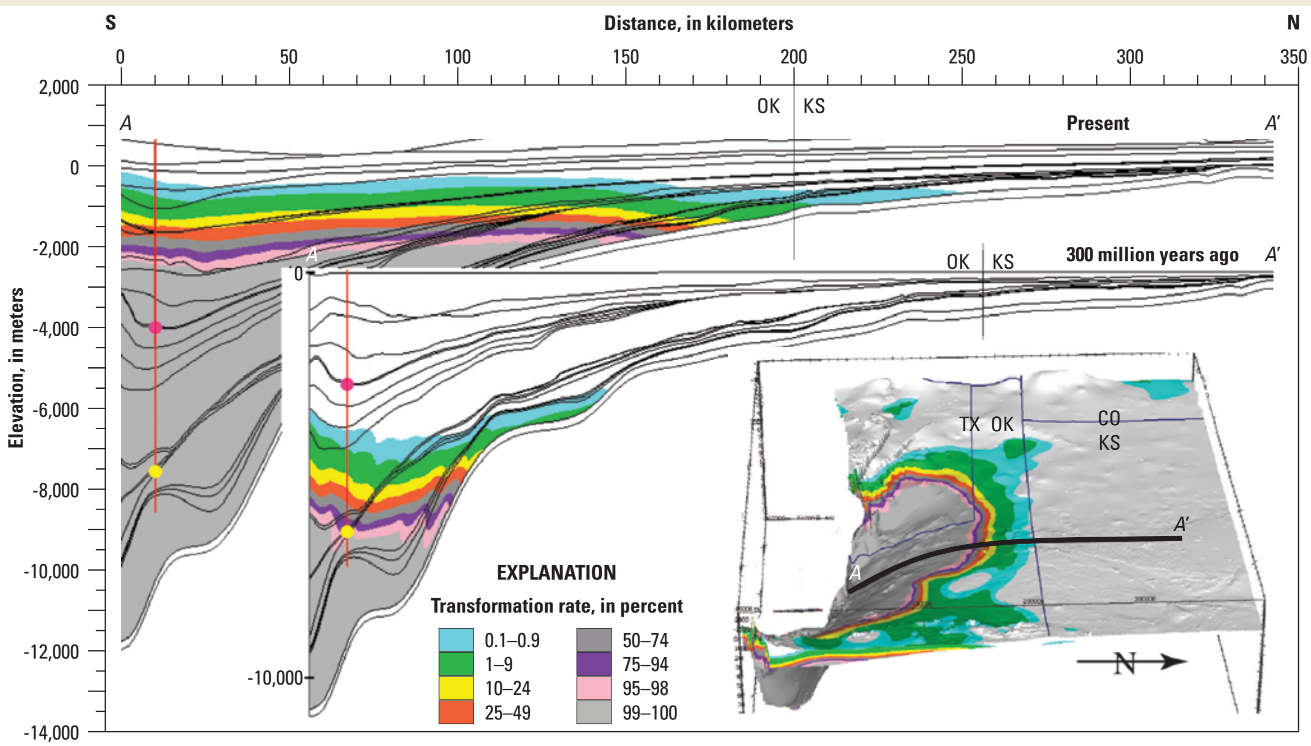


Figure 4. Geologic model output showing a south-to-north cross section (*A*–*A*′) at (*A*) present day and (*B*) 300 million years ago and (*C*) a three-dimensional (3D) model of thermal maturation using Woodford Shale transformation ratio. Woodford Shale in the Anadarko Basin in Oklahoma is the source of much of the oil and gas in the basin. Yellow and pink dots are approximate locations of the Woodford Shale and Thirteen Finger limestone. Elevation is relative to sea level, and vertical and lateral scales are equivalent for the cross sections. The black line in the 3D model shows the location of the cross-section *A*–*A*′. Map image is transformation ratio on the Woodford Shale layer at present day and at 10 times vertical exaggeration. Modified from Higley (2011, fig. 8).

An exploitable petroleum (oil, natural gas, and natural gas liquids) system encompasses the source rock, the rocks adjacent to source rocks, migration pathways, and conventional reservoirs. Source rocks that are the locus of petroleum generation may also house developable resources (shale gas and shale oil). Rocks adjacent to source rocks (such as found in tight gas systems), formerly not developed, are now routinely exploited in the conterminous United States. Thus, source rocks and tight rocks are two types of continuous petroleum systems supplying a rapidly expanding fraction of hydrocarbons, especially gas. Fluid migration pathways and charge mechanisms in these geologic settings continue to be elusive, poorly understood, and little studied. Despite advancements in seismic and well-logging technologies, the productivity of continuous petroleum systems is not readily predictable and must often be determined empirically. In contrast to the poorly understood nature of source rocks and tight rocks, the principles governing the occurrence of conventional (buoyant) oil and gas reservoirs are well understood and are not considered further here.

Energy resources currently contributing to the U.S energy mix (for example, oil, gas, coal, coalbed methane) are fairly well understood in terms of their geologic formation and occurrence. For these resources, we identify research priorities pertaining to environmental effects (goal 2) and assessments (goal 3). Other resources, such as oil shale, gas hydrates (also referred to as methane hydrates), and geothermal energy, which currently contribute little (or not at all) to the U.S. energy mix, are not well understood. Because these resources have the potential to make significant contributions to the energy mix in the future, we further identify research activities to address the many geologic and extractive questions pertaining to these emerging resources.

The concept of a mineral system is analogous to that of a petroleum system, but mineral systems are found in a wider range of rock types and structural settings. The formation of an ore deposit requires a source of metals, a mode of transport (often a hydrothermal fluid, but also magmatic, weathering, or sedimentary processes), and a site of deposition or accumulation where metals are concentrated to an extent that allows economically viable extraction. In a broad sense, the mineral system includes geologic and geodynamic factors, at many scales, that control the inception, evolution, and preservation of ore deposits. Mineral systems must be understood in their broadest possible context in order to support accurate resource assessments on regional, national, and global scales. For example, understanding the role of magmatic arcs in the geologic evolution of North America is critical for understanding the genesis and localization of hydrothermal and epithermal mineral deposits. Similarly, understanding the evolution of major sedimentary basins, including configuration, extent, and processes related to evolution, is critical for understanding the ore deposits associated with them. Such focus on the evolution of geologic entities and mineral systems on a geologic-system-scale will lead to more effective ore deposit models and resource assessments. The current state of knowledge varies considerably among deposit types; some deposit types that are becoming important owing to emerging national demand, such as platinum group elements, rare earth elements (REEs), and lithium, are not well understood, and focused research would benefit from deposit-scale studies. Other mineral systems, such as porphyry copper deposits, are well understood in terms of their origin and evolution, and future research would benefit from a broader approach, such as understanding the distribution and geologic evolution of magmatic arcs in which porphyry deposits form.

Energy and mineral systems are also linked in some cases. Examples are sedimentary basins that contain petroleum accumulations and base metal deposits, such as northern Alaska and the Appalachian Basin. Other examples include gold deposits associated with graphite and uranium enrichment in black shales and coals. Although the spatial associations of organic matter and petroleum on the one hand and specific mineral deposits on the other are well documented, the possible overlapping processes or genetic associations are not understood. These relationships may be passive (where petroleum and ore fluids use the same plumbing system but otherwise have no genetic association) or dependent (where organic matter or petroleum establishes proper conditions for ore deposition and (or) serves as a necessary component for transport of metals).

Major Questions

- What are the most important factors affecting the development of self-sourced and low-permeability (“tight”) petroleum systems, and how can this knowledge be applied to ongoing energy assessment needs?
- What areas of research will lead to advances in the usage of underutilized and high-priority mineral and energy sources?
- What are the primary controls on the timing and location of ore deposits, and in particular what are the factors that lead to formation of deposits of scarce commodities?
- What is the genetic association, if any, between petroleum systems and certain types of mineral deposits?

Strategic Actions

- *Action 1–2a.*—Investigate the geologic and geochemical factors regarding the genesis, evolution, and productivity of source rocks and low-permeability reservoirs (shale gas, shale oil, and tight gas). The improved understanding of the systematics of self-sourced and low-permeability systems can be used to improve resource assessments.

- *Action 1–2b.*—Conduct research on emerging energy resources to address geologic and extractive questions. In particular, studies on the chemistry of oil shale (highlight 2) and the conditions under which gas hydrates accumulate would be useful.
- *Action 1–2c.*—Conduct deposit-scale studies of selected types of high-priority commodities. Examples include commodities, such as lithium and REEs, for which relatively little is currently known about the genetic factors that control the distribution of mineralization and the physicochemical processes leading to deposition. The genetic models that are generated by such studies will characterize the geologic setting and abundance of important materials on land and on the sea floor and aid in assessments of such resources (goal 3).
- *Action 1–2d.*—Determine broad-scale controls on the formation and preservation of mineral systems. These studies would target systems that are well understood in terms of how they form, such as porphyry copper deposits.
- *Action 1–2e.*—Investigate the processes that result in some sedimentary basins hosting both petroleum and ore systems, emphasizing relationships between the localization of hydrocarbons and metals occurrences.

1–3. Frontier Studies

Many of the mineral resources in the United States, at least those exposed at the surface, have been identified and many are being exploited. However, frontier geographic areas, such as the Exclusive Economic Zone (EEZ; highlight 3) and Alaska are largely unexplored, and many areas of the United States may contain resources that are not exposed at the surface. Such areas require novel or “frontier” approaches or methods for exploring and assessing the potential of undiscovered resources.

Exclusive Economic Zone.—The mineral potential of the vast area of the EEZ is little known. Research in the underexplored EEZ is needed because the marine deposits of the area host a wide variety of rare metals and REEs, which are essential to emerging, green, and high-technology applications. Fundamental research on processes instrumental in concentrating metals into ore deposits in the deep-ocean can be carried out while the type and distribution of the deposits are being surveyed. These research results could provide a framework to support future assessments of deep-ocean mineral potential. Collaborative work with USGS coastal and marine scientists, other Federal agencies, university scientists, and oceanographic institutions will improve the quality and utility of these studies.

Beyond the EEZ is the Extended Continental Shelf (ECS), as defined by the United Nations Convention on the Law of the Sea (UNCLOS) (United Nations, 1982). The ECS can be established by coastal nations based on specific geologic and geomorphologic criteria. The potential ECS of the United States could significantly increase the size of the already expansive EEZ, especially north of Alaska in the Arctic Ocean (for example, in the Beaufort Sea and the Canada Basin). In this area, the ECS may double the area of the present EEZ, placing the Nation’s seaward resource jurisdictional boundary about 1,000 kilometers (km) north of the Alaskan coast. The ECS of arctic Alaska is a poorly understood tectonic region for which fundamental crustal geological questions must be resolved for both territorial resolution and resource delineation. International collaborative studies can potentially optimize research on the geologic framework and the endowment of energy and mineral resources, which are currently unknown but likely to include oil and gas, gas hydrate, and rare and critical metals.

Alaska.—Similar to the ECS of arctic Alaska, some landward portions of Alaska are still relatively unexplored, with world-class mineral deposits still being discovered at the surface. Alaska contains vast resources of coal and other fossil fuels, significant potential for geothermal energy, some of the world’s largest zinc, copper, and gold deposits, as well as deposits of high-demand mineral commodities, such as REEs, indium, and tin. In general, Alaska has the potential to supply staple commodities that will be needed to maintain and grow the national infrastructure for many years to come. Alaskan baseline geoscience data are incomplete and of lower resolution, are available in smaller quantities, and are not as recent as corresponding data for the conterminous United States. The upgrading, updating, and maintaining of geoscience base data for Alaska are important for supporting USGS efforts to conduct energy and mineral resources assessments. Research on the spatial occurrence, geologic settings, structural and lithologic controls, and processes of formation for geothermal energy, heavy oil, shale gas, coalbed methane, and mineral deposit types that occur within Alaska will help evaluate the State’s potential for nontraditional energy supplies and commodities.

Concealed resources.—Most of the conterminous United States has been effectively explored on the surface for the presence of mineral resources. Undiscovered resources lie beneath cover (rocks, colluvium and alluvium, and water) that conceals a resource from recognition. One of the key challenges and opportunities the USGS faces in the future is assessing resources under cover and in deep settings (more than 1 km). Recent efforts by the USGS, industry, and academia have been initiated to develop methods for exploring beneath cover and to develop geologic frameworks (goal 1–1) that incorporate source, transport, and trap mechanisms to predict where deposits formed and where they should be today. In addition, there is work underway to develop better and more powerful deep-penetrating geochemical and geophysical methods and technology to help visualize those targets. However, there is no coherent protocol for estimating the possibility or probability of undiscovered resources beneath cover.

Highlight 2

Oil Shale: Evaluating an Energy Resource and Its Extractive Effects

Oil shale potentially can constitute a very large untapped oil resource. Decades of field work by U.S. Geological Survey (USGS) geologists determined that the Green River Formation, which hosts the kerogen-rich shales, was deposited in a single large lake that covered the Piceance and Uinta Basins and the intervening Douglas Creek arch and that many rich and lean oil shale zones could be traced between the two basins. Combined with assay data, the correlation work was vital in establishing estimates of the total in-place oil shale resources, recently assessed by the USGS to be 1.5 trillion barrels of oil in the Piceance Basin and 1.3 trillion barrels in the Uinta Basin (fig. 5).

If the solid kerogen is to be converted into liquid oil, the rock must be heated to between 350 degrees Celsius (°C) and 500°C. To achieve a high enough temperature, the rock must either be mined and retorted or else heated electrically in the subsurface with the oil recovered from wells. Environmental issues include significant amounts of water for mining and retorting, surface disturbance (either for mining or for wells required for in-situ conversion), greenhouse gas emissions generated during retorting, the disposal and reclamation of spent solids if mining and retorting is employed, and the migration of groundwater contaminated with organic and metallic compounds if in-situ conversion is utilized. Laboratory research is underway at the USGS to document the chemistry of waste products. A major concern is the presence of metals, such as arsenic and mercury, and volatile and dissolved organic compounds.

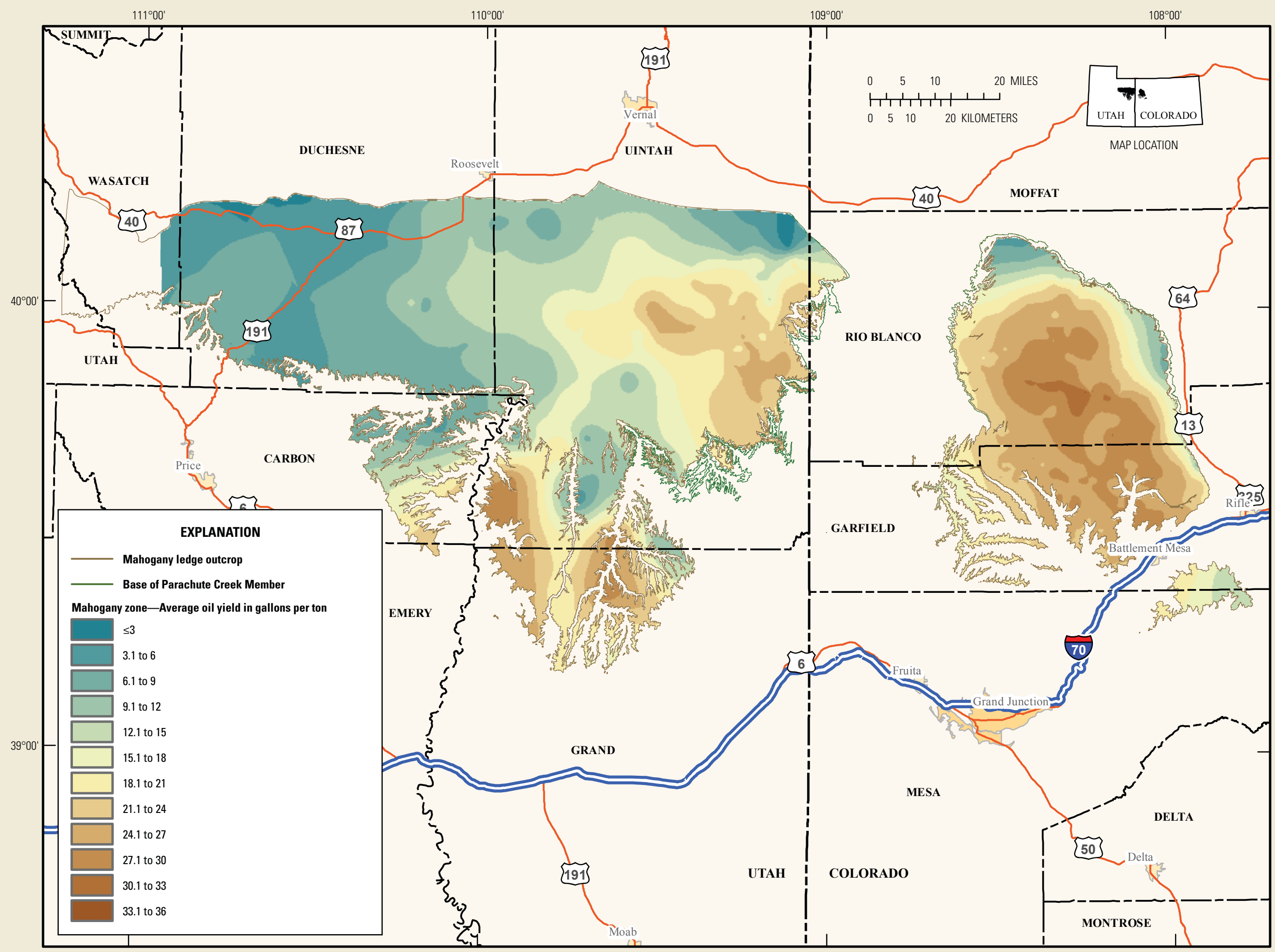


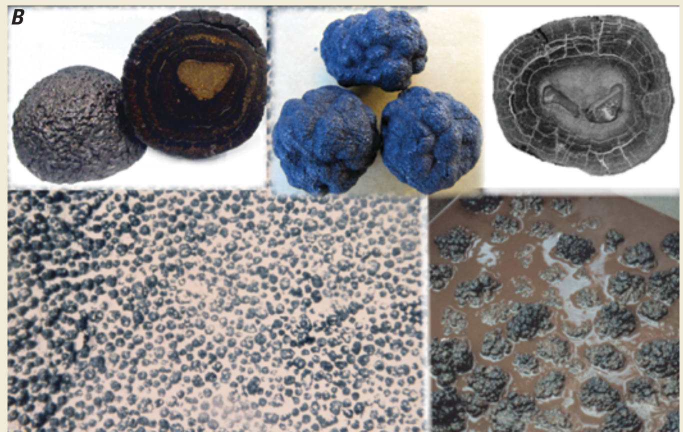
Figure 5. Average oil yield for the Mahogany Zone, Uinta and Piceance Basins in Utah and Colorado. Oil yield (in gallons per short ton) is calculated from Fischer assay, formation thickness, and areal extent. Data are from U.S. Geological Survey Oil Shale Assessment Team (2010a,b).

Highlight 3

Minerals in the U.S. Exclusive Economic Zone

The U.S. Exclusive Economic Zone (EEZ) comprises all marine areas within 200 nautical miles of the nearest U.S. land, including Pacific islands of U.S. affiliation, a total area approximately 20 percent greater than the entire U.S. land area (fig. 6). The United States has sovereign rights for the purpose of exploring, exploiting, conserving, and managing natural resources in the EEZ. These resources include deep-ocean strategic and critical minerals essential for U.S. security and economic growth, especially in high-technology and green applications.

Deposit types that have promising resource potential are sea floor massive sulfides, ferromanganese crusts, manganese nodules, and phosphorite. Significantly, some of these deep-ocean mineral deposits have high concentrations of rare earth elements, precious metals, base metals, and many other resources, but the resource potential of these deposits is yet to be determined. In fact, reconnaissance minerals data do not exist for substantial parts of the EEZ. The knowledge base of the U.S. Geological Survey (USGS) combined with published and unpublished databases and collections of new data can be used for resource and environmental evaluation and development of deposit models. USGS resource assessment techniques developed for land-based deposits may have applications for offshore deposits once sufficient relevant data for the EEZ have been collected on research cruises specifically designed to study mineral deposits.



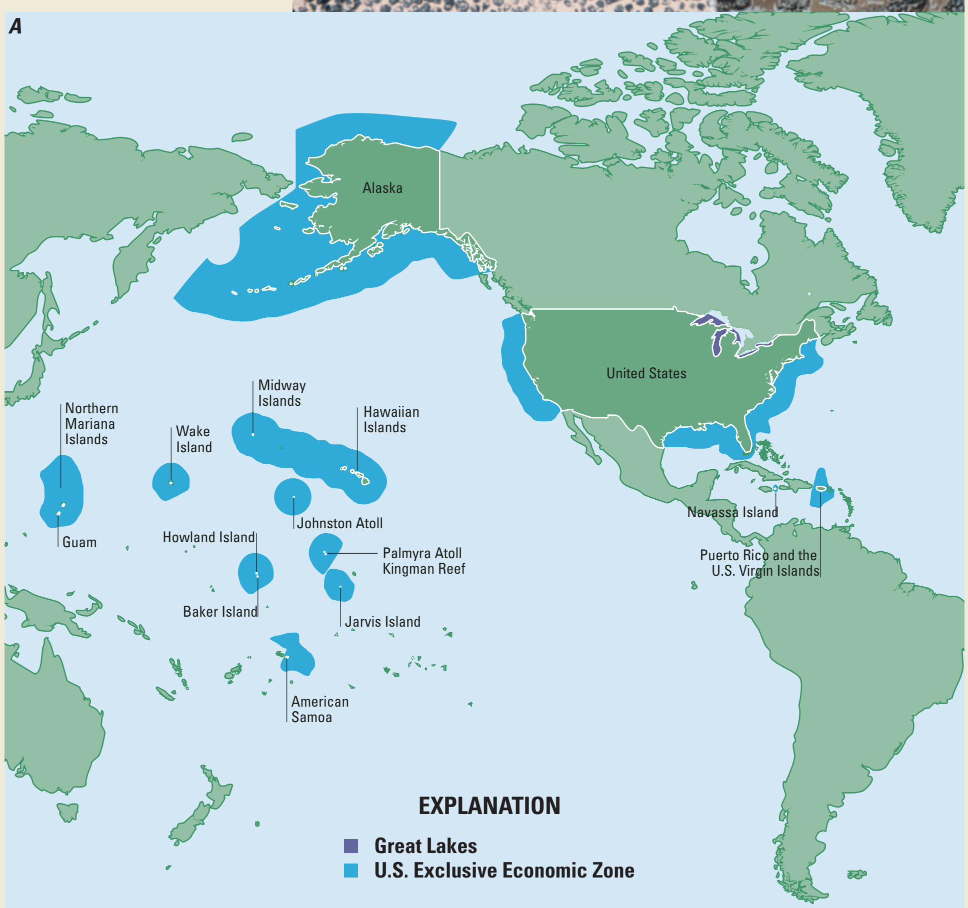


Figure 6. *A*, The U.S. Exclusive Economic Zone (EEZ; dark blue shaded areas); from U.S. Commission on Ocean Policy (2004). The area of the U.S. EEZ could increase once data are collected that address criteria in the Law of the Sea Convention defining the Extended Continental Shelf (ECS), especially in the Arctic Ocean north of Alaska, where the U.S. EEZ could double in size. *B*, Clockwise from upper left: 13.6-centimeter (cm) diameter nodule from Marshall Island in the EEZ; three abyssal nodules, each 3 cm in diameter, from the Clarion-Clipperton prime nodule zone (international waters); cross-section of nodule from the Blake Plateau off the coast of Florida, Georgia, North Carolina, and South Carolina; diagenetic nodules in a box core from the Peru Basin; dense concentration of nodules rich in nickel, copper, lithium, and molybdenum from the Johnston Atoll EEZ, an area about 4 meters (m) by 3 m.

Application of new methods and protocols for covered regions will give the USGS the ability to make more objective, repeatable, and reliable assessments of undiscovered resources. The identification of covered mineral resources, particularly in the western United States, also has important effects on environmental and hydrologic studies.

Major Questions

- What are the dominant processes that result in a concentration of metals in the deep ocean, and what are the geological, geochemical, and geophysical characteristics that distinguish these deposits?
- What are the geologic data needs in Alaska and the Arctic?
- What are the processes that enhance the surface expression of subsurface resources, and what are the geological, geochemical, biological, and geophysical characteristics that can be used to assess concealed resources?

Strategic Actions

- *Action 1–3a.*—Promote the collection of the geological, geophysical, and geochemical data within the U.S. EEZ. These data are needed to begin evaluation of the types and distribution of deep-ocean mineral deposits within the U.S. EEZ and globally. This effort will require collaborations with coastal and marine programs, oceanographic institutions, and other government agencies, such as the Bureau of Ocean Energy Management (BOEM), on relevant oceanographic, geological, and geochemical process research.
- *Action 1–3b.*—Expand collection and evaluation of geological, geophysical, and geochemical field data for energy and minerals resources in Alaska and the Arctic offshore. Prioritize regions in Alaska in which significant upgrades in base data, satellite imagery (including multispectral and hyperspectral remote sensing data such as Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) and Hyperion Imaging Spectrometer), and geophysical, geochemical, and geologic maps are required. This activity would benefit from coordination with the State of Alaska and other government agencies, the academic community, and industry.
- *Action 1–3c.*—Construct geologic frameworks for concealed deposits. These frameworks would be based on source, transport, and trap mechanisms to predict where deposits are formed, where they occur today, and what features can be detected at the surface. The frameworks will enable development of new methods for predicting terranes with potential for concealed resources and incorporate these into assessments of undiscovered resources.

Goal 2.—Understand the Environmental Behavior of Energy and Mineral Resources and Their Waste Products

Introduction

The research challenges associated with sustainability of energy and minerals resources and the environment are woven together in a complex tapestry that spans the entire lifecycle of resource development from formation and occurrence through exploration, discovery, permitting, construction, and operation to closure and beyond. A comprehensive understanding of the interactions between energy and mineral resources and environmental and biological receptors will enable the resource industries to identify efficient and cost-effective means of mitigating adverse environmental effects; land-use managers and regulators to insure proper stewardship and protection of the environment; and citizens to be educated about risks associated with resource extraction and benefits derived from these resources. This research will provide a basic scientific foundation needed to analyze and forecast the total benefits and costs of energy and mineral resources, sometimes referred to as a “full cost accounting,” with the aim of facilitating scientifically informed decisionmaking for all stakeholders for the sustainable development of conventional, emerging, and frontier nonrenewable resources and renewable energy systems. Because of the interdisciplinary nature of environmental research related to energy and mineral resources, future success will necessarily benefit from partnerships within the USGS and with numerous external collaborators. These collaborations will build on expertise from the respective mission areas within USGS and incorporate partner strengths as well. Global economic growth will maintain the demand for those commodities that have traditionally formed the staples of society, including aluminum, coal, copper, gas, gold, iron, lead, silver, uranium, and zinc. Continued production and possible exhaustion of existing energy and mineral reserves will likely lead to exploration in less accessible geologic environments, such as deeper in the Earth’s crust and offshore, production of larger deposits of lower grade, and technological advances in resource recovery methods that lead to the exploitation of energy and mineral resources from nontraditional sources. Collectively, these future trends in resource production will lead to a host of new environmental challenges requiring cutting edge scientific insights to solve in addition to the existing, unsolved environmental challenges associated with traditional resource recovery and use. For example, use of domestic coal supplies influences the production of greenhouse, mercury, nitrogen, and sulfur gas emissions, providing an impetus to understanding how decisions made during exploration are linked to the ultimate environmental effects. Additionally, most conventional production will provide significant challenges in managing the quantity and quality of water associated with resource development.

Increased demand for emerging commodities (such as REEs used in permanent magnets for wind turbines and hybrid car batteries; lithium used in batteries for hybrid cars and other uses; cadmium, gallium, indium, and tellurium used in solar cells; PGMs used in fuel cells; and potash and phosphate in mineral fertilizers needed for biofuel production) will present additional unique environmental challenges and opportunities. These commodities fall into two main categories: those that are the primary target of mineral production, such as most REEs, lithium, PGMs, potash, and phosphate; and those that are produced as byproducts of other commodities, such as gallium, indium, cadmium, tellurium, and some REEs (highlight 4). In many cases, these commodities are derived from geologically and mineralogically unique deposit types that require specialized ore-processing techniques to extract the metals, which result in unconventional wastes. Byproducts associated with other commodities could have significant resource production potential from waste material found at existing or abandoned mines.

As the United States plans its energy and minerals future, it must be cognizant that past extraction and development of energy and mineral resources historically have led to adverse environmental effects. Research at legacy sites can not only provide alternative sources of resources through reprocessing of waste streams or beneficial reuse but can also provide opportunities to understand long-term biogeochemical processes influencing environmental signatures under worst-case-scenario conditions that, in turn, could potentially provide insights into the naturally occurring or anthropogenic interactions with air, land, and water resources; provide insight into complex natural exposure routes to surrounding ecosystems and humans; and provide information needed for mitigation and remediation.

To contribute to the economic and environmental vitality and the overall security of the Nation, a more comprehensive view of the lifecycle of resource development that is firmly founded in objective science would be beneficial. The USGS has contributed to and maintains specialized core expertise needed to understand and evaluate the lifecycle stages of resource development. This goal is expected to be achieved through state-of-the-art, process-oriented research focused on the source, transport, and fate of contaminants associated with resource development and their interactions with the surrounding environment and ecosystems. This comprehensive, systematic approach can be applied to the landscape at various time and spatial scales, based on sound scientific principles, to better inform the decisionmaking process.

The strategic research actions presented in this section outline opportunities for the USGS that can be tailored to advance the state of knowledge of environmental research for a number of different commodities, highlight research opportunities throughout the resource lifecycle, emphasize the concepts that represent common denominators in energy and minerals research, and provide linkages with other mission areas. These strategic actions present numerous opportunities for partnering with other Federal agencies, including (but not limited to) resource stewardship and (or) regulatory agencies such as the BOEM, the BLM, the National Institutes of Health, the National Park Service, the Office of Surface Mining, Reclamation, and Enforcement, the U.S. Army Corps of Engineers, the U.S. Environmental Protection Agency, the U.S. Fish and Wildlife Service, and the USFS. Likewise, partnership opportunities also exist at local, regional, and State levels, such as State geological surveys, as well as private industry for advancing our understanding of the relationship between energy and mineral development and the environment.

Major Questions

- What processes enhance or limit the migration of contaminants associated with energy and mineral resources in complex natural settings in terms of their source, transport, and fate, including toxicological effects?
- How can we best transfer insights gained from detailed controlled settings in the laboratory to large-scale field settings to improve the transfer of scientific insights from basic research to field applications?
- Are there chemical and physical characteristics of emerging energy and mineral resources that determine beneficial reusability, byproduct recovery, environmental effects, and (or) appropriate disposal options?
- How will climate change affect the environmental characteristics of energy and mineral resource waste associated with past, present, and future production?
- How significant are greenhouse gas emissions or removals associated with energy and mineral production relative to global greenhouse gas budgets?
- What is the natural endowment of inorganic and organic compounds in the vicinity of energy and mineral resources, how do these become mobilized and introduced to the surface environment naturally, and how does resource development alter pre-existing concentrations?
- Can we distinguish between natural backgrounds and concentrations of elements enhanced by human activities?

Strategic Actions

The questions outlined above will be addressed through three sets of actions:

- *Fundamental studies* designed to improve our understanding of basic biogeochemical processes as they relate to the environmental effects of energy and mineral resources at all stages of their lifecycles;

Highlight 4

Renewable Energy and Nonrenewable Mineral Resources

Significant amounts of nonrenewable mineral resources will be needed to support the growing demand for domestic renewable energy, requiring knowledge about both the sources and the environmental effects of using these minerals. For example, many of these mineral commodities come from foreign sources; rare earth elements (REEs), which are used to manufacture magnets for wind turbines and hybrid car batteries, currently (2011) are mined almost exclusively in China. Diversifying REE supplies may prove challenging, as the mineral deposits that yield REEs are atypical with respect to environmental challenges associated with mining and are poorly understood. Similarly, the manufacture of new, higher efficiency or lower cost photovoltaic cells (fig. 7) relies on mineral commodities such as cadmium, gallium, germanium, indium, selenium, and tellurium, which typically are produced as byproducts of the mining of metals such as copper and zinc. Significant amounts of these technologically important commodities may occur in waste piles from historical mines where ore beneficiation techniques were not designed to recover these elements. Regardless of the source, environmental protection and stewardship of lands associated with future mining for all these mineral commodities will rely on a sound scientific understanding of the source, transport, and fate of all potential contaminants associated with the deposit types that will yield these commodities.

Figure 7. Solar panels installed at the Denver Federal Center in Lakewood, Colorado. Renewable energy sources such as solar energy from photovoltaic cells are reliant on a number of nonrenewable mineral commodities. Newer, lower cost and higher efficiency photovoltaic cells are made from mineral commodities, such as arsenic, cadmium, gallium, selenium, and tellurium. In addition, to transfer electricity generated by solar "farms" to market, an expanded electrical grid will be needed, spurring demand for copper wire.

- *Applied investigations* focused on applying basic research to the energy and mineral resource landscape; and
- *Synthesis activities* intended to integrate knowledge from critical aspects of energy and mineral environmental research at the USGS to inform decisionmaking related to legacy and future resource issues to facilitate sound resource stewardship.

2–1. Fundamental Studies

- *Action 2–1a.*—Investigate carbon sources and potential sinks associated with energy and mineral resource and renewable energy production to improve understanding of carbon cycling. Carbon dioxide release from limestone during cement manufacturing, CO_2 in geothermal waters, and methane leakage from shale-gas production represent examples of sources of carbon. Likewise, magnesium and calcium-silicate minerals in mine waste represent sinks for atmospheric CO_2. These examples represent poorly understood sources and sinks of greenhouse gases, and the magnitude of carbon cycling related to these sources and sinks is largely unknown.
- *Action 2–1b.*—Investigate perturbations to the natural landscape during the resource lifecycle. Use multidisciplinary studies at both legacy and current energy and mineral production sites. Geological, biogeochemical, and geophysical studies can be used to identify and quantify environmental factors, such as climate, geologic setting, and proximity to drainages and the water table, that influence changes to natural resources during energy and mineral resource development. This research will assist in discerning the differences between natural background and anthropogenic effects of energy and mineral development.
- *Action 2–1c.*—Develop studies to understand the role of climate in altering natural background environmental signatures of energy and minerals systems and the behavior of waste products from energy and mineral resource development. Seasonal or global changes or differences in temperature and precipitation can exacerbate or mitigate weathering of wastes, hence the growing recognition of the importance of climate in environmental investigations of energy and mineral systems. This understanding is essential for devising effective mitigation or remediation strategies for proposed, ongoing, or legacy mining activities, for establishing reasonable closure goals that will withstand future changes in climate, or for predicting behavior of wastes under variable climate regimes.

2–2. Applied Investigations

- *Action 2–2a.*—Characterize waste streams associated with energy and minerals production and processing. These studies will improve the understanding of the linkages between the energy and mineral resource characteristics and waste products, of opportunities for recycling and byproduct resource recovery, and of mitigation or management of contaminant releases to the environment from these wastes.
- *Action 2–2b.*—Conduct research on deep geologic reservoirs for disposal of wastes from energy and mineral resources development, extraction, and use. Deep, subsurface geologic formations are used for the disposal of wastes from energy and mineral extraction and production activities, including uranium-contaminated groundwater produced during in-situ recovery, high-salinity and poor-quality water coproduced with oil and gas, and CO_2 generated from fossil fuels (geologic carbon sequestration). Likewise, spent nuclear fuel and high-level nuclear waste could potentially be energy-related waste candidates for storage in such deep disposal units.
- *Action 2–2c.*—Investigate the environmental geochemistry of emerging energy- and mineral-resource production technologies. These technologies include a number of in-situ or leaching techniques such as hydraulic fracturing for shale gas production, in-situ conversion of oil shale (highlight 2), in-situ leach mining for copper and uranium recovery, and gas hydrate recovery using hot water, steam injection, and depressurization. All these techniques require alteration of the physical and (or) chemical characteristics of the ambient environment to extract the resource but likely also affect a wide variety of other constituents and geologic aspects of the area being developed. Such insights will be invaluable in designing methods to perform integrated assessments of future resource development (goals 3 and 4).
- *Action 2–2d.*—Expand USGS capabilities for research on the geologically based environmental effects of the construction and operation of renewable energy resources (geothermal, solar, wind, hydropower, and biomass) to provide information for assessment activities. Renewable sources of energy by necessity require nonrenewable mineral commodities for their construction and operation. A rigorous understanding of the processes that control the fluxes of these mineral commodities through the environment will advance comprehensive knowledge of geologically based environmental effects from renewable energy development.

2–3. Synthesis Activities

- *Action 2–3a.*—Create geologically based environmental models. These models, known as geoenvironmental models (duBray, 1995), address priority, conventional energy resources (such as coal and uranium) and emerging critical mineral and energy commodities (such as shale gas and rare earth elements). This extension of geoenvironmental models will assist in understanding the geological and geochemical controls on contaminant transport and fate, identifying potential environmental risks, identifying data gaps, and improving energy and minerals assessment activities.
- *Action 2–3b.*—Enhance the ability to transfer insights between simple process-oriented, short term, and small-scale laboratory experiments and complex, longer term, and large-scale natural energy and mineral resource systems. The application of the fundamental properties of Earth and biologic (including microbial) materials derived from laboratory studies to modeling of complex natural systems can be complicated by synergistic or antagonistic effects or by heterogeneity. Approaches that span gaps in both temporal and spatial scales will improve predictive capacity for processes operating within Earth systems, which necessarily will require well-designed field studies in key settings.

Goal 3.—Provide Inventories and Assessments of Energy and Mineral Resources

Introduction

Where will the United States obtain the energy and mineral commodities necessary to support its future infrastructure and technology? Policymakers, the global financial sector, and industry rely on the USGS to provide the information they need to understand the global distribution of energy and mineral resources and the supply of and demand for those resources.

The USGS founding directive to examine the "... mineral resources and products of the national domain" includes fuel (coal, oil, uranium) and nonfuel mineral materials, as well as studies outside the national domain when such studies are in the national interest. The USGS is one of the principal Federal agencies that develop global information and comprehensive science for nonfuel minerals (fig. 8). The USGS provides key energy resource assessments but shares responsibility for many aspects of global energy data and science with other Federal agencies, such as the Department of Energy (DOE), the Energy Information Administration (EIA), and the BOEM. Responsibility for managing fuel and nonfuel resources and the lands on which they occur belongs to other agencies.

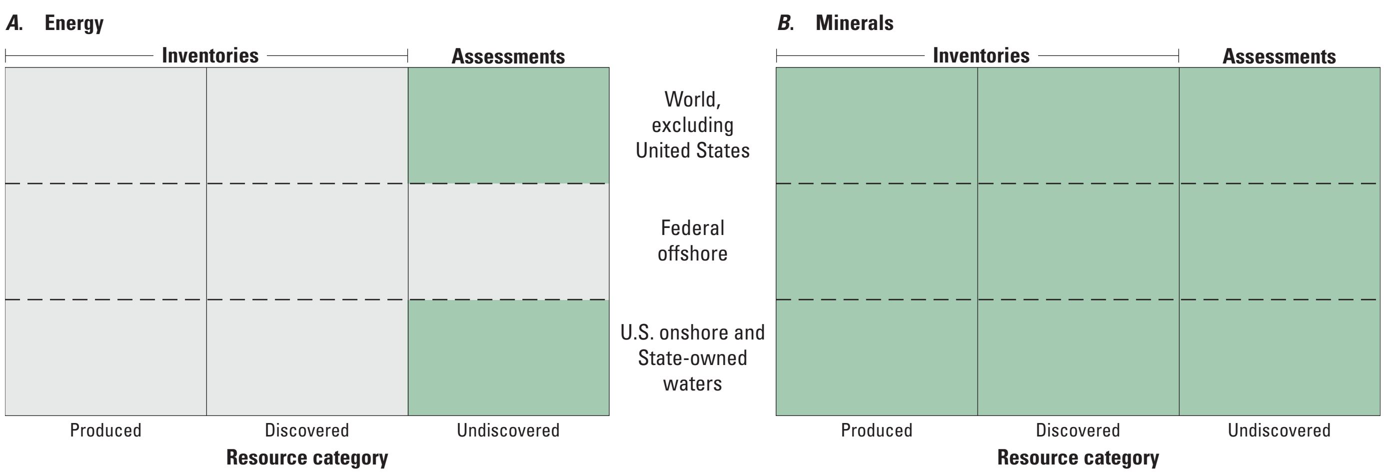


Figure 8. Matrix showing where the U.S. Geological Survey (USGS) provides assessment and information (green areas) for (*A*) energy resources and (*B*) mineral resources by geographic region and resource category. Discovered resources are those accumulations known to exist. Undiscovered resources are those theorized to exist, based on local geology being permissive for a specific type of energy or mineral deposit. For energy, the USGS conducts assessments of undiscovered resources. For nonfuel minerals, the USGS provides scientific data and inventories of produced and discovered resources as well as conducts assessments of undiscovered resources. The regulatory and resource stewardship responsibilities for these resources reside with other agencies.

The USGS uses a broad range of tools to provide accurate inventories and assessments of fuel and nonfuel minerals at scales ranging from global to regional. Both technological innovations (for example, improvements in extraction methods or new processing methods) and market changes can profoundly shift the U.S. energy and minerals supply mix (for example, such as from recent increases in gas production from shale and rising demand for REEs). Accurate assessment of previously unexploited resource types requires fundamental understanding of how these resources form and accumulate (goal 1) and how new technologies may affect the extraction environment (goal 4). Extending the economic information incorporated in inventories and assessments provides additional data on extraction, transportation, and potential environmental and related costs that may be useful to Federal, State, and other decisionmakers (goal 4). Depending on the scale and scope of innovation, iterative evaluations, new assessments (for newly significant elements or geographic regions, for example), or significant changes to assessment methodology may be required to adequately evaluate projected supply fluctuations (goal 5) and their effect.

Energy

The role of the USGS in evaluation of energy resources is focused on geologically based, undiscovered resources, exclusive of the Outer Continental Shelf. Periodic USGS assessments of technically recoverable, undiscovered oil, gas, and natural gas liquids in the United States and the world (Ahlbrandt and others, 2005) based on a systematic, vetted, probabilistic methodology are used by a wide variety of institutions around the world. The geologic reports (for example, U.S. Geological Survey Bighorn Basin Province Assessment Team, 2010) that accompany most domestic petroleum assessments are highly valued by customers and serve as long-lasting geoscience compilations for sedimentary basins across the United States.

When geologic understanding and extraction technologies advance, assessments must be updated, and assessment methodologies must evolve. The rapidly expanding production of oil and gas from low-porosity and permeability reservoirs (tight gas, shale gas, and shale oil) requires innovation in assessment methods as well as improved understanding of the geologic and geochemical nature of the reservoirs (goal 1). For example, a recent assessment (Coleman and others, 2011) of the undiscovered oil and gas potential of the Marcellus Shale (fig. 9) used production data from shale gas accumulations in this and other U.S. sedimentary basins to more effectively visualize and understand the long-term production profiles that characterize shale gas production over time. The use of such analog data (U.S. Geological Survey Marcellus Shale Assessment Team, 2011) supplemented the data examination phase of the resource assessment methodology.

The USGS also assesses domestic undiscovered resources of several nonpetroleum sources of energy. Undiscovered coal resources in the United States have been assessed, and reserve estimates are currently underway (for example, Scott and others, 2011). Uranium, currently the subject of an ongoing, joint USGS–EIA study of undiscovered resources, is hosted in a variety of geologic environments, which complicates the assessment process. An effort to develop a uranium environmental assessment methodology would complement the ongoing resource assessment effort and provide the scientific understanding of the influences of uranium resources and their potential effects on the environment. Geothermal energy, gas hydrates, and oil shale currently contribute only a small amount of the U.S. energy supply but are expected to contribute increasingly more. Likewise, renewed interest in thorium may necessitate additional study of the domestic potential for this resource (highlight 5). Future assessments of these resources would benefit from an improved geologic understanding of their occurrence (goal 1) and consider technological advances in their use. Effective assessment methodologies must be tailored to the commodity under consideration, the range of geologic settings, the status of past production, and the evolution of extraction techniques and must portray the range of uncertainty of data and results at all stages of the assessment.

Major Questions

- What are the undiscovered resources of technically recoverable oil, gas, coal, uranium, and geothermal energy in the United States and in the world?
- What is the range of economic and environmental consequences of extraction and delivery of these energy resources?

Strategic Actions

3–1. Undiscovered Geologically Based Energy Resources

- *Action 3–1a.*—Conduct periodic assessments of technically recoverable undiscovered gas and oil resources of the United States and the world with increasing emphasis on reserve growth and unconventional resources (for example, tight gas reservoirs).
- *Action 3–1b.*—Complete the ongoing national assessment of undiscovered uranium resources.
- *Action 3–1c.*—Conduct targeted assessments of emerging energy resources (for example, gas hydrates, geothermal energy, oil shale) as warranted by research findings (goal 1) and by advances in extraction technology.
- *Action 3–1d.*—Develop additional components of economic and environmental analyses, where possible in cooperation with other bureaus, in the assessment of technically recoverable resources as needed for specific

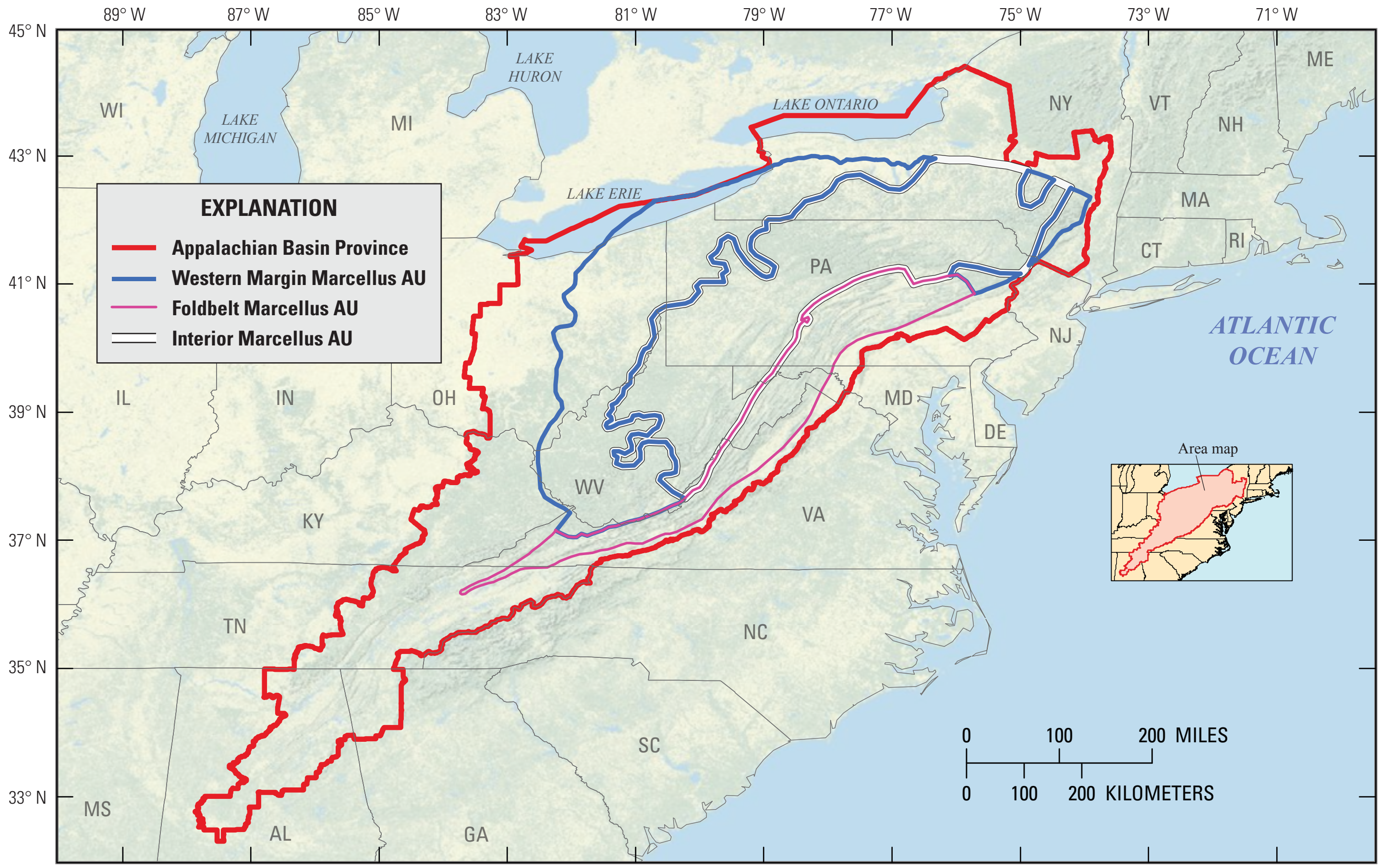


Figure 9. The extent of the Marcellus assessment units (AUs) within the Appalachian Basin geologic province. The Marcellus Shale is now exploited as a combination reservoir and source rock for natural gas and natural gas liquids. A probabilistic resource assessment conducted by the U.S. Geological Survey in 2011 estimated a range of 43 trillion to 144 trillion cubic feet of undiscovered, technically recoverable gas (not counted as reserves), with a mean estimate of 84 trillion cubic feet. Most of the undiscovered gas is within the Interior Marcellus AU. From Coleman and others (2011).

geographic areas. For example, build on completed coal assessments to evaluate the effects of coal composition on the effects of its extraction and use. The linking of these economic and environmental analyses with future integrated assessment approaches, as outlined in goal 4, will enhance the utility and relevance these analyses to resource stewardship agencies.

Minerals

The responsibility of the USGS for mineral materials includes evaluating the complete range of production data, reserves, resources, and undiscovered deposits (fig. 8) throughout the world and across the full spectrum of globally traded commodities. The agency's responsibility for examining resources and products coupled with increased demand for information concerning these resources brings attention to the role of the USGS as a leader in developing a comprehensive, accurate, and reliable database of reserves and resources of fuel and nonfuel minerals.

The responsibility for tracking reserve and discovered resource information as well as global supply and demand requires a broad scope of USGS activities related to minerals. These range from collection and compilation of geologic, production, and economic data to inventories of domestic and global reserves and resources, analyses of spatial and temporal patterns and materials flow, and domestic assessments of undiscovered resources.

The USGS National Minerals Information Center (NMIC) collects, analyzes, and publishes data on domestic and global reserves. These domestic data collection activities are facilitated by cooperative agreements with State government agencies, and international minerals information is obtained annually by questionnaires and exchanges with organizations in approximately 100 countries. The USGS also tracks active mines, mineral operations, and facilities globally, and the Mineral Resources Data System (MRDS) provides limited geologic data for some domestic and global deposits,

Highlight 5

Thorium: Why and Where?

Globally, thorium is experiencing much renewed interest and research investment as a potential fuel source because it provides a source of nuclear power that does not proliferate weapons-caliber plutonium, has the potential to generate electrical power with a low carbon footprint, and may have operational advantages compared with uranium-fueled reactors in terms of power density, cost, scale, and waste disposal. Major research and development efforts on thorium-based reactors are currently underway in China and India. U.S. research on thorium and molten-salt nuclear reactors was discontinued in 1969, but recent national energy policy discussions have renewed calls for research and development of thorium as an energy resource.

Geochemically, thorium and rare earth elements (REEs) coexist. The radioactivity of REE deposits is principally owing to thorium, which presents an environmental issue in the waste streams of REE mining and processing. Within the United States, thorium could be produced as a byproduct from the production of REEs, thereby converting a once undesirable waste into a valuable commodity.

The United States has some of the largest thorium resources in the world. The U.S. Geological Survey (USGS) conducted a considerable amount of research on thorium geology (fig. 10) from the late 1950s to the late 1980s. Many thorium-bearing districts in the United States were studied, described, mapped, and sampled (Van Gosen and others, 2009). Given the growing interest in thorium, an improved understanding of the geology, mineralogy, geochemistry, and resource potential of thorium-bearing systems could provide information needed for the development of comprehensive energy policies and consideration of alternatives during the next decade.

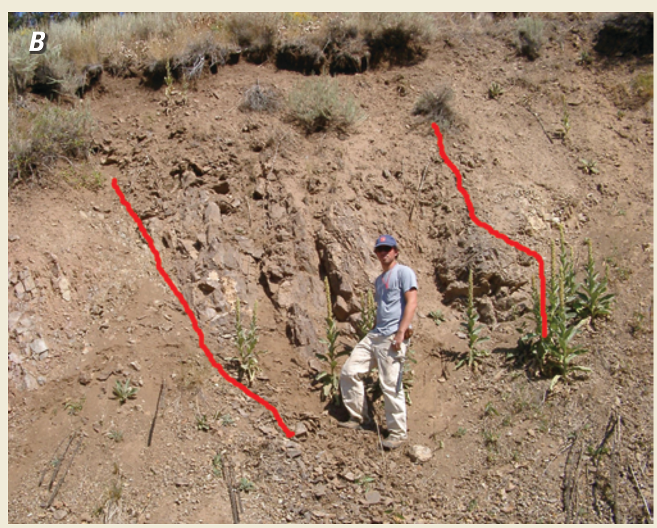


Figure 10. Photographs of the Lemhi Pass thorium district in Idaho and Montana. *A*, View to the north of the Lucky Horseshoe prospect (middle of photograph), which is one group of numerous exploration trenches, cuts, and short adits that explored thorium-rich vein systems of the Lemhi Pass thorium district in the 1950s through the 1980s. More than 200 thorium-rich veins in the Beaverhead Mountains form the Lemhi Pass district, which is thought to contain the largest concentration of thorium resources in the United States and is the site of renewed thorium exploration activity (Van Gosen and others, 2009). *B*, Outcrop of the Wonder vein (between red lines) in the Lemhi Pass thorium district exposed in a mined bench. The vein is heavily oxidized and consists mainly of silica, likely some carbonate, and iron oxide minerals with thorite and altered thorite. The host rock is Precambrian quartzite and siltite (Van Gosen and others, 2009).

prospects, and mineral occurrences, but comprehensive and systematically updated coverage of discovered deposits worldwide is not currently available through the MRDS. Public and private sectors rely on USGS minerals information for improving the understanding of how mineral materials are used within the economy and to forecast future supply and demand for these materials. This domestic and global information is subsequently used in the analysis of national and international policies, in formulating plans to deal with potential shortages and interruptions in mineral supplies, and in fostering the development of strategies for maintaining a competitive position within the global economy.

Assessments of domestic undiscovered minerals are amenable to probabilistic methodologies similar to those used for energy. However, mineral resources occur in a broader range of geologic settings and require an understanding of a much wider array of geologic frameworks and more expansive study of the geochemistry of Earth systems (goal 1). With such additional knowledge, more accurate geologic models of mineral resources can be built and used to constrain estimates of the location, quality, and quantity of potential undiscovered resources.

Major Questions

- What are the global reserves and annual production of nonfuel mineral materials, and what potential supply restrictions do these indicate?
- What are the discovered and potential undiscovered resources of nonfuel minerals in the United States that could bolster future supplies?
- What types of information are needed to provide unbiased assessments of undiscovered mineral resources and effectively portray their uncertainty, and at what scales?

Strategic Actions

3–2. Discovered Nonfuel Mineral Resources

- *Action 3–2a.*—Expand partnerships with governments, industry, and the Nation's research and development sectors to ensure that the USGS has timely, accurate, long-term, and comprehensive global commodity data for all nonfuel mineral commodities.
- *Action 3–2b.*—Establish a periodic review, in consultation with governmental and industrial partners, of the range of commodities covered, process and scope of data collection, and the format, range, and availability of data products.
- *Action 3–2c.*—Expand due-diligence field studies to confirm the geologic characteristics and the resource and grade data for high-priority commodities. Work could include the tracking of reserve-growth characteristics of individual mineral deposit types.
- *Action 3–2d.*—Enhance the scope and functionality of the domestic discovered resources database. This spatially oriented, continuously updated national reference system ideally would contain geologic, production, reserve, and resource data for all mines, prospects, and mineral occurrences within the United States. This approach includes mechanisms for capturing updated reserve and resource information (for example, from NMIC, State, industry, and other sources) into a single point-of-entry database for USGS reporting, research, and assessments.
- *Action 3–2e.*—Strengthen and expand the analytical functions of the NMIC to provide more comprehensive overviews of changes to global nonfuel mineral supply and demand. In particular, expand spatially oriented analyses of global production, trade, manufacturing, and materials end-use to document global shifts.

3–3. Undiscovered Nonfuel Mineral Resources

- *Action 3–3a.*—Reevaluate the methodology, scale, scope, coverage, and output of undiscovered mineral resource assessments. Include consideration of base data, engineering (technology, processing), environmental, and mineral economics expertise in assessments and evaluate the uncertainty and effectiveness of qualitative and quantitative (probabilistic) methodologies.
- *Action 3–3b.*—Adapt the methodologies for assessment of undiscovered nonfuel mineral resources to frontier regions. Define the information needed to initiate assessments of undiscovered mineral deposits for selected high-priority commodities in remote and frontier regions of the United States, particularly Alaska, the EEZ, and the ECS, and for resources more than 1 km below the Earth's surface. This activity would benefit from appropriate strong partners, including the BOEM, in the offshore realm. Assessments in remote regions can be linked to research (goal 1) on the scientific nature and character of potential minerals in these regions.

Goal 4.—Understand the Effects of Energy and Mineral Development on Natural Resources

Introduction

Increased domestic energy and mineral production, use of new technologies, renewable energy development, and mandates to consider the cumulative effects of development present complex challenges for agencies responsible for managing natural resources in the United States. For example, refinements in directional drilling and hydraulic fracturing to produce unconventional hydrocarbon resources have increased the accessible resources in the United States, but these methods have potential subsurface and above-ground environmental effects that are only partially understood. Similarly, the current focus on reduction of greenhouse gas emissions has contributed to the growth of renewable energy sources, such as wind and solar, but the environmental effects of using these energy resources also warrant study. Recognizing the need for more comprehensive information, State, Federal, and nongovernmental organizations are increasingly interested in broader assessment, inventory, and research activities, especially for sizeable geographic areas. Large landscape initiatives—such as DOI landscape conservation cooperatives, BLM rapid ecoregional assessments, National Park Service vulnerability assessments, and the Western Governors Association wildlife corridors initiative—all incorporate these kinds of energy and minerals information but could benefit from additional sources and improved access to such information. Large landscape initiatives and assessments are currently providing valuable information at spatial scales suitable for supporting regional or cumulative effects analyses, but these initiatives will benefit from additional research and technical assistance.

The overarching approach of this goal is to develop the energy and minerals data, frameworks, analytical methods, and products to support the information needs of policymakers and decisionmakers who must "accommodate ecosystem-based management practices as they face competing demands for recreation, transport, leasing, conservation, and economic growth" (U.S. Geological Survey, 2007, p. 26). Key first steps in this approach are designating liaisons to work with land and resource managers to better understand their needs and developing new targeted spatial products based on existing data and knowledge. This goal will bring together scientists across the USGS, researchers at other institutions, and public resource stewards to make better use of existing information and develop new methods and integrated approaches to inform energy and minerals decisions involving multiple resources.

Meeting these needs requires application of the research and foundational understanding developed through goals 1 and 2, the reliable inventory products discussed in goal 3, and strong integration of research across the USGS. Together, these components provide science understanding and products that are applicable to the needs of public resource stewards. Achieving this goal will require dedicating resources to adaptation and integration of existing energy and minerals activities with the evolving adaptive management strategies developed by the DOI (Williams and others, 2009) and other users of USGS assessment products.

An integrated assessment (highlight 6) is a holistic approach that can be used by public resource stewards to study and evaluate resource development issues. Integrated assessment approaches provide an organizing framework for analysis and communication that is adaptable to the scope and complexity of the question or issue and can comply with parallel legal requirements for Federal land management and planning (for example, environmental impact statements). The common characteristics of integrated assessment approaches include collaboration between policymakers or managers and scientists, consideration of multiple resource values and societal needs, and development of relevant products based on the best available information and analytical methods. Collaboration and partnership between scientists and managers will advance the basis for informing natural resource stewardship decisions. The USGS will provide integrated research and technical assistance to policymakers and decisionmakers at scales relevant to their needs. This integrated approach will require capabilities that range from broad scales (for example, global scales to address worldwide resource abundance and use) to local scales (for example, local scales—tens of hectares—to inform leasing decisions on federally managed lands).

Conducting integrated assessments for energy and mineral resources is a multifaceted and interdisciplinary approach that leverages expertise across the USGS (highlight 7). USGS research on fundamental Earth processes, interactions between energy and mineral resources and the environment, and quantitative assessments of the distribution and abundance of resources (goals 1–3) form an essential scientific and technical foundation for integrated assessments. Improved scientific understanding and information on ecosystems, water resources, land use, and climate change will be developed through focused work across the USGS. Using multidisciplinary teams, the USGS can provide information (goal 2) on different classes or specific types of energy and mineral resources, such as uranium, wind energy, or coal, to inform integrated assessment and national energy policy questions. For example, what are the consequences of meeting a goal of 30 percent of projected electricity demand through wind energy by 2040? An integrated assessment approach could evaluate the potential environmental effects of wind energy on the landscape and how these might affect the development of other energy and mineral resources, while integrating information from across the USGS and other agencies and stakeholders.

Highlight 6

Uranium in the Grand Canyon: A Case Study in Integrated Research and Assessment

Issues involving legacy environmental effects, such as those caused by historical mining activities, could challenge the availability of uranium for energy production by resulting in increased environmental costs, societal resistance to uranium mining, or restrictions on accessibility. For example, about 1 million acres of Federal land in the Grand Canyon region of Arizona (fig. 11) was temporarily withdrawn from new mining claims in July 2009 by the Secretary of the Interior because of concerns that uranium mining could have negative effects on the land, water, people, and wildlife.

Figure 11. The Kanab North Mine, one of several breccia-pipe uranium mines in northern Arizona. The U.S. Geological Survey made field assessments of the mine where operations have been on standby since the 1980s.

As directed by the Secretary of the Interior, the Bureau of Land Management engaged the U.S. Geological Survey (USGS) to assist in evaluating the effects of withdrawing these lands through multidisciplinary studies to provide estimates of uranium resources, examine the effects of previous breccia-pipe mining, summarize water-chemistry data for streams and springs, and investigate potential biological pathways of exposure to uranium and associated contaminants (Alpine, 2010). An integrated approach (fig. 12) and careful planning were needed to integrate data from various components of uranium lifecycle research across minerals, energy, environmental health, ecosystems, and water mission areas and to package data so that they could be used in an "integrated assessment" by social scientists and economists to assess alternative scenarios and thereby help decisionmakers weigh the tradeoffs of uranium mining in the Grand Canyon area. Working together, these USGS groups conducted a study that could become a model for integrated USGS studies in the future.

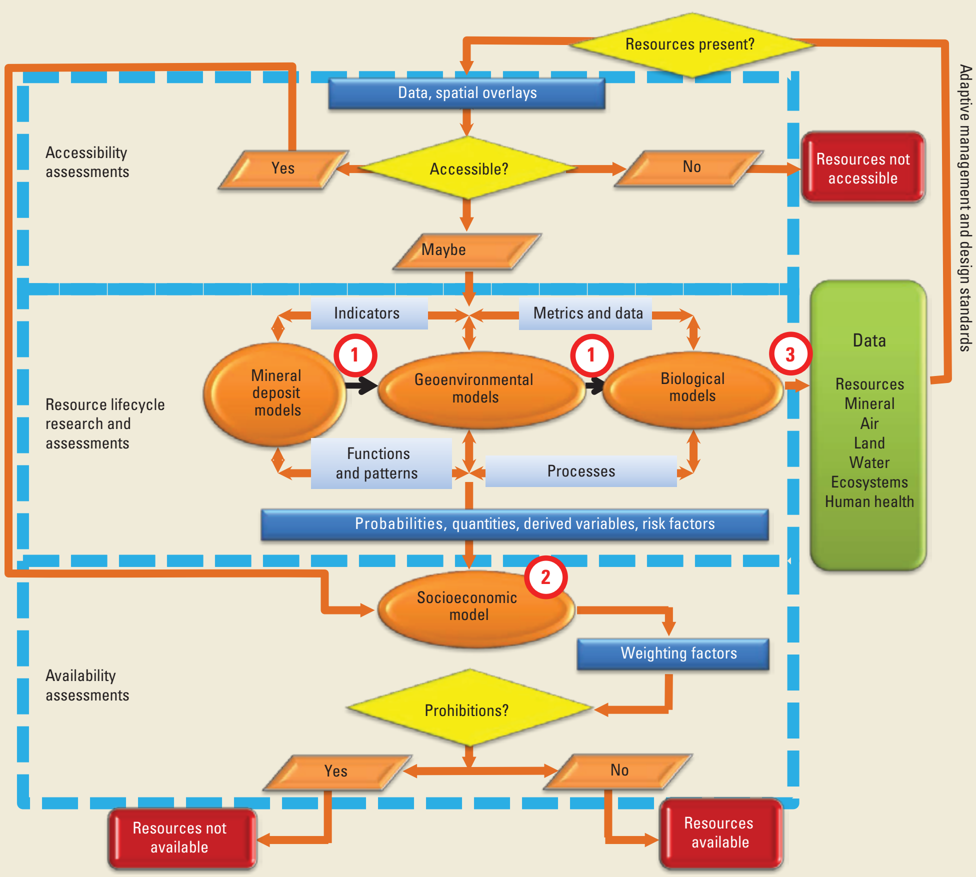


Figure 12. Example of an integrated assessment. Integrated assessments are carried out to answer a specific question, for example, "What are the effects of withdrawing lands in the Grand Canyon region from mineral entry?" The diagram shows a conceptual framework for integrating lifecycle research and science across multiple disciplines within the U.S. Geological Survey (points designated with "1") and integrating assessments with additional socioeconomic considerations (point designated with "2"). Data generated during lifecycle research ultimately can be used to make decisions regarding land management or establish designs or design standards for resource development and protection (point designated with "3"). The data and information must be communicated so that they can be effectively used, exchanged, and combined at points 1, 2, and 3.

Highlight 7

Integrated Assessment for Southwestern Wyoming

Driven by local and regional leaders, the Wyoming Landscape Conservation Initiative (WLCI) was officially launched in 2007 with support from the U.S. Department of the Interior. The mission of the WLCI is to implement a long-term, science-based program for assessing, conserving, and enhancing fish and wildlife habitats while facilitating responsible energy and other development through local collaboration and partnerships. Partners in the WLCI include the Bureau of Land Management, the U.S. Geological Survey (USGS), the U.S. Fish and Wildlife Service, the Wyoming Game and Fish Commission, the Wyoming Department of Agriculture, the U.S. Forest Service, six Wyoming county commissions, nine of Wyoming's conservation districts, and the Pinedale Anticline Project Office.

The role of the USGS is to provide multidisciplinary scientific and technical assistance support to WLCI partners and to advance the overall scientific understanding of ecosystems in the southwestern Wyoming landscape. Working with WLCI partners, the USGS has developed an integrated assessment for southwestern Wyoming (fig. 13). The assessment is an integrated analysis of WLCI resources based on best available data and information and includes roads, energy development, mines, and urban areas along with aquatic and terrestrial natural resources and priority management areas designated by partners. Information is summarized by watershed using a transparent and hierarchical approach that facilitates understanding of multiple resources and their contribution to summary index scores. The integrated assessment is a support tool for landscape-scale conservation planning and evaluation and a data and analysis resource for addressing specific agency management questions.

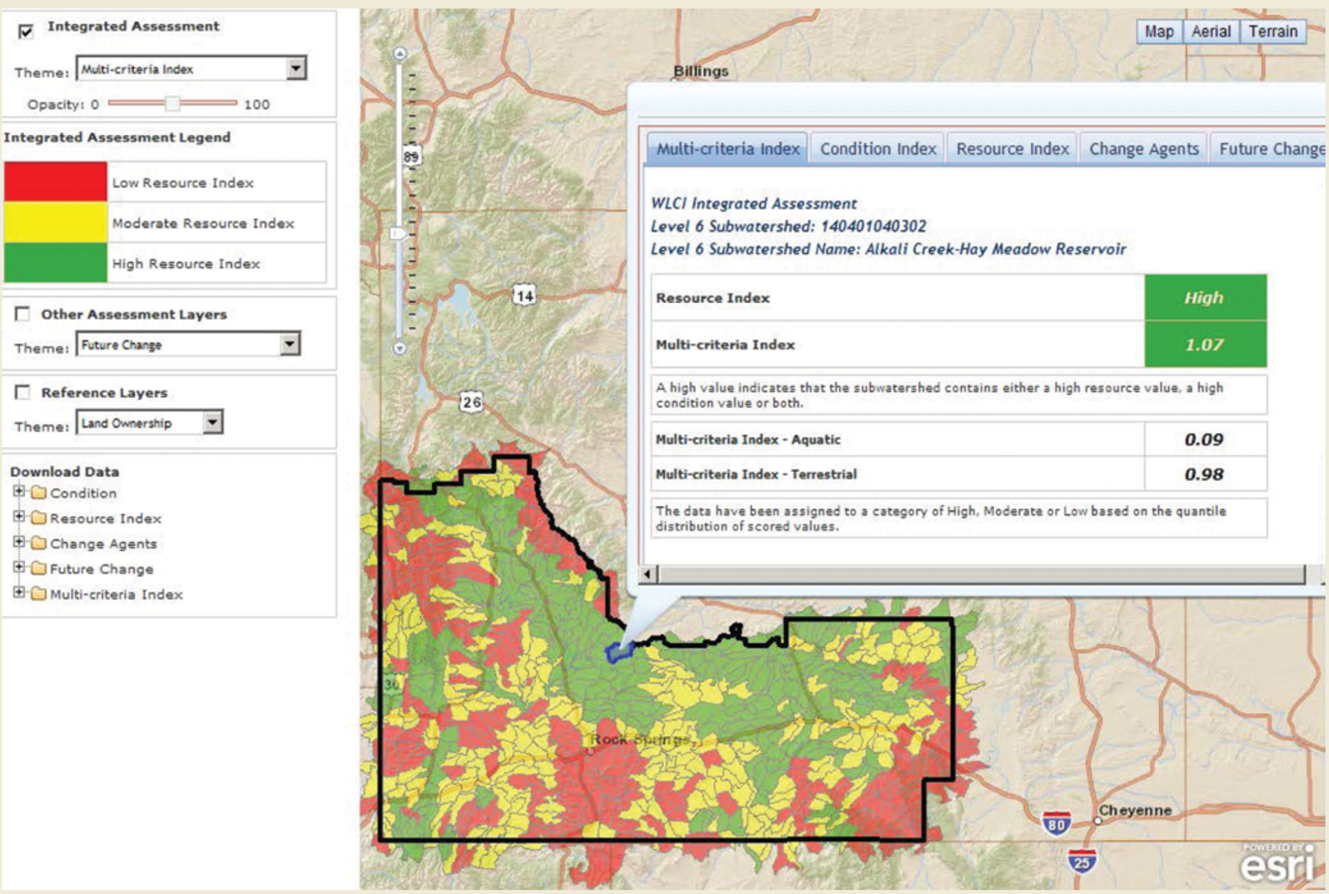


Figure 13. The Wyoming Landscape Conservation Initiative integrated assessment Web interface for which the U.S. Geological Survey provided assessment data for southwestern Wyoming. Information on key resources is summarized by watershed, and data used in the development of the assessment are available for download and further analysis (Wyoming Landscape Conservation Initiative, undated).

Major Questions

- What science can the USGS provide to help assess the range of effects of energy and mineral resource development on other natural resources including wildlife, habitat, water resources, and sensitive areas?
- How can the USGS best characterize and evaluate the environmental footprints and environmental risks of renewable, fossil, and nuclear energy resources, taking into account the full life cycle of resource development, use, and disposal?
- What USGS data and information are needed by other Federal agencies and public resource stewards to implement best practices throughout the life cycle of energy or mineral resource development to lessen the effects to habitat and the environment?

Strategic Actions

4–1. Spatial Analysis of Energy and Mineral Resources Occurrence and Development

- *Action 4–1a.*—Designate liaisons and a network of energy and minerals resource experts within the USGS who work with land and resource managers, including those from DOI bureaus, to identify important information needs.
- *Action 4–1b.*—Provide information on energy and mineral development potential to large landscape conservation initiatives that are overlaying energy and mineral resource development with other priority natural resources.
- *Action 4–1c.*—Develop new nationwide spatial data products for energy and mineral resources. This activity could be coordinated with other agencies, as appropriate, to leverage use of existing datasets. These products could include existing areas of development for these resources and associated infrastructure, such as roads, pads, pipelines, ponds, compressor stations, and other facilities associated with natural gas development.

4–2. Exploring Interdisciplinary Approaches for Assessing Effects of Energy and Mineral Resources Development

- *Action 4–2a.*—Identify metrics or indicators that reflect the effects and uncertainty of energy and mineral development on other natural resources. This information could assist stakeholders in considering environmental effects or provide a foundation for additional analyses to consider effects on ecosystem functions and services. Likewise, a method for evaluating water use and production associated with unconventional oil and gas resource development could improve the understanding of the potential effects of such development on the availability and (or) quality of water resources.
- *Action 4–2b.*—Develop and refine methods for incorporating social, cultural, economic, and ecosystem service metrics into integrated assessment approaches through collaboration with partners and stakeholders.
- *Action 4–2c.*—Develop methods to estimate potential land surface and seabed disturbance associated with potential development. These methods will draw on knowledge of the resource, including expanded use of USGS estimated ultimate recovery information for oil and gas resources and requirements for development.
- *Action 4–2d.*—Evaluate models, assumptions about effects, and the effectiveness of different mitigation strategies. This work ideally will be done in coordination with resource stewardship agencies, with particular emphasis on areas where resource conflicts exist, such as the potential effects of energy development and infrastructure on habitat use by mule deer, on surface water quality from coal bed methane development, and on treatment-discharge or deep-well injection of produced waters.
- *Action 4–2e.*—Develop decision analysis and support tools to address resource stewardship needs. Examples of such recognized needs include BLM work processes, such as inventory and assessment, planning, permitting and managing uses, and monitoring.
- *Action 4–2f.*—Conduct an assessment of potential environmental consequences associated with renewable energy development on DOI lands.

Goal 5.—Understand the Availability and Reliability of Energy and Mineral Resource Supplies

Introduction

Challenges to national security, economic vitality, quality of life, and environmental well-being can arise suddenly and catastrophically or as a result of long-term trends. Therefore, our scientific enterprise must remain responsive and adaptable to meet new and evolving challenges. Goal 5 transitions from an emphasis in the first four goals on currently recognized science and its application to known societal concerns to an emphasis on proactive planning for the future. We emphasize in this section the application and adaptation of existing USGS expertise to address the future adequacy of energy and mineral supplies for the Nation.

Natural and societal factors affecting energy and mineral resources supply and demand over the next decade will test the limits of our current understanding and our ability to adjust to emerging priorities and directions. The human drivers of change are complex and diverse, including advances in technology, competition for natural resources, evolution of national and international policies and conflicts, land use change, effects on ecosystems, and shifting social mores and attitudes. Climate change and natural and anthropogenic disasters and emergencies can also affect energy and minerals resource supplies. Some of these events may trigger perturbations in the immediate reliability of energy and mineral supplies; other events may create perturbations in the longer term availability of supplies (National Research Council, 2008).

The USGS already provides information that is essential underpinning for policy, management, and stewardship decisions on resource extraction, use, regulation, and waste management but the magnitude and speed of world events and societal changes are placing a premium on flexibility and foresightedness. This section addresses modifications or additions to existing science capabilities to improve the capacity of USGS to respond to short-term, emergency and long-term developments in the supply of energy and mineral resources and to support national resiliency in the face of possible supply disruptions.

Major Questions

- How might the emergence of new technologies or patterns of resource use affect the mineral and energy requirements of the Nation, and what science and information are needed to meet these national requirements?
- What approaches can be used to identify vulnerabilities within the supply chain of mineral materials and energy resources?
- How can the USGS better prioritize energy and minerals research activities to address the most critical future issues?
- How can the USGS more effectively disseminate knowledge about energy and mineral resources to inform public discourse and decisionmaking?

5–1. Emerging or Longer Term Issues Affecting Resource Availability

The United States is likely to diversify energy sources to reduce dependence on imports from specific countries and to address issues of greenhouse gas emissions (U.S. Geological Survey, 2007, p. 25). As the Nation's energy mix changes, the USGS will likely expand its research and assessment portfolio to include a more comprehensive suite of energy resources, including hydrocarbon- and nonhydrocarbon-based sources (U.S. Geological Survey, 2007, p. 25). Similarly, the United States will likely be involved in building new technologies based on novel mineral resource components. The USGS must include the minerals necessary for emerging technologies within its portfolio of minerals research and information collection activities.

The global increase in demand for energy and mineral resources, especially in countries undergoing rapid economic development, is in part a reflection of the need to build a modern infrastructure. For example, China has accounted for the majority of the global increase in mineral consumption from 2000 to 2010. Global mineral consumption is expected to increase in response to further development in China and economic development in countries with large populations, such as India.

The use of new technologies represents another factor that changes mineral consumption rates and patterns. For example, consumption may decrease in response to more efficiently designed goods or may increase through the use of new materials in goods that are consumed by large numbers of customers; the aerospace and light-vehicle transportation sectors are rapidly transforming construction design for structures, power sources, and size optimization, while still maintaining a large volume of the working fleet that uses older technologies. This transition in engineering design is steering a significant shift in consumption of high-technology materials (for example, aluminum alloys, avionics doped crystals and films, carbon-composite fibers, specialty metal blends of glass, stabilized ceramics, and titanium) and associated fuels (for example, high-octane fuels), all produced with different forms of metals and mineral materials. This rapid evolution in consumption patterns has highlighted the limits of our knowledge about the distribution and concentration of some of the raw materials that these industries use.

In order to respond to issues of energy and mineral supply, the USGS must understand the availability of energy and mineral materials at national and global levels. The USGS studies energy and mineral resource formation, distribution, character, and quality (goal 1), produces assessments of undiscovered domestic energy and mineral resources (goal 3), and collects global data on reserves, production, consumption, stocks, recycling, and trade for all nonfuel mineral materials (goal 3). In addition, the USGS collects and compiles information on an as-needed basis on material consumption by different industry sectors, data on corporate ownership (for example, in efforts to assist in U.S. Department of Justice evaluations of mergers and acquisitions), global manufacturing and trade data, and materials flow analysis for selected commodities. The next, more comprehensive step in tracking the movement of materials and their derivatives through the global economy are materials flow and supply chain analyses (highlight 8).

The methodologies for analyzing the materials flow of energy and mineral materials are evolving, yet the development of these methodologies is fundamental to understanding how natural and human systems interact with and influence global economies. USGS data on materials flows, in combination with energy-flow information from partners such as the EIA, can be used to monitor supply fluctuations, predict energy and material demands for different industry sectors, provide warnings of potential supply risks, and illuminate vulnerabilities in global production and manufacturing supply chains. Materials flow analyses and network models also provide an active, quantifiable mechanism (fig. 14) for prioritizing future USGS energy and minerals research and assessments.

Models of mineral supply chains can only be as good as the data and assumptions on which they are based. The depth and consistency of USGS databases on mineral statistics and mineral resources are a vital component in building viable models for minerals and mineral materials. Combining USGS minerals data with EIA energy data would provide the comprehensive databases needed to model the energy and minerals requirements for new materials technologies. The output of these models would be a platform for comprehensive planning and management of national resources and for identifying short- and long-term vulnerabilities in the supply chain of minerals critical to the national economy and defense.

5–2. Short-Term Fluctuations Affecting Reliability of Resource Supplies

Some future events will arrive with little warning and will require immediate responses that make the best use of existing information and capabilities. Disaster response precipitated by natural hazards, such as earthquakes, tsunamis, and floods, by terrorist acts, or by catastrophic human error requires the ability to provide relevant information almost instantaneously.

The ability of the USGS to respond rapidly and effectively to unforeseen disasters with energy and minerals expertise is dependent on leveraging a suite of existing geological, geochemical, geophysical, and mineral economics

Highlight 8

Materials Flow Analysis: Illustrating Global Commodity Supply Vulnerabilities

Materials flow analysis is the systematic accounting of a material or commodity from extraction through processing, manufacturing, reuse, and ultimate disposal (Brown and others, 2000; National Research Council, 2004). The U.S. Geological Survey (USGS) National Minerals Information Center provides information on the demand for minerals and mineral materials across industry sectors and develops materials flow analyses for selected commodities.

Supply-chain analysis (fig. 14), a more comprehensive form of materials flow analysis, illustrates each step in the chain of use from source to disposal. Supply-chain analysis accounts for all steps of production and processing (mines, mills, smelters, refineries, fabricators, and the manufacture of final goods), inventories and stockpiles, costs (fixed, variable, and new capacity startup), and necessary transportation facilities. Fully developed models require extensive data on the economics of production and trade, values of processed materials, demand variations over time, knowledge of materials properties specific to individual sectors of the economy, information on the capacity and manufacturing capabilities, and location for all downstream infrastructure (processing and production facilities).

Supply-chain analysis can also account for energy usage at each step in the material's flow. In turn, by using mathematical algorithms, the economic efficiency of each point in the usage cycle can be estimated. For example, network-flow models can show the lowest cost of supplying demand within current limits of capacity and market organization or the highest value use of a particular mineral resource. An analysis of supply chains for materials critical to the United States is required to identify economic vulnerabilities that could be precipitated by global trends and circumstances. The USGS is uniquely positioned to develop these tools. These models can be crafted to include early warning features that signal disruptions to material supply at individual points or used to illustrate propagation of problems to subsequent steps. Such an early-warning framework would allow U.S. agencies, foreign governments, and industrial sectors to target risk assessments and disaster response strategies to those disruptions most likely to affect specific interests.

expertise and analytical capabilities. The existing regional and national scale datasets provide a snapshot of conditions prior to an environmental event or natural disaster. These data are essential for evaluating the extent of change that occurs during a natural or other disaster. This broad capacity enables the USGS to bring science to bear in responses to natural hazards, such as earthquakes, tsunamis, hurricanes, and wildfires (highlight 9). Within the past decade, the USGS has responded to manmade disasters by providing remote sensing to environmentally map the World Trade Center (WTC) area with imaging spectroscopy (Clark and others, 2006) and chemical characterization of dusts generated by the WTC collapse (Plumlee and Ziegler, 2003); chemical measurements before and after wildfires to assess changes to soils and waters (Eppinger, 2002; Eppinger and others, 2003; Wolf and others, 2010); inorganic, organic, and microbial characterization of

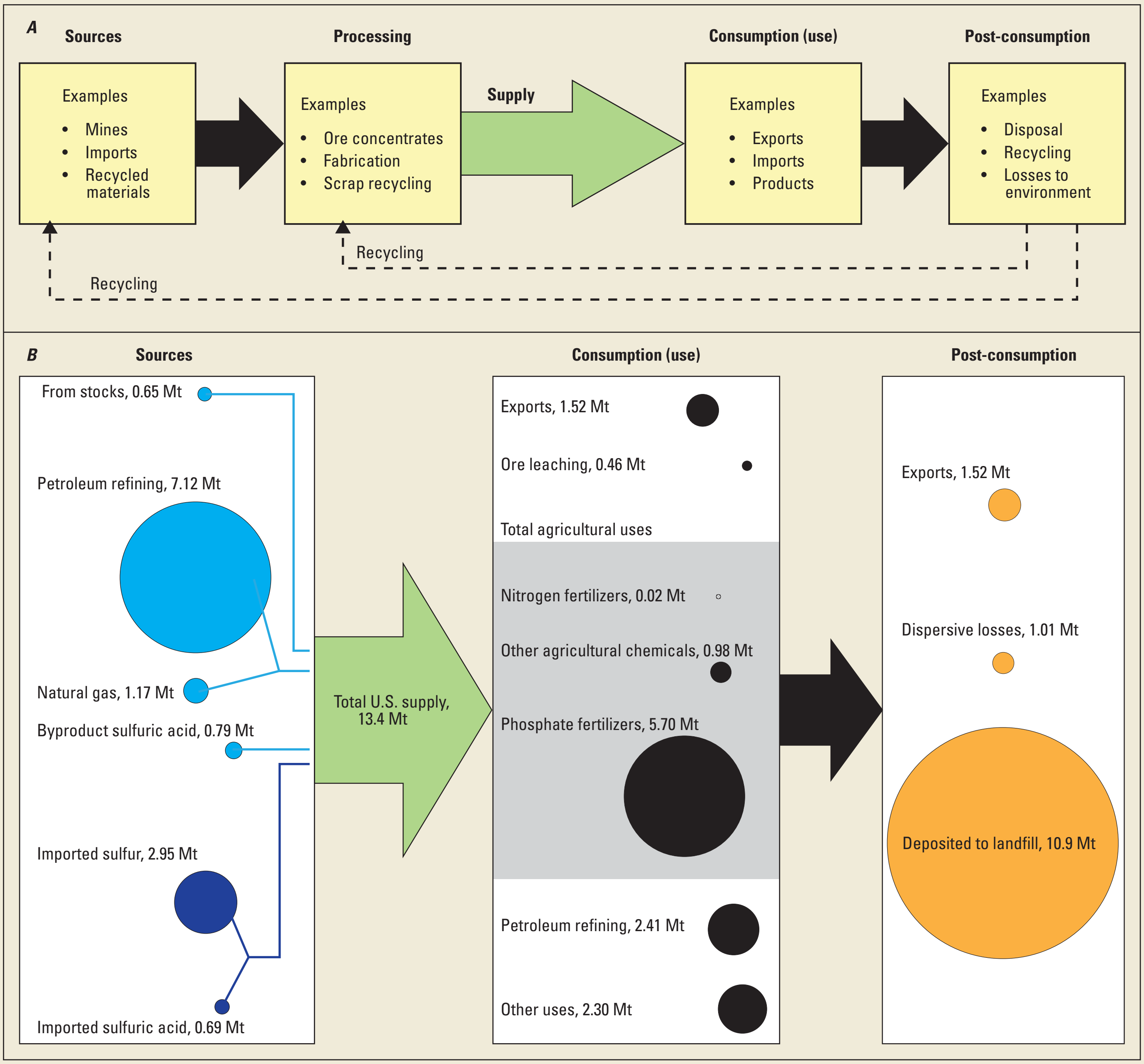


Figure 14. Examples of materials flows. *A*, Conceptual framework for a material supply model; modified from Kostick (1996). *B*, Example flow model for sulfur in the United States. A derivative application of materials flow analysis is the ability to evaluate human influences on global biogeochemical cycling of elements, such as sulfur; data are reported in million metric tons (Mt) (Lori Apodaca, U.S. Geological Survey, written commun., April 4, 2012).

Highlight 9

Energy and Minerals Contributions to Disaster Response Following the 2011 Japan Earthquake and Tsunami

The devastating, magnitude 9.0 earthquake and subsequent tsunami that struck the eastern coast of Japan near Tohoku on March 11, 2011, required coordinated disaster response efforts, including significant science contributions. With at least 15,000 people killed and hundreds of thousands displaced from their homes, the humanitarian efforts were paramount, but determining the full effect of the disaster also involved assessing the local and global physical and economic effects. In addition to the damage to the nuclear reactors at Fukushima, there was widespread damage to the area's industry and infrastructure. The U.S. Geological Survey (USGS) analyzed the effect of the earthquake and tsunami on mineral facilities in the region to assess potential disruptions to Japanese and global mineral and material supply chains (fig. 15). Nine cement plants in the affected area produced 30 percent of Japan's cement; eight iodine plants in the same region accounted for 25 percent of the world's iodine supply. The earthquake-affected zone also included nine metal refineries, four iron and steel plants, four limestone mines, and two titanium facilities.

The USGS briefed policymakers soon after the quake and published a report on the findings within 8 business days of the event (Menzie and others, 2011). This type of rapid data analysis immediately following a disaster is of major importance for response planning by governments and industry. As a result of the Tohoku effort, USGS minerals information and analyses are now being incorporated into disaster-planning scenarios, such as the U.S. regional ShakeOut earthquake exercises.

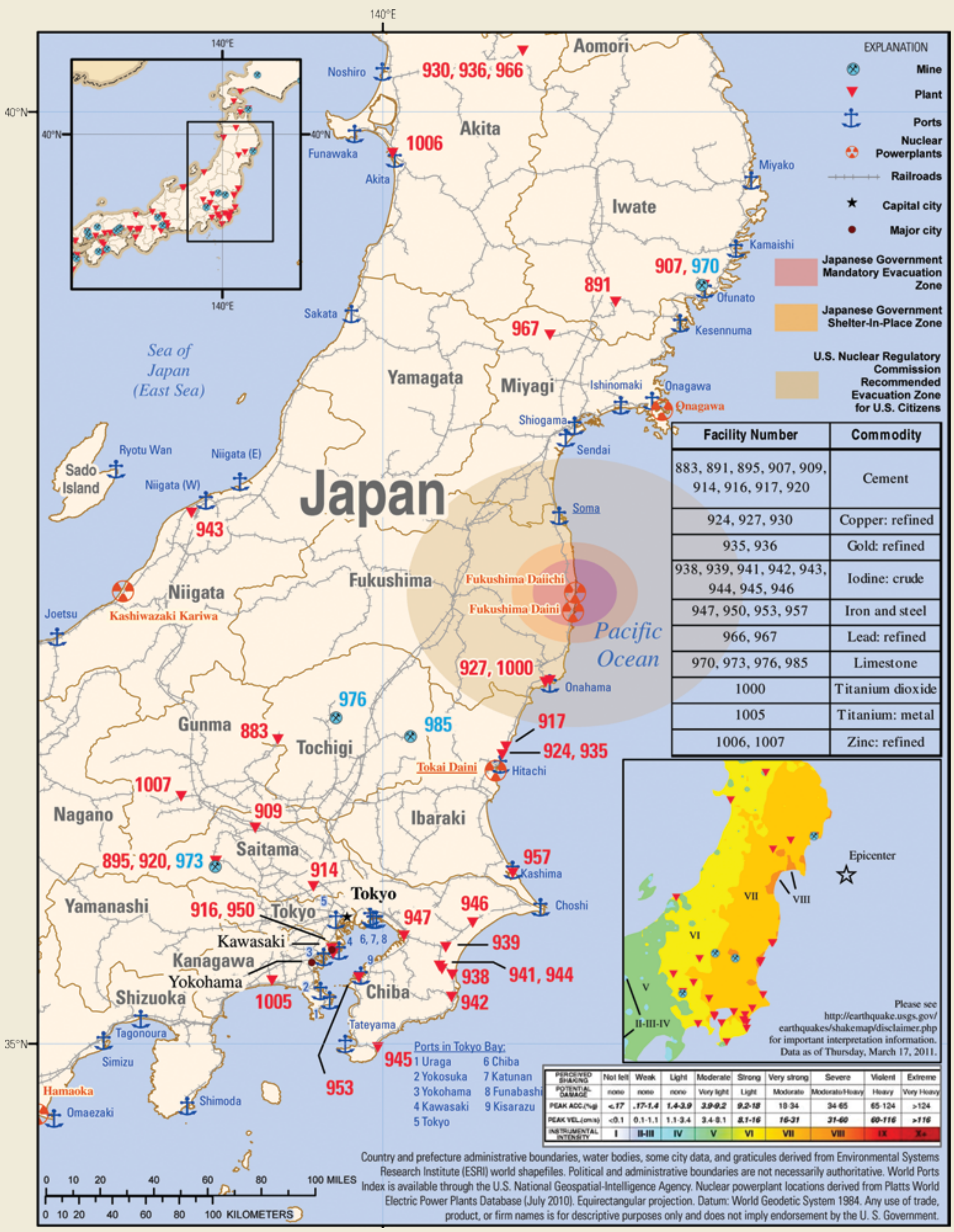


Figure 15. Locations of mines and mineral facilities in Japan, from Menzie and others (2011).

flood sediments immediately following Hurricane Katrina (Plumlee and others, 2006); and volume and flow rate measurements of oil from the Deepwater Horizon oil spill (Labson and others, 2010). Efforts such as these are important to characterizing the initial effects from catastrophic events and providing the foundational knowledge for informing damage assessment and recovery efforts.

In terms of anticipating and preparing for future events, USGS expertise and information can be used to underpin the development of scenarios and help inform response planning and recovery efforts. As one example, the southern California ShakeOut scenario (Jones and others, 2008) was the basis for a cooperative project to evaluate the physical, social, and economic consequences of a modeled large earthquake (magnitude 7.8 on the Richter scale), and provided a wide range of emergency response and other organizations with information for potential recovery efforts following such an event. A magnitude 7.8 earthquake as described in the ShakeOut Scenario would cause significant damage to buildings and infrastructure. Langer (2011) estimated that more than 6 million metric tons of newly mined aggregate would be needed for emergency repairs and for reconstruction within the study area in the 5 years following the event. This information is important for understanding both the potential magnitude and the duration of this perturbation on regional aggregate supplies. Greater emphasis on this type of follow-on study exemplifies the kind of research directions anticipated by this goal.

Strategic Actions

5–1. Emerging or Longer Term Issues Affecting Resource Availability

- *Action 5–1a.*—Develop approaches for identifying mineral materials that are strategic and critical to the U.S. economy, energy supply, infrastructure, and national security. This activity would benefit from consultation with partners, such as the U.S. Department of Defense, industrial manufacturers, the National Institute of Standards and Technology, the DOE, and the Office of Science and Technology Policy. USGS information and analytical capabilities are essential for evaluating which materials are critical and for estimating the risk of supply disruptions. Because the supply chains and end uses of mineral materials are dynamic, the suite of materials identified as strategic or critical are also dynamic and will require periodic reevaluation.
- *Action 5–1b.*—Conduct targeted studies on the global flow of a select number of critical mineral materials as identified in action 5–1a. Global materials flow analyses can be used to identify vulnerabilities in supply chain nodes caused by human and natural events and knowledge gaps in our current understanding of supply chain complexities. Supply disruption can be defined in terms of facility capacities along all segments of the chain. Opportunities to complement ongoing research and development of alternative material or energy sources, remanufacturing, reuse, or recycling could also be addressed as mitigation strategies for dealing with supply risk.
- *Action 5–1c.*—Conduct research to reduce the uncertainty and refine the understanding of how the endowment of undiscovered resources may contribute to future supplies. As one example, the extreme uncertainty regarding undiscovered Arctic oil and gas resources results from several factors, including data scarcity or disparate data density, environmental concerns, high development costs, and technological requirements. An important extension of an undiscovered resource assessment is the development of a full-cycle model that evaluates these economic and other factors to estimate the amount of resource that could be added to global supply.
- *Action 5–1d.*—Synthesize energy resource commodity assessments (for example, coal, geothermal, natural gas, and oil) into a global evaluation of the future energy mix. Although the thrust of this effort will be forward looking, it can also establish an historical basis ("lessons-learned") for analysis, such as the age and decline rates of giant domestic fields from which a large proportion of our oil is produced. Furthermore, the results of such a synthesis may identify new fundamental research directions and could be used to refine approaches to resource assessments.
- *Action 5–1e.*—Develop an active, unified, and recurring mechanism for prioritizing USGS energy and minerals research, assessments, and other science and information products to address identified data gaps and emerging needs. For example, a new genetic model may be needed for a previously unrecognized deposit type (goal 1) or geochemical research may be required to trace the cycling of an element with emerging uses (goal 2).

5–2. Short-Term Fluctuations Affecting Reliability of Resource Supplies

- *Action 5–2a.*—Enhance capabilities for rapidly responding to events, such as natural disasters or manmade disruptions, that result in significant perturbations to resource supplies and (or) the release of energy resources or mineral materials to the environment. Enhancing these capabilities would require strengthening of coordination mechanisms to facilitate deployment of rapid-response science teams and equipment to collect time-sensitive data from the field and to extract scale-appropriate data or other information from existing databases (highlight 9). To support this endeavor, additional investments would be needed to establish mechanisms for timely sample and data analysis, interpretation, and delivery to the responders, decisionmakers, and the general public in understandable and needed formats.

- *Action 5–2b.*—Conduct research on coupled systems affecting energy and minerals availability, such as the complex relation between technology and resource economies, and develop scenarios of perturbations affecting the reliability of energy and mineral supplies. Such analysis and reporting could identify specific nodes and links in supply chains that are vulnerable to disruption. Scenarios incorporating such relations can be useful in estimating the consequences of an event on the availability of energy and minerals resources and will likely empower decisionmakers and responders to develop proactive measures to adapt to or mitigate potential consequences and accelerate the response and (or) recovery phases following an event.

Energy and Minerals Linkages Across the U.S. Geological Survey

The USGS science strategy (U.S. Geological Survey, 2007) established a plan for linking scientific expertise and capabilities across USGS mission areas. The objectives are to encourage more studies that use integrated information resources and to create a highly accessible environment for application of data resources available from the USGS and other Federal agencies. From this emphasis on integration, the energy and minerals strategic plan mirrors the reality that complex societal issues demand diverse capabilities from every corner of the USGS. The potential linkages across mission areas are open ended and dependent on the particular blend of science a given issue demands; however, the following discussion provides a starting point for recognizing the possibilities.

Table 3 provides an initial evaluation of the energy and minerals mission area goals and actions that will require support of other mission areas. Placing an action at an appropriate intersection point with other USGS mission areas is the key to understanding table 3. For example, most of the energy and mineral actions of goal 2 on environmental effects, goal 3 on assessments, and goal 4 on land management point to the need for enlisting expertise from across mission areas to deliver research and assessment products from a variety of disciplines.

While this perspective focuses on opportunities for other mission areas to advance energy and minerals goals, we recognize that the converse is also true: efforts precipitated by the energy and minerals strategic plan will contribute to other goals across the USGS. When leveraged with expertise from other mission areas, the energy and minerals actions yield results that provide a more comprehensive and integrated understanding of natural resources. The use of pilot studies based on the concept of early integration of resources and personnel can help determine when and where collaboration among mission areas would be most successful. These pilot studies are scalable and could be used to leverage collaboration at regional and national levels within the DOI and among other Federal agencies.

The actions in this report reflect the importance of early planning so that integration of interdisciplinary Earth science research can be established across mission areas of the USGS. These actions further stimulate the creation of information and databases that, when combined with those of other Federal agencies and public resource stewards, lead to the type of integrated assessments that will further our understanding of the complexities of the energy and minerals resource lifecycle related to resource development issues.

Coordination across the USGS is important to fully understand the breadth and magnitude of interactions among energy and mineral lifecycles and air, land, soil, water, ecosystems services or functions, and human health from local, regional, national, and global perspectives. The science actions developed as part of this energy and mineral science strategy represent key components of integrated studies at multiple scales.

By linking the science resources and data from all USGS mission areas in the early stages of key integrated studies, the USGS could develop new abilities to identify science gaps and data needs from linked resources that a single mission area alone might not recognize or be able to develop on its own. Early integration of data from multiple mission areas could also generate information relevant to socioeconomic issues that are important to the understanding of complex energy and minerals lifecycles. The extent and implications of these linkages point to better data management and integration and new research and development methods as the two science directions that are essential to the success of the USGS science strategy in the coming decade. In a lifecycle or systems approach to science, the USGS can find ways to better manage and integrate data from all mission areas to facilitate a greater understanding of Earth science systems and provide new and innovative ways to make this information accessible across discipline and geographic boundaries. These data must be presented in ways that can reach a range of audiences that include scientists, cooperators, resource managers, policymakers, and the public, all of whom have diverse interests, data needs, backgrounds, and responsibilities for resource systems.

Table 3. U.S. Geological Survey energy and minerals science strategy actions and intersections with other mission areas.

[Gray-shaded rows denote actions for which the outcomes can be achieved largely through energy and minerals core expertise and capabilities. Red dots denote actions for which significant leveraging of expertise and capabilities from other mission areas will be needed to fully achieve desired outcomes. DOI, U.S. Department of the Interior; EEZ, Exclusive Economic Zone; NMIC, National Minerals Information Center; USGS, U.S. Geological Survey]

Focus area and action	Climate and land-use change	Core science systems	Ecosys-tems	Environ-mental health	Natural hazards	Water
Goal 1. Understand fundamental earth processes that form energy and mineral resources						
1–1. Geologic and tectonic framework studies:						
1–1a. Map regional-scale geologic features		●				
1–1b. Acquire regional-scale geophysical data					●	
1–1c. Apply 3D models to areas of high resource potential		●			●	●
1–2. Evolution of energy and mineral systems:						
1–2a. Investigate geologic and geochemical factors						
1–2b. Conduct research on emerging energy resources					●	●
1–2c. Conduct deposit-scale studies						
1–2d. Determine broad-scale controls on mineral systems		●			●	●
1–2e. Investigate sedimentary basin petroleum and ore formation						
1–3. Frontier studies:						
1–3a. Promote collection of U.S. EEZ data			●	●	●	
1–3b. Expand data collection and evaluation of Alaska and Arctic offshore	●	●	●		●	●
1–3c. Construct geologic frameworks for concealed deposits						
Goal 2. Understand the environmental behavior of energy and mineral resources and their waste products						
2–1. Fundamental studies:						
2–1a. Investigate carbon sources and sinks	●					●
2–1b. Investigate perturbations to natural landscape during resource lifecycle	●		●	●		●
2–1c. Understand climatic alteration of energy and minerals systems	●			●		●
2–2. Applied investigations:						
2–2a. Characterize waste streams			●	●		●
2–2b. Conduct research on deep geologic reservoirs for waste disposal				●	●	●
2–2c. Investigate environmental geochemistry of resource production technologies						●
2–2d. Expand capabilities to research renewable energy development effects	●	●	●	●	●	●
2–3. Synthesis activities:						
2–3a. Create geologically based environmental models	●	●	●	●	●	●
2–3b. Enhance transfer of insights between experiments and system-wide studies			●	●		●
Goal 3. Provide inventories and assessments of energy and mineral resources						
3–1. Undiscovered geologically based energy resources:						
3–1a. Conduct periodic assessments						
3–1b. Complete uranium assessment						
3–1c. Assess emerging resources						
3-1d. Develop additional components of economic and environmental analyses			●	●		●

Table 3. U.S. Geological Survey energy and minerals science strategy actions and intersections with other mission areas.—Continued

[Gray-shaded rows denote actions for which the outcomes can be achieved largely through energy and minerals core expertise and capabilities. Red dots denote actions for which significant leveraging of expertise and capabilities from other mission areas will be needed to fully achieve desired outcomes. DOI, U.S. Department of the Interior; EEZ, Exclusive Economic Zone; NMIC, National Minerals Information Center; USGS, U.S. Geological Survey]

Focus area and action	Climate and land-use change	Core science systems	Ecosys-tems	Environ-mental health	Natural hazards	Water
3–2. Discovered nonfuel mineral resources:						
3–2a. Expand partnerships						
3–2b. Establish a periodic review						
3-2c. Expand due-diligence field studies						
3-2d. Enhance scope and functionality of domestic discovered resources database						
3-2e. Strengthen and expand NMIC analytical capabilities						
3–3. Undiscovered nonfuel mineral resources:						
3–3a. Reevaluate methodologies for undiscovered mineral resources assessments						
3–3b. Adapt methodologies for use in frontier regions					●	
Goal 4. Understand the effects of energy and mineral development on natural resources						
4–1. Spatial analysis of energy and mineral resources occurrence and development:						
4–1a. Designate liaisons and energy and minerals resource experts in USGS	●	●	●	●	●	●
4-1b. Provide usable information to large landscape conservation initiatives						
4-1c. Develop new nationwide spatial data products		●				
4–2. Explore interdisciplinary approaches for assessing effects of energy and mineral resources development:						
4–2a. Identify metrics or indicators	●	●	●	●	●	●
4–2b. Develop and refine methods for incorporating metrics	●	●	●	●	●	●
4–2c. Develop methods to estimate potential land surface and seabed disturbance	●		●	●	●	●
4-2d. Evaluate models, effects, and effectiveness of mitigation strategies	●	●	●	●	●	●
4-2e. Develop decision analysis and support tools	●	●	●			
4-2f. Assess potential environmental consequences of renewable energy development	●	●	●	●	●	●
Goal 5. Understand the availability and reliability of energy and mineral resource supplies						
5–1. Emerging or longer term issues affecting resource availability:						
5–1a. Develop approaches for identifying strategic and critical mineral materials						
5–1b. Conduct targeted studies on global flow of critical mineral materials						
5-1c. Conduct research on resource endowment contribution to future supplies						
5-1d. Synthesize energy resource commodity assessments						
5-1e. Develop mechanisms for prioritizing USGS energy and minerals research						
5–2. Short-term fluctuations affecting reliability of resource supplies:						
5–2a. Enhance capabilities for rapidly responding to events	●	●	●	●	●	●
5–2b. Conduct research on reliability of energy and mineral supplies					●	

References Cited

Ahlbrandt, T.S., Charpentier, R.R., Klett, T.R., Schmoker, J.W., Schenk, C.J., and Ulmishek, G.F., 2005, Global resource estimates from total petroleum systems: American Association of Petroleum Geologists Memoir 86, 324 p.

Alpine, A.E., ed., 2010, Hydrological, geological, and biological site characterization of breccia pipe uranium deposits in northern Arizona: U.S. Geological Survey Scientific Investigations Report 2010–5025, 353 p., 1 pl., scale 1:375,000, available at *http://pubs.usgs.gov/sir/2010/5025/*.

Biewick, L.R.H., 2008, Areas of historical oil and gas exploration and production in the United States: U.S. Geological Survey Digital Data Series 69–Q, available at *http://pubs.usgs.gov/dds/dds-069/dds-069-q/*.

Brown, W.M., III, Matos, G.R., and Sullivan, D.E., (comps.), 2000, Materials and energy flows in the Earth science century—A summary of a workshop held by the USGS in November 1998: U.S. Geological Survey Circular 1194, 76 p., available at *http://pubs.usgs.gov/circ/2000/c1194/*.

Clark, R.N., Swayze, G.A., Hoefen, T.M., Green, R.O., Livo, K.E., Meeker, G.P., Sutley, S.J., Plumlee, G.S., Pavri, Betina, Sarture, Chuck, Boardman, Joe, Brownfield, I.K., and Morath, L.C., 2006, Environmental mapping of the World Trade Center area with imaging spectroscopy after the September 11, 2001 attack, chap. 4 *of* Gaffney, J.S., and Marley, N.A., eds., Urban aerosols and their impacts—Lessons learned from the World Trade Center tragedy: American Chemical Society Symposium Series, v. 919, p. 66–83.

Coleman, J.L., Milici, R.C., Cook, T.A., Charpentier, R.R., Kirschbaum, Mark, Klett, T.R., Pollastro, R.M., and Schenk, C.J., 2011, Assessment of undiscovered oil and gas resources of the Devonian Marcellus Shale of the Appalachian Basin Province, 2011: U.S. Geological Survey Fact Sheet 2011–3092, 2 p., available at *http://pubs.usgs.gov/fs/2011/3092/*.

duBray, E.A., (ed.), 1995, Preliminary compilation of descriptive geoenvironmental mineral deposit models: U.S. Geological Survey Open-File Report 95–831, 272 p., available at *http://pubs.usgs.gov/of/1995/ofr-95-0831/*.

Eppinger, R.G., 2002, Pre-fire baseline stream-sediment and stream-water geochemical data from a recently burned area in central Idaho, and suggestions for application of geochemical data to wildfire science, *in* Coffelt, J.L., and Livingston, R.K., 2002, Second U.S. Geological Survey Wildland Fire Workshop; Los Alamos, New Mexico; October 31–November 3, 2000: U.S. Geological Survey Open-File Report 2002–11, p. 51, available at *http://pubs.usgs.gov/of/2002/0011/report.pdf*.

Eppinger, R.G., Briggs, P.H., Rieffenberger, Betsy, Van Dorn, Carol, Brown, Z.A., Crock, J.G., Hageman, P.H., Meier, Allen, Sutley, S.J., Theodorakos, P.M., and Wilson, S.A., 2003, Geochemical data for stream sediment and surface water samples from Panther Creek, the middle fork of the Salmon River, and the main Salmon River, collected before and after the Clear Creek, Little Pistol, and Shellrock wildfires of 2000 in central Idaho: U.S. Geological Survey Open-File Report 2003–152, 32 p., available at *http://pubs.usgs.gov/of/2003/152/*.

Gundersen, L.C.S., Belnap, J., Goldhaber, M., Goldstein, A., Haeussler, P.J., Ingebritsen, S.E., Jones, J.W., Plumlee, G.S., Thieler, E.R., Thompson, R.S., and Back, J.M., 2011, Geology for a changing world 2010–2020—Implementing the U.S. Geological Survey science strategy: U.S. Geological Survey Circular 1369, 68 p. (Also available at *http://pubs.usgs.gov/circ/circ1369/*.)

Higley, D.K., 2011, Undiscovered petroleum resources for the Woodford Shale and Thirteen Finger Limestone-Atoka Shale assessment units, Anadarko Basin: U.S. Geological Survey Open-File Report 2011–1242, 3 sheets, available at *http://pubs.usgs.gov/of/2011/1242/*.

Jacobsen, L.J., Glynn, P.D., Phelps, G.A., Orndorff, R.C., Bawden, G.W., and Grauch, V.J.S., 2011, U.S. Geological Survey—A synopsis of three-dimensional modeling, chap. 13 *of* Berg, R.C., Mathers, S.J., Kessler, Holger, and Keefer, D.A., eds., Synopsis of current three-dimensional mapping and modeling in geological survey organizations: Illinois State Geological Survey Circular 578, p. 69–79, available at *http://water.usgs.gov/nrp/proj.bib/Publications/2011/jacobsen_glynn_etal_2011.pdf*.

Jones, L.M., Bernknopf, Richard, Cox, Dale, Goltz, James, Hudnut, Kenneth, Mileti, Dennis, Perry, Suzanne, Ponti, Daniel, Porter, Keith, Reichle, Michael, Seligson, Hope, Shoaf, Kimberley, Treiman, Jerry, and Wein, Anne, 2008, The ShakeOut scenario: U.S. Geological Survey Open-File Report 2008–1150 and California Geological Survey Preliminary Report 25, 312 p. (Also available at *http://pubs.usgs.gov/of/2008/1150/*.)

Kostick, D.S., 1996, The material flow concept for materials: Nonrenewable Resources, v. 5, no. 4, p. 211–233.

Labson, V.F., Clark, R.N., Swayze, G.A., Hoefen, T.M., Kokaly, Raymond., Livo, K.E., Powers, M.H., Plumlee, G.S., and Meeker, G.P., 2010, Estimated minimum discharge rates of the Deepwater Horizon spill—Interim report to the Flow Rate Technical Group from the Mass Balance Team: U.S. Geological Survey Open-File Report 2010–1132, 4 p., available at *http://pubs.usgs.gov/of/2010/1132/*.

Langer, W.H., 2011, The ShakeOut scenario—Meeting the needs for construction aggregates, asphalt, and concrete: Earthquake Spectra, v. 27, p. 505–520.

Menzie, W.D., Baker, M.S., Bleiwas, D.I., and Kuo, Chin, 2011, Mines and mineral processing facilities in the vicinity of the March 11, 2011, earthquake in northern Honshu, Japan: U.S. Geological Survey Open-File Report 2011–1069, 7 p., available at *http://pubs.usgs.gov/of/2011/1069/*.

National Research Council, 1996, Mineral resources and sustainability—Challenges for earth scientists: Washington, D.C., The National Academies Press, 26 p.

National Research Council, 2004, Materials count—The case for materials flow analysis: Washington, D.C., The National Academies Press, 144 p.

National Research Council, 2008, Minerals, critical minerals, and the U.S. economy: Washington, D.C., The National Academies Press, 264 p.

Plumlee, G.S., and Ziegler, T.L., 2003, The medical geochemistry of dusts, soils, and other earth materials, *in* Lollar, B.S., ed., Environmental geochemistry: Treatise on Geochemistry, v. 9, p. 1–61. (Also available at *http://www.sciencedirect.com/science/article/pii/B0080437516090502*.)

Plumlee, G.S., Meeker, G.P., Lovelace, J.K., Rosenbauer, R.J., Lamonthe, P.J., Furlong, E.T., and Demas, C.R., 2006, USGS environmental characterization of flood sediments left in the New Orleans area after Hurricanes Katrina and Rita, 2005—Progress report: U.S. Geological Survey Open-File Report 2006–1023, 74 p., available at *http://pubs.usgs.gov/of/2006/1023/*.

Scott, D.C., Haacke, J.E., Osmonson, L.M., Luppens, J.A., Pierce, P.E., and Rohrbacher, T.J., 2011, Assessment of coal geology, resources, and reserves in the northern Wyoming Powder River Basin: U.S. Geological Survey Open-File Report 2010–1294, 136 p., available at *http://pubs.usgs.gov/of/2010/1294/*.

United Nations, 1982, United Nations convention on the law of the sea: Montego Bay, Jamaica, United Nations, 202 p., accessed April 12, 2012, at *http://www.un.org/Depts/los/convention_agreements/convention_overview_convention.htm*.

United Nations World Commission on Environment and Development, 1987, Our common future: United Nations, 374 p. (Also available at *http://worldinbalance.net/intagreements/1987-brundtland.php*.)

U.S. Commission on Ocean Policy, 2004, An ocean blueprint for the 21st century—Final report: Washington, D.C., U.S. Commission on Ocean Policy, 438 p. plus appendixes. (Also available at *http://www.oceancommission.gov/documents/full_color_rpt/000_ocean_full_report.pdf*.

U.S. Energy Information Administration, 2011, Annual energy review 2010: U.S. Energy Information Administration DOE/EIA–0384(2010), 384 p., available at *http://www.eia.gov/totalenergy/data/annual/pdf/aer.pdf*.

U.S. Geological Survey, 2007, Facing tomorrow's challenges—U.S. Geological Survey science in the decade 2007–2017: U.S. Geological Survey Circular 1309, 67 p. (Also available at *http://pubs.usgs.gov/circ/2007/1309/*.)

U.S. Geological Survey Bighorn Basin Assessment Team, 2010, Petroleum systems and geologic assessment of oil and gas in the Bighorn Basin Province, Wyoming and Montana: U.S. Geological Survey Digital Data Series 69–V, available at *http://pubs.usgs.gov/dds/dds-069/dds-069-v/*.

U.S. Geological Survey Oil Shale Assessment Team, 2010a, Oil shale and nahcolite resources of the Piceance Basin, Colorado: U.S. Geological Survey Digital Data Series 69–Y, available at *http://pubs.usgs.gov/dds/dds-069/dds-069-y/*.

U.S. Geological Survey Oil Shale Assessment Team, 2010b, Oil shale resources of the Uinta Basin, Utah and Colorado: U.S. Geological Survey Digital Data Series 69–BB, available at *http://pubs.usgs.gov/dds/dds-069/dds-069-bb/*

U.S. Geological Survey Marcellus Shale Assessment Team, 2011, Information relevant to the U.S. Geological Survey assessment of the Middle Devonian Marcellus Shale of the Appalachian Basin Province, 2011: U.S. Geological Survey Open-File Report 2011–1298, 22 p., available at *http://pubs.usgs.gov/of/2011/1298/*.

U.S. Geological Survey, 2012, Mineral commodity summaries 2012: U.S. Geological Survey, 201 p. (Also available at *http://minerals.usgs.gov/minerals/pubs/mcs/2012/mcs2012.pdf*.)

Van Gosen, B.S., Gillerman, V.S., and Armbrustmacher, T.J., 2009, Thorium deposits of the United States—Energy resources for the future?: U.S. Geological Survey Circular 1336, 21 p., available at *http://pubs.usgs.gov/circ/1336/*.

Williams, B.K., Szaro, R.C., and Shapiro, C.D., 2009, Adaptive management—The U.S. Department of the Interior technical guide: U.S. Department of the Interior, 72 p., available at *http://www.doi.gov/initiatives/AdaptiveManagement/TechGuide.pdf*.

Wolf, R.E., Hoefen, T.M., Hageman, P.L., Morman, S.A., and Plumlee, G.S., 2010, Speciation of arsenic, selenium, and chromium in wildfire impacted soils and ashes: U.S. Geological Survey Open-File Report 2010–1242, 29 p., available at *http://pubs.usgs.gov/of/2010/1242/*.

Wyoming Landscape Conservation Initiative, [undated], Integrated assessment: Wyoming Landscape Conservation Initiative, accessed April 6, 2012, at *http://www.wlci.gov/*.