Appendix C

Additional Materials Available Electronically

This appendix provides detailed descriptions of additional study materials available for viewing and downloading in the *Prudent Development: Realizing the Potential of North America's Abundant Natural Gas and Oil Resources* report section of the National Petroleum Council's (NPC) publicly accessible website (http://www.npc.org), which contains the following files:

- Final Report
- Report Slide Presentation
- Webcast of NPC Meeting and Press Conference
- Study Topic and White Papers
- Study Survey Data Aggregations.

Final Report

The final report, *Prudent Development: Realizing the Potential of North America's Abundant Natural Gas and Oil Resources*, as approved by the members of the NPC and submitted to Secretary Chu, is available electronically on the NPC website. This copy of the printed report is in PDF format, contains hyperlinks among sections, and is searchable using Adobe software. It provides report sections as follows:

- Transmittal Letter to Secretary Chu (two-page summary of report)
- Table of Contents
- Preface
- Executive Summary
- Report Chapters
  - Chapter One: Crude Oil and Natural Gas Resources and Supply
  - Chapter Two: Operations and Environment
  - Chapter Three: Natural Gas Demand
  - Chapter Four: Carbon and Other Emissions in the End-Use Sectors
  - Chapter Five: Macroeconomics
- Appendices
  - Appendix A: Request Letters and Description of the NPC
  - Appendix B: Study Group Rosters
  - Appendix C: Additional Materials Available Electronically
- Acronyms and Abbreviations
- Conversion Factors.

Report Slide Presentation

On September 15, 2011, a detailed slide presentation on the report, *Prudent Development: Realizing the Potential of North America's Abundant Natural Gas and Oil Resources,* was delivered to Secretary of Energy Steven Chu and the membership of the NPC. This slide presentation is included on the report's website to allow readers access to materials that will be used to help explain the study process and results to various interested parties. The slide presentation is provided in PDF format.

Webcast of NPC Meeting and Press Conference

The report's website also contains a webcast of the September 15, 2011, NPC meeting as follows:

- Presentation on the report to the NPC membership

- Report approval and delivery to Secretary of Energy Steven Chu
- Remarks by Secretary Chu
- Press conference on September 15, 2011, following the NPC meeting.

STUDY TOPIC AND WHITE PAPERS

On September 15, 2011, the NPC in approving its report, *Prudent Development: Realizing the Potential of North America's Abundant Natural Gas and Oil Resources,* also approved making available certain materials used in the study process, including detailed, specific subject matter papers that were part of the analyses that led to the development of the summary results presented in the report's Executive Summary and Chapters. The Topic Papers were prepared by the Task Groups and their Subgroups, and the White Papers were prepared for these study groups. These papers are available on the NPC's website (www.npc.org).

These Topic and White Papers represent the views and conclusions of the authors. The National Petroleum Council has not endorsed or approved the statements and conclusions contained in these documents but approved the publication of these materials as part of the study process.

The NPC believes that these papers will be of interest to the readers of the report and will help them better understand the study results. These materials are being made available in the interest of transparency.

A list of these Topic and White Papers with brief abstracts for each follows.

Resource & Supply Task Group

Subgroup Topic Papers

Paper #1-1: Oil and Gas Geologic Endowment

This paper focuses on the gaseous and liquid hydrocarbons that form the North American hydrocarbon endowment. It describes:

- The major types of petroleum resource endowment hydrocarbons and how they are formed;
- Commonly used North American petroleum endowment classification systems;
- The distinction between proved reserves and other classes of petroleum resources;
- Reserves growth;
- The distinction between conventional and unconventional resources;
- Current estimates of North American petroleum resources; and
- Study observations and suggestions for future estimates.

Paper #1-2: Data and Studies Evaluation

The data/studies team was established to evaluate the wide spectrum of industry, government, and public supply outlooks. Our primary objective was to understand the uncertainty surrounding the size of North America's conventional and unconventional oil and natural gas resource base, and the challenges and enablers to convert this endowment into production/supply volumes that can help meet the future energy needs of North America. The industry, government, and public data and outlooks indicate a large North America gas resource base, but a more limited oil resource base. North American resources can provide all natural gas needs over the study time frame (2035–2050), but approximately only 50% of current and forecast demand for U.S. liquid petroleum requirements. Using natural gas to displace foreign oil and some domestic coal as an energy source would increase the United States' self-sufficiency and reduce reliance on foreign supply. Achieving this level of North American production would require an aggressive development plan and agreement between industry, regulators, policymakers, and the public as to the appropriate balance between supply development, environmental protection, and economic growth. Consumer preferences and future demand requirements will be met by multiple energy sources. We can optimize the supply mix by growing U.S./North American natural gas (in the power and transportation sectors) and optimizing the remaining North American oil resources, thereby:

- Reducing the need for foreign imports;
- Increasing investment in the U.S. workforce and infrastructure; and
- Promoting investment in research and technology in all viable energy sources.

Paper #1-3: Offshore Oil and Gas Supply

Development and production of offshore hydrocarbons are significant to total North American (United States and Canada) supply of crude oil and natural gas. U.S. lower-48 offshore oil production is expected to grow annually by 0.2 to 0.9%, while natural gas production will increase by 0.4 to 0.7% annually. Canadian offshore production of oil and gas, confined to the eastern shore in Newfoundland/Labrador and Nova Scotia, is relatively lower in comparison to the U.S. lower-48 offshore. These production outlooks are contingent upon expanded access to offshore lands currently under moratoria, and specific technological challenges. Those technologies are: reservoir characterization, extended system architecture, high-pressure and high-temperature (HPHT) completion systems, seismic technologies, controlled electromagnetism, interpretation technology, earth systems modeling, and metocean (meteorological and subsurface) forecasting and system analysis. The topic paper describes North American offshore hydrocarbons production prospects, the impacts of increased access to lands, and the factors of technological progress inherent to increased oil and natural gas production in more challenging environments.

Paper #1-4: Arctic Oil and Gas

The North American Arctic contains significant oil and natural gas volumes and is believed to contain substantial unproven reserves in Alaska, Canada and Greenland. This topic paper describes: (1) the onshore and offshore exploration and development history of this region; (2) the significant volumes discovered and produced to date; (3) the mean, risked, undiscovered oil and gas resource potential of each prospective basin; (4) the challenges facing future oil and gas exploration and development in this cold and remote region; (5) an attempt to describe a range of future production forecast scenarios; and (6) Findings and Recommendations that attempt to frame the issues and stimulate a rational approach to enabling the safe and timely evaluation of Arctic oil and gas resources (with a focus on Alaska). This last item takes on an even greater significance, as dwindling oil input into the Trans-Alaska Pipeline System is providing operational challenges and may limit the lifespan of this important delivery option.

Paper #1-5: Onshore Conventional Oil Including EOR

The conventional oil/enhanced recovery segment is an important part of U.S. and Canadian oil supply, representing over 40% of total production. The historical production decline trend has moderated in the last few years and even increased as technology improvements and economic viability generated significant investment activity. This topic paper provides background information, identifies key technologies and issues, and describes a potential supply fairway for the segment. Growth in enhanced recovery using carbon dioxide is considered along with perspective on the large resource targets, which still exist. Based on this foundation work, findings were developed and areas for possible action by industry or government institutions are identified.

Paper #1-6: Unconventional Oil

North America's unconventional resource is massive – oil in the ground is over 3.5 trillion barrels – nearly two times larger than all of the world's economically recoverable conventional oil. Even though only a fraction of this oil can be commercially produced, it is already an important pillar of North American oil supply – equivalent to 14% of total U.S. crude oil demand. Today, the majority of unconventional production comes from the Canadian oil sands.

Oil supply from North America's unconventional resources is forecast to grow. In our likely scenario, unconventional supply grows from 2 million barrels per day now to 7 million barrels per day by 2035. By 2035, unconventional production is equivalent to 50% of U.S. crude oil demand. The majority of the growth stems from the Canadian oil sands. However, tight oil – oil produced from tight formations using a combination of horizontal wells and fracturing – also makes a sizable contribution. Tight oil production grows from 400,000 barrels per day now to between 2 and 3 million barrels per day by 2035. These are early days for tight oil production, and its full potential could even exceed current estimates.

The Canadian oil sands, by far the world's largest source of unconventional oil supply, offer a constructive example for unconventional resource development. Ingredients for success include long-term investment supported by public-private partnerships and fiscal measures aimed at risk reduction. These factors, combined with high-cost investments in actual field trials (an activity critical to advancing new methods and ideas), were critical in the development of the Canadian oil sands industry. For noncommercial unconventional resources in the United

States (oil shale and oil sands), the ingredients that were critical to the development of the Canadian oil sands are, for the most part, absent.

Actions most likely to foster sustainable economic and environmentally sustainable growth of North American unconventional oil supply include; clarifying environmental and regulatory aspects of unconventional supply that are uncertain, and creating an environment that fosters continuous technical innovation and healthy investment.

Paper #1-7: Crude Oil Infrastructure

Changing supply and demand fundamentals in North America have driven significant changes in oil infrastructure. Falling onshore domestic supply in some regions, combined with significant growth in offshore Gulf of Mexico production and unconventional supply from existing basins have transformed North America's oil infrastructure. Supportive, market responsive policies and oversight along with predictable regulatory regimes have enabled the investments in oil infrastructure to take place in a timely fashion. Redeploying underutilized assets in new services has allowed low cost infrastructure to be put in place rather than requiring new construction. Low cost, accessible transportation infrastructure, in turn, has been a key enabler to developing emerging supply in the North American context. This relationship is expected to continue into the future.

North American crude oil infrastructure is not without challenges. Continuing service in some of the traditional corridors is occurring on infrastructure, which was constructed in the mid-1950s. The maintenance requirements and costs of this aging infrastructure continue to grow. The industry has responded accordingly by investing in integrity management programs and technology to understand and improve safety and reliability. Future developments in oil infrastructure will be required to continue to link emerging supply with future demand. The combination of existing and new infrastructure will ensure the efficient, orderly development of North America's resource potential.

Paper #1-8: Onshore Natural Gas

New techniques, particularly cost-effective multiple-stage fracture stimulations in horizontal wellbores, have recently and rapidly enabled production from vast resources of shale gas and tight gas never before considered economic at any reasonable price. These advances in technology have been instrumental in reversing the decline in North American natural gas production, onshore particularly, virtually eliminating the need for natural gas (and LNG) imports into the region. This phenomenon is creating expanded natural gas utilization; opening avenues for affordable, abundant energy and higher employment. This topic paper examines the U.S. lower-48 and non-arctic Canada onshore natural gas resource and its ability to provide reliable energy over many decades under various scenarios and ultimate recoverable gas resource volumes.

Paper #1-9: Natural Gas Infrastructure

The natural gas infrastructure topic paper explores issues and trends impacting the natural gas gathering and processing, transmission pipeline, and storage industries and the need for new infrastructure in these industry segments. Dramatic growth in shale gas supply has driven strong recent investment in gathering and processing facilities and transmission pipelines. Future infrastructure requirements in these industry segments will also be significant, while investment in storage facilities is expected to be relatively modest. Strong oil prices are driving development to areas rich in natural gas liquids and may create a need for new pipelines to transport these liquids. Growing shale gas supply and related infrastructure improves the reliability of natural gas supply and supports both significant switching from coal to natural gas for electricity generation and the use of natural gas as a transportation fuel. It will also put competitive pressure on existing infrastructure in high cost supply regions.

Task Group White Papers

Paper #1-10: Liquefied Natural Gas (LNG)

LNG, or liquefied natural gas, comprises a small but important and growing part of the global natural gas market. According to the BP Review of World Energy, LNG consumption in 2009 was 23.5 billion cubic feet per day (Bcf/d), or 8.2% of total world demand for natural gas. Although 2009 natural gas consumption in its entirety declined by 2.1% in 2009 due to the recession, LNG demand grew by 7.2%. This continues a multi-decadal growth pattern of 6 to 7% per year, far faster than the overall growth in the total natural gas market of 2 to 4%.

The United States imported 1.24 Bcf/d in 2009, or approximately 5.2% of the global trade of 23.5 Bcf/d.

The inclusion of Canada and Mexico raises that volume to 1.67 Bcf/d for slightly over 7% of the worldwide total. North America is thus having a demonstrable effect on the LNG industry, although the rapid expansion of shale gas production has called into question the region's future share of the market.

Paper #1-11: Methane Hydrates

Gas hydrate is a solid, naturally occurring substance consisting predominantly of methane gas and water that occurs broadly in shallow sediments in Arctic regions and on the outer continental shelves. The scientific consensus is that gas hydrate occurs in large volumes in nature and, therefore, has potentially significant, but as yet poorly constrained, implications for both long-range energy supply and for a variety of natural environmental processes. This topic paper provides a status report on ongoing research into natural gas hydrate, with a primary focus on U.S. domestic energy supply potential through the year 2050.

Paper #1-12: Mexico Oil and Gas Supply

Mexico has been a long-term supplier of oil to the United States and partner in natural gas trade. Significant two-way trade in oil and gas occurs along the southern border of the United States. At times, Mexico was the biggest exporter of crude oil into the United States. Recent trends in Mexico's oil and gas sector, both on the supply and demand side, indicated that the dynamic between the United States and Mexico will be quite different than was historically the case. Increasing demand for natural gas in Mexico, particularly in the electricity sector, is likely to encourage Mexico to import more natural gas from the United States and elsewhere. The decreasing production of oil in Mexico will likely restrict Mexico's ability to export oil to the United States in the medium to long term. Additionally, the call on crude oil products in Mexico will further cut into Mexico's potential exports to the United States. Similarly, growing Mexico natural gas demand coupled with slowing growth in Mexico gas production could lead to sustained increases in Mexico's need to import natural gas, with the United States clearly well-placed to supply a significant portion of this gas. These market dynamics will take place in a context where the Mexican government will be assessing its framework for hydrocarbons production, which has historically limited foreign investment.

Paper #1-13: Natural Gas Liquids (NGLs)

Assuming dry gas supply grows from 60 to 110 Bcf/d by 2035, this white paper examines estimated NGL production, NGL infrastructure requirements, processing and refining constraints, as well as supply and demand dynamics for ethane, propane, n-butane, isobutane, and natural gasoline. This white paper provides conclusions on the changing and evolving natural gas liquids market.

Operations & Environment Task Group

Environmental & Regulatory Subgroup Topic Papers

Paper #2-1: Water/Energy Nexus

The exploration, production, and use of oil and gas are dependent on water resources and typically generate water as a byproduct. Water use requirements for oil and gas production vary depending on the source of oil and gas and the region. This paper provides an overview of water requirements for both traditional and newer types of production and recovery techniques, including the quantity of water for hydraulic fracturing for natural gas production and for extraction and processing of oil from oil sands and shale. Estimates are given for water consumption by the different resources and technologies and for the water intensity of transportation fuels. Water quality issues are identified for the water needed for the energy production. In most instances, water is also produced as a byproduct with oil and gas, and the quality and quantity of this produced water varies significantly by region.

Paper #2-2: Regulatory Framework

The regulations associated with the production of oil and natural gas provide a framework to ensure protection of public health, safety, and the environment. This paper traces the evolution of regulations from the early 1900s, when the states' focus was on protecting the production of oil and gas, to the current federal, state, and local concerns and regulatory schemes. Significant events have influenced developments on both a state and federal level. Regulations have to address the concerns of landowners and neighboring communities, and the interest in having production take place. This paper discusses the complex array of concerns beyond the traditional development of the energy resources.

Paper #2-3: U.S. Oil and Gas Environmental Regulatory Process Overview

The U.S. government has various roles in the development of oil and gas, including the leasing of the federal lands and federal mineral rights, and implementation of federal environmental regulations. This paper discusses the laws and regulations regarding, and federal agencies involved in leasing and management of the federal oil and gas leases. The structure and cooperation between federal agencies, state agencies, and private surface owners is described. Several of the more significant federal environmental laws are discussed. The roles of the tribal governments and U.S. agencies in oil and gas development on tribal lands and applicable federal laws and regulations are described. The paper highlights how companies are required to work with various federal agencies and tribal governments, and the processes between the tribes and the EPA national, regional, and program offices policies and plans.

Paper #2-4: U.S. Environmental Regulatory and Permitting Processes

Oil and gas exploration and production is regulated at the federal, state, and local levels in the United States. This paper identifies the major federal environmental laws and regulations as applied to oil and gas exploration and production. This includes the broad categories for air, water, and waste laws and regulations, highlighting many of the specific requirements for different aspects of oil and gas operations. Other federal requirements, such as spill prevention and control, wetlands and wildlife protection, and cultural and archaeological preservation are discussed. The use of water resources by industry and the different regional approaches are described. Examples of some state environmental and wildlife requirements and the role of the states in regard to federal regulations are included. The recent increase in regulation through zoning ordinances or other means by local governments, particularly in urban areas, is also discussed.

Paper #2-5: Canadian and Provincial Permitting and Environmental Processes

Oil and gas development in Canada is regulated by the Canadian federal government and the provincial governments. This paper discusses the processes and applicable regulatory requirements, including environmental, for leasing and exploration through production and reclamation. The government of Canada holdings include lands located in national parks, Indian reserves, and military bases. The Canadian government, through its boards and agencies, regulates international and interprovincial aspects of the oil, gas, and electric utility industries. This includes oil and gas in Frontier lands and offshore areas not covered by provincial/federal management agreements. Most of the mineral rights for natural gas are held by the provincial government (about 80% in Alberta) and the remaining are held by an individual or the government of Canada. The programs in Alberta are described as examples of the role of the provincial governments.

Paper # 2-6: Evolving Regulatory Framework

In response to the recent growth and change in the oil and gas industry, there is greater public interest in the operations. Federal and state regulators have been reviewing existing policies, legislative mandates, and regulations. This paper highlights several of the emerging trends that may reshape and advance the regulatory framework for environmental protection and human safety in oil and gas operations. Water use and discharge, waste management, and air emissions management, among other issues, are discussed.

Offshore Operations Subgroup Topic Papers

Paper #2-7: Safe and Sustainable Offshore Operations

This paper brings together the key elements of each of seven individual topic papers originated in the Offshore Subgroup of the Operations and Environment Task Group and summarizes findings derived. All topical areas in offshore oil and gas development are affected both by technology and policy. Each topical area is affected in specific ways and some effects are common to all topical areas. The sense of each finding is an observation by subject-matter specialists and practitioners on how development is generally conducted in the offshore context and whether significant gaps exist between what currently is done and what might be developed by industry and/or government into an improved best practice.

Paper #2-8: Offshore Environmental Footprints and Regulatory Reviews

In the context of offshore oil and gas development, the environmental footprint refers to the spatial extent of exploration and production activities that may produce perceptible modifications to the sea bottom or sea surface as well as to air, water, or marine life. Minimizing and managing environmental footprints is the shared purview of technology and regulations. This topic report discusses why the prudent development of offshore oil and gas resources requires effective management and safe operation in conjunction with a coordinated regulatory process that can quickly adjust to changing technological capabilities and environmental conditions.

Paper #2-9: Offshore Environmental Management of Seismic and Other Geophysical Exploration Work

This topic report describes the use of geophysical exploration for offshore oil and gas resources and the associated environmental concerns. Offshore geophysical exploration relies heavily on seismic techniques where sound waves penetrate through, and are reflected from, sub-surface geologic structures and rock units. Seismic noise generated by offshore natural gas and oil exploration activities is recognized as a concern for whale populations and other marine life, including fish. Mitigating impacts of seismic noise on marine life can involve attention to performance protocols as well as implementation of upgrades in specific equipment. In the United States, the National Marine Fisheries Service (NMFS) and/or the Bureau of Ocean Energy Management, Regulation and Enforcement (BOEMRE) require seismic operators to use ramp-up (or "soft start") and visual observation procedures when conducting seismic surveys. Other requirements may be implemented by NMFS to place certain seasons and locations off-limits in recognition of vital marine animal activities such as breeding, calving, foraging, or migration.

Paper #2-10: Offshore Production Facilities and Pipelines, Including Arctic Platform Designs

The development of offshore oil and gas reserves requires the construction and installation of facilities to produce and process the oil and gas, the construction and operation of pipelines to transport oil and gas to shore, combined with design requirements to withstand regional environmental conditions. This report explains the purpose and operation of production facilities, which are needed to separate the produced oil from natural gas. Historically, this has required the installation of numerous platforms on structures fixed to the seafloor and located in the immediate proximity of the target reserves. Over the past two decades, technologies have been developed to reduce the number of facilities required, and thus reduce the physical footprints of oil and gas facilities. Pipelines are the safest, most reliable, and economical method to transport oil and gas from offshore waters around the United States. There are approximately 33,000 miles of liquid and gas pipelines on the U.S. Outer Continental Shelf (OCS) and many more miles in shallow, offshore waters and coastal areas. Platforms and pipelines around the world are designed to resist location-specific environmental forces, ranging from hurricane winds, waves, currents, tides, mudslides, earthquakes, and ice.

Paper #2-11: Subsea Drilling, Well Operations, and Completions

One of the remarkable accomplishments of the oil and gas industry has been the development of technology for drilling wells offshore to access additional energy resources. This topic report explains that offshore drilling rigs have become larger and more complex with workers who are more highly skilled, as drilling has extended farther offshore into deeper water. This also requires a mechanically stable offshore platform or floating vessel from which to drill. The types of rigs range from permanent offshore fixed or floating platforms to temporary bottom-supported or floating drilling vessels. A *well completion* involves a set of actions taken to convert an individual borehole into an operational system for controlled recovery of the hydrocarbon resources. A *subsea completion* refers to a system of pipes, connections, and valves that reside on the ocean bottom and serve to gather hydrocarbons produced from individually completed wells and direct those hydrocarbons to a storage and offloading facility that might be either offshore or onshore.

Paper #2-12: Offshore Transportation

This topic report discusses the types of offshore transportation required to develop and maintain offshore oil and gas facilities, and the environmental considerations regarding their use. Offshore service vessels may include crew and supply boats, utility boats, seismic ships, anchor handling tugs, diving support, well stimulation ships, lift boats, and pipe laying vessels. Helicopters are also routinely used to service offshore facilities, primarily for transporting crew and conducting emergency evacuations, but they may transport equipment and supplies, as well. Ocean vessels and helicopters may involve different sets of potential environmental impacts.

Helicopters are associated with air emissions, potential noise disturbances of birds and marine mammals, and also with potential collisions with birds in flight. Ocean vessels are associated with air emissions, liquid discharges, and potential noise disturbances of marine mammals or collisions with marine mammals. In addition, ocean vessels can be associated with the release of invasive (non-native) species and with the disturbance of coastal waterways and wildlife habitats. Noise or potential chemical pollution from vessels is regulated by a collection of federal regulations that are enforced by the United States Coast Guard (USCG).

Paper #2-13: Offshore Well Control Management and Response

This report examines the understanding that well control is a multifaceted endeavor meant to assure commercially successful and environmentally responsible drilling and completion of oil and gas wells and the subsequent operation of such wells after they are placed into production. Well control includes the prevention of uncontrolled hydrocarbon releases ("blowouts") of wells, the contingency plans aimed at preventing oil spills or responding to spills if they cannot be prevented, and the prevention or control of fires that could be fueled by uncontrolled releases of oil or gas. The assembly of pipes, rams, and valves that are applied to blowout prevention at a wellhead is called a blowout preventer (BOP). The primary response objectives in any open water marine spill are to stop or reduce the source of hydrocarbon; recover as much hydrocarbon as possible; protect sensitive ecological, economic, and cultural resources; and speed the removal of unrecovered oil to minimize harm to the ecosystem. Offshore fire control is divided into a succession of topics that include prevention (failure), loss of containment, flammable atmosphere, occurrence of fire, and control of fire.

Paper #2-14: Offshore Data Management

Imagine a data management system that not only provides all regulatory agencies with their needs but also allows lease operators and other interested organizations to access historical information and lessons learned that would help them make decisions for protecting the environment. This topic paper explores the need for a data management system with the attributes to easily provide data and information and also retrieve the same in a manner that is understood and applicable to an end user's need. Although prescriptive practices may help, they cannot ensure that a lesson learned yesterday by one operator can be applied today by another operator. To ensure prudent development of offshore oil and gas resources, improvement in data management systems are needed.

Technology Subgroup Topic Papers

Paper #2-15: Air Emissions Management

Natural gas production, processing, and transmission include activities that result in emissions of regulated air pollutants. Emission sources are broken down into five categories: (1) fugitive dust from vehicular traffic; (2) combustion emissions; (3) glycol dehydrators; (4) sources of methane and volatile organic compounds (VOC; both fugitive and point); and (5) acid gas emissions from sour gas sweetening.

Best practices and appropriate application of emission control technologies can reduce emissions of air pollutants. For every source of air emissions from oilfield and gasfield operations, technologies have been developed to reduce emissions although widespread deployment of those technologies are not always economical for commercial projects. Ongoing challenges are to make retrofits of newer technologies easier and more economical for older systems and to make new technologies more affordable during construction of new systems. The more promising approaches include:

- Reduce road dust by reducing the vehicle miles traveled through consolidating and sharing roads, using existing roads wherever possible, and designing and managing operations to eliminate or reduce trips. Suitable consolidations would include multiple wells per pad and three-phase gathering (gas, petroleum liquids, produced water), which can eliminate the need to haul water and condensate.

- Reduce emissions from combustion sources using fuel cells can be used in lieu of combustion engines. However, additional research and development is needed to make fuel cells economical at the scale needed for oil and natural gas production.

- Reduce emissions from dehydration using an alternative process to glycol dehydrators. In areas where it is applicable, a desiccant dehydrator can substantially reduce methane, VOC, and hazardous air pollutant (HAP) emissions.

- Reduce VOC and methane emissions from storage tanks and loading by reducing the number of tanks and loading demand on trucks. Closed-loop and three-phase gathering systems can reduce the number of tanks in a field and the need for loading into trucks.

- Reduce fugitive emissions from other equipment through an enhanced directed inspection and maintenance (DI&M) program, beginning with a baseline survey and followed by a comprehensive repair plan.
- Reduce acid gas emissions using underground injection of the acid gases where that avenue is available. Otherwise, work to optimize combustion flares where sulfur recovery is not practical.

Paper #2-16: Biodiversity Management and Technology

Exploration and production (E&P) technologies and business practices have the ability, motivation, and demonstrated case histories to drive forward biodiversity protection along with hydrocarbon resource development. Some common polarized viewpoints – such as all development is bad for biodiversity or that biodiversity protection is prohibitively expensive to commerce – are rendered obsolete by many global case studies where development and biodiversity have enjoyed balanced, positive outcomes thanks to thoughtful collaborations among stakeholders.

Technology plays a significant role in the E&P efforts to protect biodiversity in three ways. First, in the area of direct impacts, technology can play a key role in reducing the footprint of E&P operations. Secondly, the science of measuring biodiversity indicators to evaluate the effectiveness of biodiversity protection can be enhanced. Finally, communication technology and practices are key elements to manage secondary E&P impacts to biodiversity. Global citizenship programs and social responsibility programs are a growing element of the cultural evolution that includes health, safety, and environmental protection.

One of the key aspects of biodiversity protection in the E&P industry has been a focus on reducing the operational footprint of E&P activities. Major progress has been made to reduce the number of well pads that must be built to recover available oil and gas resources. Refinements in seismic prospecting techniques have led to many fewer "dry holes," thereby allowing emphasis to shift toward developing hydrocarbon fields with a minimum number of well locations. Smaller-footprint development typically is accomplished with directional and horizontal drilling that allows many wells to be drilled from a single well pad, thus removing the need for multiple locations and associated roads.

Biodiversity challenges will be met with a combination of proactive programs and technology. Social responsibility programs and related biodiversity protection programs will move toward reduced impacts from E&P operations. Biodiversity technology will involve the following:

- Advanced systems of monitoring biodiversity resources and documenting existing resources;
- Advanced systems for planning to protect biodiversity resources;
- Advanced products, drilling techniques, seismic techniques, production techniques all moving toward lowering footprint and negative impacts on biodiversity;
- Developing systems for monitoring the effectiveness of biodiversity protection technology; and
- Advanced systems for recovery, remediation, and offsetting negative impacts to biodiversity resources form E&P activities.

Paper #2-17: Management of Produced Water from Oil and Gas Wells

Produced water is water that is returned to the surface through an oil or gas well. It is made up of natural formation water as well as the uphole return of water injected into the formation (flowback water) that was sent downhole as part of a fracture stimulation (frac) process or an enhanced recovery operation. Produced water is typically generated for the lifespan of a well.

Although produced water varies significantly among wells and fields, several groups of constituents are present in most types of produced water. The major constituents of concern in produced water are: salt content (expressed as salinity, total dissolved solids, or electrical conductivity); oil and grease (identified by an analytical test that measures the presence of families of organic chemical compounds); various natural inorganic and organic compounds (e.g., chemicals that cause hardness and scaling such as calcium, magnesium, sulfates, and barium); chemical additives used in drilling, fracturing, and operating the well that may have some toxic properties (e.g., biocides, corrosion inhibitors); and naturally occurring radioactive material (NORM).

Technologies and strategies applied to produced water comprise a three-tiered water hierarchy: (1) minimization; (2) recycle/reuse; and (3) disposal. Techniques to minimize produced-water volumes are tailored as is feasible for individual locations but disposal must ultimately be addressed. Most onshore produced water is reinjected to underground formations, either to provide additional oil and gas recovery or for disposal, under permits issued by state agencies or regional offices of the U.S. Environmental Protection Agency (EPA). Most offshore produced water is disposed as discharge to the ocean following treatment according to requirements of the National Pollutant Discharges Elimination System (NPDES) as permitted by EPA regional offices. Techniques to minimize produced-water volumes are tailored as is feasible for individual locations. Recycling or reuse of produced water is an ongoing area of focused research and development that has equipped the oil and gas industries with numerous technological solutions that can be tailored for individual applications.

Produced water is an inescapable fact of life for oil and gas production that offers both opportunities and challenges for sustainable recovery of hydrocarbon resources. Based on a review of current practices and future outlooks, key findings are:

- For most forms of oil and gas production, produced water is by far the largest byproduct stream (estimated at 21 billion barrels per year in the United States in 2007) and has given rise to numerous technologies that treat different components of produced water to allow discharge, injection, or beneficial reuse.
- Flowback water tends to be very salty and can contain high concentrations of various chemical constituents. Flowback water is often injected into commercial disposal wells where they are available, although over the past few years, the gas industry has utilized various approaches to collect the flowback, treat it, and reuse the water for future frac operations.
- Many companies have developed technologies to treat produced water and flowback water, in part because this sector has great potential for business growth. Treatment performance has increased and costs have become more competitive.
- Two of the most important emerging and future opportunities for management or produced water through reuse are: (1) treatment and reuse as a water supply for towns, agriculture, and industry; and (2) secondary industrial processes such as extraction of minerals from produced water or repurposing as the working fluid into geothermal energy production.
- Future water management technologies are likely to focus on: (1) reduced treatment costs; (2) reduced air emissions, including CO_2; (3) minimizing transportation; (4) minimizing energy inputs; (5) capturing secondary value from the repurposed water.

Paper #2-18: Oil Production Technology

There are three main categories of hydrocarbons that are liquid phase in their native-state underground reservoirs: conventional oil, heavy oil, and bitumen. That sequence of categories represents substantial increases in density and viscosity and, therefore, in the amount of effort required to produce the petroleum from its reservoir. Conventional oil typically is produced, at least initially, using the natural drivers of flow that are native to the reservoir, including gas pressure or geologic formation pressure. In contrast, heavy oil is resistant to flow, and bitumen typically does not flow, without significant artificial intervention by engineering techniques.

The developmental techniques used for oil production recognize the category of petroleum to be produced as well as the maturity stage of the reservoir to be developed. The three established developmental categories are: primary recovery, secondary recovery, and enhanced oil recovery (EOR). Primary recovery denotes initial stages of production whereas secondary recovery and EOR denote increasing levels of effort to re-work previously produced reservoirs.

Specific findings are:

- Technologies are well-established for producing a variety of petroleum categories (conventional oil, heavy oil, bitumen) through a succession of production stages (primary recovery, secondary recovery, enhanced recovery). For every type of petroleum deposit, there exist technologies to produce at least some fraction of the recoverable oil.
- Likewise, long-proven technologies exist for separating the oil, gas, and water streams that are the typical outputs from petroleum wells. Those technologies include methods for upgrading bitumen to be more transportable and marketable and for making heavy oils easier to refine.

- EOR has been accomplished through several different variations, including polymer water flooding, CO_2 flooding, and solvent flooding, in addition to steam flooding and other thermal methods. Significant industry experience has been accumulated through tailoring EOR technologies and practices for individual petroleum reservoirs.
- Non-conventional petroleum deposits, including oil shales and gas hydrates, comprise the most conspicuous challenges for development of new technologies for safe, sustainable, and economical recovery of the subject hydrocarbon resources. Retorting of oil shales can be viewed as already operational, although the techniques require additional research to reduce input-energy requirements and environmental footprints. In contrast, production of gas hydrates remains highly experimental and significantly distant from operational status.

Paper #2-19: Natural Gas Pipelines Challenges

Expanding the utilization of natural gas in the United States will require development of additional pipeline systems and increased use of existing pipeline infrastructure. In order to achieve this augmented natural gas utilization while avoiding a proportionate rise in adverse pipeline incidents, it will be necessary for pipeline operators to reduce the overall rate of adverse natural gas pipeline incidents.

The two leading causes of significant pipeline incidents, excavation damage and corrosion, have been addressed through improved technologies, although industry emphasis historically has focused on detection as a higher priority than prevention. Detection evolved as the focus of efforts, in part, because the complementary regulatory components needed for prevention have been uneven and not consistently enforced. Prevention requires clear, robust and diligently enforced regulations for all pipelines. But historically, different rules and authorities (federal and state) have existed for different types of pipelines including production (flow) lines, gathering lines, transmission lines, and distribution lines.

Although the Pipeline and Hazardous Materials Safety Administration (within the U.S. Department of Transportation) commonly is regarded as the nexus for pipeline safety standards, other federal agencies with various degrees of authority over pipelines include the Federal Energy Regulatory Commission (FERC), National Transportation Safety Board (NTSB), Environmental Protection Agency (EPA), Bureau of Land Management (BLM), and the Fish and Wildlife Service (FWS). In addition, intrastate pipelines are subject to regulation by individual state commissions. All federal and state regulations either directly or indirectly reference federal statutes under 49 CFR Part 192 (updated 2010).

Excavation damage has been addressed using One-Call Centers ("call before you dig" clearinghouse phone banks), pipeline marking, public education, and rights-of-way patrols by pipeline operators. In addition, special industry-government collaborative programs have been established to track incidents, analyze trends, and develop better preventive measures. Notable special programs include the Common Ground Alliance (CGA) and the Pipelines and Informed Planning Alliance (PIPA). In fact, the CGA Information Reporting Tool (DIRT) is regarded as the best consolidated pipeline-incident database in the United States.

Progress in control of excavation damage must be proactively led by the pipeline industry but with substantial involvement by regulators, excavation contractors, municipal planners and other stakeholders. Solutions must include not only improved encroachment-detection technologies but also establishment and enforcement of regulations to prevent and document incidents of excavation-related damage.

Progress in corrosion control must be led by a pipeline industry commitment to develop and deploy improved technologies for prevention of corrosion as well as for earlier and more reliable detection of corrosion. Solutions must include continuous improvements and adoption of pipeline materials, coatings, and cathodic protection methodologies as well as retrofitted inline inspections for "un-piggable" pipelines in addition to ongoing use of smart pigs.

Paper #2-20: Regulatory Data Management

State oil and gas regulators are required to enforce regulatory requirements, properly track oil and gas activities throughout the well life cycles; and provide data to local governments, other state and federal agencies, as well as the regulated industry and public.

The majority of oil- and gas-producing states currently operate data systems that allow commercial developers to make online reports and also allow stakeholder to make online queries of permit and production data. Many of those systems are based on the Risk Based Data Management System (RBDMS) that was developed in the 1990s through a joint effort of the U.S. Department of Energy (DOE) and the American Petroleum Institute (API).

Operational capabilities of RBDMS are complemented by the State Review of Oil and Natural Gas Environmental Regulations (STRONGER) which is a non-profit, compliance-attainment service to state agencies and which resulted from another 1990s collaboration between the Interstate Oil and Gas Compact Commission (IOGCC) and the U.S. Environmental Protection Agency (EPA).

Online data management systems offer many environmental and economic benefits, including reduction of administrative costs, time and errors associated with manual systems and overall reduction of paperwork and associated wastes.

Even though progress in data management has been substantial, additional investments both by developers and regulators are necessary to achieve the goal of a national oil and gas data portal. Success of the RBDMS and STRONGER initiatives provide examples of how joint government-industry collaborations can accomplish mutually beneficial goals of improved data management.

Paper #2-21: Research, Development and Technology Transfer

Research, product development, and technology transfer comprise different stages in a continuum of progress based on growth of knowledge, improvement of capabilities, and deployment of those capabilities to improve the quality of life. Technology development turns knowledge into actionable goods and services while technology transfer enables permeation of technology from its origins into a wide variety of applications. The ongoing and future importance of oil and gas (O&G) industrial progress requires well-planned and vigorous research and development (R&D) as well as effective technology transfers both to and from the O&G enterprises.

The U.S. Department of Energy (DOE) invests more in basic and applied research than any federal agency other than the National Institutes of Health (NIH) and the National Science Foundation (NSF). But DOE investment in O&G-related R&D is almost entirely through the National Energy Technology Laboratory (NETL), which is the only national laboratory dedicated to fossil-fuel energy. Applied research is carried out by a combination of federal and business organizations, with business operating at twice the level of the federal government. Most O&G-related research is, in fact, funded privately by energy companies.

As a result of federal government legislation from 1980 through 2007, government-sponsored research, development, and technology transfer has increasingly favored collaborations comprising consortia of government, academic, nonprofit, and industry researchers and technologists. As part of that trend, three main initiatives by the DOE have included: (1) Energy Innovation Hubs, involving large numbers of distributed efforts but led by a central institution to integrate fundamental research through commercial technology deployment; (2) Energy Frontier Research Centers, comprising a few dozen senior investigators at multiple institutions and focused on fundamental research to overcome technology roadblocks; and (3) ARPA-E projects, based on small groups at single institutions who focus sharply on high-risk/high-return technologies of near-term payoff. However, none of those three initiatives have emphasized or substantially included O&G-related projects.

Technology deployment includes training of personnel to understand and effectively use new technologies in productive, commercial applications. Indeed, the technology-sociology theory of Charles Perrow holds that the inability of effective training to keep pace with complicated growth of advanced technologies is a contributor to "normal accidents" in all technology-dependent enterprises, including O&G. Even so, there currently is no clearinghouse of information to assess how effectively training is accomplished during the rollout of new technologies during O&G developments.

Accomplishing safe and environmentally sustainable O&G developments, as needed for the nation's energy security during transition to renewable sources of energy, improvements must be made to better include O&G concerns in the nation's overall R&D programs and priorities. Key findings and related recommendations are that:

- Funding is not well aligned with the critical role of O&G among balanced national priorities. The majority of the funds dedicated to hydrocarbon-based energy R&D are focused on carbon capture and sequestration (CCS) rather than on minimizing the life-cycle footprint of O&G development. More attention is needed on sustainable production of petroleum and, especially, natural gas which is an abundant domestic resource.

- Consortia have become the dominant and most beneficial R&D performance platform. A formal infrastructure should be created to facilitate communication between organizations and projects involved in O&G-oriented R&D. Establish an Energy Frontier Research Center or Hub that is focused on low-environmental-impact O&G exploration, processing, and use.
- Communication of R&D progress on energy topics remains ineffective. The federal government could organize an annual Energy Research Summit, which brings together leading researchers working in fields having or having the potential on energy advances, including but not limited to researchers working in energy and in environmental, computer and social sciences.
- Crossover of other technology into O&G is underappreciated. The communication gap should be addressed through the proposed Energy Research Summit or other equivalent clearinghouse.
- Effectiveness of training in O&G technology deployment is not well documented. The federal government should a make meaningful participation in setting standards for training in the industry. There should be an immediate effort to set standards for training in the O&G field, including content, trainee performance levels, along with company processes to monitor the level of the training effort.

Paper #2-22: Siting and Interim Reclamation

Balancing positive and negative aspects of oil and gas developments on environmental and socioeconomic outcomes remains one of the most important and challenging aspects of successful development of oil and natural gas resources. Creating a "win-win" situation for developers and community stakeholders usually requires a larger up-front investment of time and effort by all parties but returns value through smoother and more mutually agreeable outcomes in the long term.

There exist examples where negative impacts of oil and gas development have dominated socioeconomic outcomes but there also are case studies that demonstrate success in planning for, and accomplishing, beneficial outcomes. Prospects for positive outcomes are enhanced by early collaborations among developers and stakeholders, including summation of agreements in written documents that can be referenced by all parties as the benchmarks for evaluating progress and compliance.

Key factors in planning and execution of oil or gas projects with the best levels of community acceptance include context-sensitive designs and a deliberate approach to the balance between socioeconomic benefits and environmental impacts. Plans must be customized individually to accommodate different stages and extents of development as well as different metrics for benefits or impacts. Furthermore, the extent and magnitude of benefits and impacts must be accommodated differently for situations that include rural communities, small towns or villages or cities/urban complexes.

Principal milestones by development stage comprise: (1) exploration/early development; (2) moderate development; (3) large/full-scale development; and (4) post-development production. Main metrics by benefit or impact include: (a) economics (employment and economic activity); (b) population; (c) Housing Services (Community Infrastructure, Facilities and Services); (d) Fiscal (State and Local Government Fiscal Conditions); (e) Attitudes and Values; (f) Quality of Life and Social Conditions; and (g) Community Character. The interplay among the various milestones and metrics must be anticipated according to population density and lifestyle – namely, rural, town, or city environments. Experience has shown that both perceptions and realities can be expected to change almost continuously as development begins, matures, and concludes.

The crucial first step in organizing a successful outcome from the socioeconomic and environmental perspectives is to establish full and open communication among all stakeholders. Modern communication tools, including websites and social media, can be utilized to advantage, although the most important attribute is to make available easily accessible information that is timely and reliable, including an expression of uncertainties where appropriate.

Paper #2-23: Sustainable Drilling of Onshore Oil and Gas Wells

Although not always recognized or appreciated in the public arena, the technologies and practices of drilling oil and gas wells have followed pathways of continuous improvement for many decades. Motivations for improvements have been not only the tightening regulations for environmental protection, but also geotechnical factors that have impeded the cost-effectiveness and production potential of resource-development projects. In almost every case, innovations driven by commercial factors also have brought substantial improvements in environmental safety and sustainability.

A critical area of focus in the drilling process is the proper management and disposal of drilling fluids and waste products. Drilling wastes can include drilling mud, produced water, or other byproducts that can have a harmful impact on the environment in the event of an uncontrolled release. The containment and disposal of the wastes is a main priority.

Specific findings include:

- Extended-reach drilling (ERD), and the associated technologies needed to support it, has contributed toward substantially reduced spatial footprints of drill pads by allowing multiple wells to be drilled and completed from a single pad. Not only is the required acreage needed for drilling significantly reduced, but collateral impacts likewise are reduced, including truck traffic, noise and air emissions. Development of emerging resources, such as shale-gas, will further drive optimization of multi-well pad practices.
- Muds and other fluids required to enable rotary drilling through rocks, are essential enablers of drilling and significant efforts have been made to reduce total fluid volumes as well as to reduce environmental incompatibilities in the fluid compositions. Recycling or reuse of fluids, involving a wide array of water-treatment technologies, has reduced the per-well magnitudes of disposal issues and spillage concerns.
- Construction and operation of drill rigs has benefited from evolving diesel-electric and all-electric options for powering drill-rig motors. Reduced dependence on diesel technologies has led to reductions of noise, petroleum fuel transportation, and storage and air emissions at drill pads.
- Reliable construction and verification of well integrity has improved with advances in cementing technologies and with technologies for downhole logging of cement, casing, and formation properties.

Future drilling and delivery of onshore oil and gas wells will depend upon ongoing cooperation between operators and government regulators to find mutually agreeable solutions to overlapping commercial and environmental issues.

Paper #2-24: Waste Management

Waste management technology is a critical element of successful drilling and production operations. Proper application of waste management principles is required for both efficient drilling operations and environmental protection. Use of any given waste-management approach will continue to be decided by the interplay of economic, technical and operational barriers.

During drilling the largest potential waste stream is used drilling fluids and cuttings that are produced while drilling the well. Options for handling the fluids and cuttings, or "muds," can be organized into a three-tiered water-management or pollution-prevention hierarchy:

- *Tier 1 – Minimization*: The generation of waste is minimized within the processes for drilling a well. This approach is mutually beneficial across all three objectives of minimizing the cost of drilling the well, meeting the technical of the drilling operation, and minimizing the impacts on the receiving environment. When feasible, inhibitive drilling fluids and efficient mechanical solids-control equipment can often save money for operators and results in greater protection of the environment.
- *Tier 2 – Recycle/Reuse*: For the drilling fluid and cuttings that cannot be managed through water minimization approaches, operators can plan for reuse or recycling of drilling byproducts. The most common ways to reuse drilling fluids is to re-deploy them at another drilling location or at least to recover the most valuable constituents of the drilling fluids from one location and move them to another drilling location. Substantial efforts are ongoing to develop economic methods to treat drilling fluids and drill cuttings so they can be beneficially reused in oilfield and non-oilfield applications.
- *Tier 3 – Disposal*: When drilling waste cannot be managed through minimization, reuse, or recycle, operators must dispose of it.

Four main lines of technology have been developed to address drilling waste management, which is centered on handling muds that can include water, oil, and certain chemical additives:

- Thermal treatment uses heat to separate more objectionable components from less objectionable components based on differences in volatility. It is a common process applied to oil-based mud and cuttings where centralized processing is feasible and disposal options are available for the objectionable residuals.
- Injection technology sends treated or untreated waste streams underground into geologic formations that can accept and safely isolate the waste. If geology and regulations permit, injection can serve to substantially simplify waste management while also reducing the surface footprint.
- High-order beneficial reuse on land comprises a combination of bioremediation and re-deployment of treated wastes as soil amendments. It is most readily applied to water-based muds although variations have been developed for some synthetic-based muds.
- Lower-order beneficial includes re-deployment as construction aggregates. The treatment criteria for aggregate use can focus more on stabilization rather than complete remediation so that the stabilized waste is rendered environmentally inert.

Future waste-management technologies and practices most likely will find growing attention on biodiversity protection; changing energy policy with increasing focus on greenhouse gas emissions; progressively more difficult drilling environments such as offshore deep water, Arctic conditions, and extended-reach wells; and reduced landfill space available for waste disposal with implied greater reliance on beneficial reuse options.

Paper #2-25: Plugging and Abandonment of Oil and Gas Wells

Modern regulatory standards in all U.S. jurisdictions require specific provisions for plugging and documenting oil and natural gas wells before they are abandoned. Plugging and abandonment (P&A) regulations vary to some degree among states but all state regulations prescribe the depth intervals that must be cemented as well as the materials that are allowable in plugging practices.

The basic technologies associated with the plugging and abandoning of wells has not changed significantly since the 1970s. Water-based slurries of cement and drilling mud are still the basic materials used to plug most wells, although progress has been made in use of additives to customize the cements and muds for specific types of wells.

Recent shale-gas developments have rediscovered some P&A issues in the forms of older oil or gas wells that never were adequately plugged, but which now pose possible cross-contamination or leakage risks. Furthermore, eventual retirement of uneconomical shale-gas wells must address P&A practices that are specific to issues affecting gas wells and especially horizontal gas wells.

The lack of progress in P&A practices is attributable to absence of a long-term vision, and inattention to corresponding research, that recognizes the benefits of P&A to oil and gas development projects. Specific findings are that:

- Benefits from reduced operational costs and/or increased production, especially in redeveloped, older fields, generally has been underappreciated.
- By plugging wells correctly, future environmental issues, related to fluid or gas leakage, can be avoided and thereby preserve savings otherwise eroded by remediation or litigation costs.
- Research has lagged on materials and methods for plugging wells although advances in technologies for drilling and completion should be applicable to practices in plugging and abandonment.

Onshore Operations Subgroup Topic Papers

Paper #2-26: Life Cycle of Onshore Oil and Gas Operations

This document provides a high level overview of the life cycle of onshore oil and gas from undisturbed ground prior to exploration or drilling, through reclamation and abandonment of a location, and follows the produced oil, gas, and liquids up to refining and transportation of products. The processes in the life cycle of oil and gas exploration and production that influence the environment, and how different environments – particularly the Arctic – require different processes, are described.

Paper #2-27: North American Oil and Gas Play Types

North American onshore oil and gas resources are found throughout the continent contained within the earth by numerous geologic factors.

Each resource location and geologic containment type is considered a "play" and each of these plays is unique. Due to this diversity, it is important to understand the drivers and constraints that control the extraction of the resource from each location. Specific technologies are essential to some plays, but hinder obtaining the resource in others, a distinction that is important to optimize recovery of North American resources.

Task Group White Papers

Paper #2-28: Environmental Footprint Analysis Framework

All energy source development can cause positive and negative environmental and community impacts, including those affecting air, water, land, wildlife and habitat, visibility, and community or quality of life resources. The combined effects of such environmental impacts from production to end-use are defined as the environmental footprint (EF) of the energy source. It is important that those making decisions affecting choices among energy sources take into account science-based, consistent, comparative information on the environmental impacts of each energy resource. EF can provide decision makers this environmental information to weigh against social, political and other considerations to select the energy resources appropriate for a specific circumstance consistent with national, regional and local priorities.

An equitable definition and comparative analysis of the EF for each of the energy options requires a complex methodology that must incorporate a number of factors, including consistent and compatible metrics to facilitate comparative analyses, and recognition that not all criteria for comparison are quantitative so that qualitative or semi-quantitative data must be analyzed. In addition, it has been found that some of the information and data needed for an EF analysis may not exist or exist in a form that is not easily accessible.

EF analyses can be informative and instructive. An objective understanding of impacts will enhance the decision-making process. The value of conducting an EF analysis includes support for planning and should be done in a transparent fashion involving interested stakeholders. That approach can increase an understanding of the issues and institutionalize objective analysis in public and private decision making.

Paper #2-29: Hydraulic Fracturing: Technology and Practices Addressing Hydraulic Fracturing and Completions

Hydraulic fracturing has become an integral part of oil and gas development across North America. Use of hydraulic fracturing can provide an effective means to lessen environmental impacts from the development of oil and natural gas resources, and makes the recovery of resources economically feasible. Application of this technology increases production while dramatically reducing the environmental footprint of oil and gas development and commercializing historically undevelopable resources. Today, when the technology is used on up to 95% of new wells, hydraulic fracturing design is continuously refined and modified to optimize fracture networking and to maximize resource production.

While the technology and practices for hydraulic fracturing are similar across all resource types, variations in design and impacts occur among locations and resource types. Potential environmental impacts associated with hydraulic fracturing include air emissions, surface water and ground water withdrawals, produced water management, surface impacts, biological impacts, vibrations, noise, and visual and community impacts. As hydraulic fracturing technology has progressed, operators and regulators have identified and developed extensive mitigation measures to alleviate potential adverse impacts. New advances in the areas of green chemistry, water management, hydraulic fracturing design and job management, and success tracking are expected to enhance both the environmental and economic performance of this technology in the future.

As hydraulic fracturing has been applied to unconventional resources in previously undeveloped areas, it has become the focus of many regulatory modifications at the federal, regional, state, and local levels. Although hydraulic fracturing is currently regulated at all of these levels (most prominently the state), many groups and individuals have called for additional federal regulation. The U.S. Environmental Protection Agency is currently studying hydraulic fracturing's potential impact on drinking water resources.

Demand Task Group

Subgroup Topic Papers

Paper #3-1: Power Generation Natural Gas Demand

The expectation is that there will be a significant shift in the U.S. power generation sector over the coming years, with natural gas fired generation increasing its market share. The positive change in our gas supply situation and prospects for longer term competitive natural gas prices occurs at the same time as the United States is faced with an aging infrastructure of older, and often less efficient, fossil (thermal) plants, many built at the time the interstate highway system was initially conceived and constructed. These facilities typically release more of the criteria pollutants than a modern gas-fired facility. They also face a gauntlet of new regulations, perhaps so many that a large number of these facilities might be considered candidates for early closure as the solutions to meet these new environmental requirements make the operation of the plants uneconomic. Moreover, the most recent developments in power technology are designed primarily for gaseous fuel operation – the gas-turbine-powered Natural Gas Combined Cycle (NGCC) plants. NGCCs are highly advanced and very efficient. Because they can be essentially factory produced, they also have the lowest capital costs ($/kW) available. NGCCs also have the flexibility to operate efficiently over a wide range of utilization rates and complement the growing reliance on intermittent renewable generation sources. In sum, given that we see no excessive economic or regulatory hurdles to overcome, the prospects for a substantial expansion of gas generation in the United States is a benefit as well as a practical solution to mesh with other power generation sources available.

Paper #3-2: Residential and Commercial Natural Gas and Electricity Demand

Residential and commercial energy demand since 1970 has been driven by growth in electricity sales and related system losses, in turn driven by increasing electricity use per customer. In 2010, energy system losses from the generation, transmission, and distribution of electricity represented approximately half of all the energy consumed in the residential and commercial sectors. These factors are expected to continue driving energy consumption upwards over the long-term in these sectors. In contrast to electricity, the consumption of natural gas in the residential and commercial sector has remained level since 1970, as efficiency improvements have contributed to lower gas use per customer, thereby offsetting growth in demand despite a 71% increase in the total number of natural gas customers. To assist in optimizing energy resource utilization, energy usage and efficiency should be measured and assessed across the entire energy chain in order to maximize the value of energy resources. Energy efficiency improvements have weakened the link between economic and population growth and energy demand and there remains significant technological potential for efficiency improvements for both natural gas and electricity to reduce long-term demand. However, significant investment and R&D in new residential and commercial end-use technologies and applications will be required to realize these potential improvements, particularly on the gas side, which has already demonstrated major gains. The direct use of natural gas equipment in residential and commercial applications has demonstrated success in economically reducing carbon emissions and there is considerable potential in the Northeastern United States to reduce greenhouse gas emissions and lower energy usage by displacing fuel oil with natural gas as a primary heating fuel. It would be prudent to focus increased attention, particularly over the next 10–20 years, on expanding the efficient use of natural gas in the residential and commercial sectors.

Paper #3-3: Industrial Natural Gas and Electricity Demand

Industrial consumers will play an increasingly important role in encouraging increased gas supply by demanding more as prices go down and volatility eases. In 2009, industry used 32% of the natural gas consumed and 24% of the electrical power produced with 23% of the power used generated from natural gas increasing overall gas usage by industry (direct and indirect) to 38%. History shows that when natural gas is plentiful, affordable, and reliable, industry grows stimulating local investment, creating jobs, and strengthening the U.S. industrial and economic base. Over the last decade, natural gas, petroleum, and electricity price increases contributed to plant shutdowns, decreased investment and a loss of over 5 million U.S. manufacturing jobs. Natural gas is a key raw material for chemicals and manufacturing. U.S. companies use natural gas as both a fuel source and a feedstock to create high-value, high-margin products that are used every day. Industry uses fossil fuels efficiently to create jobs. This is good for the economy and also good for the environment. When natural gas is used as a feedstock or is embodied in energy-intensive products, the value is leveraged over and over, resulting in a tremendous value-added proposition for the economy and the environment. This is in contrast to the one-time use created when natural gas is used as fuel in a power plant, truck, or automobile.

Paper #3-4: Transmission Natural Gas Demand

The North American natural gas lease, plant, pipeline, and distribution ("Natural Gas Transmission") system is an intricate network that reliably and efficiently delivers significant quantities of natural gas from the wellhead to end-users throughout the entire continent. This elaborate system is the culmination of decades of investment by countless participants and combines legacy components with state of the art improvements. Most of the natural gas infrastructure capacity added in the last 30 years has been to deliver new supply to existing load or to load that has shifted regionally. Today, lease and plant fuel consumption for the United States is about 3.5 Bcf/d, or 6%, of dry gas production while pipeline and distribution fuel consumption is about 1.7 Bcf/d, or 3%, of natural gas demand. Total natural gas transmission fuel (lease and plant, pipeline and distribution) is about 5.2 Bcf/d, or 8.5%, of throughput (total natural gas demand). These percentages have varied little over time and are not expected to do so in the future. It is important to note that each lease, plant, pipeline, and distribution supply and delivery system is unique. Consequently, a "one-size-fits-all" approach to seeking efficiency improvements will not work. Due to this reality, the greatest opportunity for maximizing either economics or efficiency is in the initial design and construction phase of a major facility.

Task Group White Papers

Paper #3-5: What Past Studies Missed

In 1992, 1999, and 2003 the National Petroleum Council (NPC) conducted three major studies of natural gas supply and demand. The purpose of these previous NPC studies were to identify measures to promote efficient natural gas markets and to propose a menu of policy choices focused upon advancing the environment, energy security, and economic well-being. An evaluation of these studies of the NPC identifies the "big" things that past studies have missed; however, past projections of the demand fairway (or range of projections) for natural gas were generally accurate enough to be useful for testing policies and indicating necessary increments to supply. Though increasing reliance upon unconventional gas was featured in each NPC study, the focus was on coalbed methane and tight sands formations while the potential role of shale gas was limited. While the models employed to prepare the studies worked reasonably well, assumptions about price of oil and gas, GDP growth rates, and trends in energy intensity (or energy efficiency) were not borne out by actual trends in later years. There are often future surprises that change the landscape from what a study assumed. The inherent uncertainty of a single reference case was recognized from the start and led to preparing multiple scenarios in the 1992 and subsequent NPC natural gas studies, resulting in a demand fairway bounded by a maximum and minimum case useful for stress testing the industry's ability to meet demand and identifying policy recommendation commensurate with the challenges facing the industry. For the 2007 NPC study, a survey of existing forecasts, or "a study of studies," was used to broaden coverage and bring a wider array of assumptions and results into consideration.

Paper #3-6: Natural Gas Exports to Mexico

The current Secretaria de Energía – the Mexican Ministry of Energy (Sener) – plan shows roughly 500 million cubic feet (MMcf/d) of net imports from the U.S. by 2024. The average for 2009 was over 800 MMcf/d. If we assume that Petróleos Mexicanos (Pemex) produces natural gas to the level forecast by Sener, that liquefied natural gas is imported to Mexico using a 50% capacity factor for their 2.0 Bcf/d of regasification capacity, and that most of the new power capacity additions are natural gas-fired, then the amount of natural gas to be imported from the United States by Mexico by 2024 is closer to 2.5 to 3.0 Bcf/d. This is consistent with the Energy Information Administration's Annual Energy Outlook 2010 Reference Case that projects U.S. exports to Mexico at 2.33 Bcf/d in 2025.

Paper #3-7: Liquids Demand

For 2010, the transport and industrial sectors account for 72% and 22%, respectively, of total U.S. liquids demand with the residential and commercial sectors accounting for about 2% and the power sector about 1%. The study of transportation fuels was not part of the North American Resource Development (NARD) study, rather transportation issues are addressed in the NPC Future Transportation Fuels (FTF) Study, which will not be completed until after this report is published. Thus liquids demand is obtained from the Energy Information Administration's Annual Energy Outlook 2010 (AEO2010) cases. In AEO2010, U.S. liquids demand increases from 40.6 quads in 2010 to 42.0 quads in 2035, with a range of 37.5 quads in the Low Macroeconomic case to a high of 46.8 quads in the High Macroeconomic case. The transport and industrial sectors show potential for growth in demand while the residential, commercial, and power sectors show decreasing demand in all three cases.

Carbon and Other End-Use Emissions Subgroup

Subgroup Topic Papers

Paper #4-1: Baseline and Projections of Emissions from End-Use Sectors

In this report, the Carbon and End-Use Emissions Subgroup describes the current and projected ranges for emissions of air pollutants and greenhouse gases (GHG) in the U.S end-use sectors. As part of its efforts, the subgroup reviewed multiple publicly available reports on historical and projected U.S. emissions and concluded that the Energy Information Administration's Annual Energy Outlook 2010 provides the best source of emissions projections for GHGs and power sector sulfur dioxide (SO_2), nitrogen oxides (NOx), and mercury.

Paper # 4-1a: Addendum: GHG Constrained Cases

In this addendum, the Carbon and End-Use Emissions Subgroup assessed the impacts of GHG constraints on the economy, and specifically, natural gas demand. The subgroup examined the relationship of GHG constraints and the larger gas supplies from unconventional sources.

Paper #4-2: Life-Cycle Emissions of Natural Gas and Coal in the Power Sector

This paper reviews the life-cycle analysis (LCA) of emissions from natural gas and coal in the power sector in the U.S. using updated 2009 EPA greenhouse gas (GHG) emissions inventory, global warming potential for methane from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4). The NPC finds that the life-cycle GHG emissions (expressed as lbs. CO_2e/million Btu) for natural gas are about 35% lower than coal on a heat input basis. For efficiencies typical of new coal- and natural gas-fired plants in the United States, the natural gas-fired plants are about 50–60% lower in GHGs (expressed as lbs. CO_2e/MWh) than a coal plant on a life-cycle basis. The NPC estimates the total methane emissions from the U.S. natural gas systems to be 2.2% of the total gross production. Other studies have shown that natural gas combined cycle plants have 99% lower SO_2 and mercury emissions and about 82% lower NOx emissions relative to a pulverized coal unit on a life-cycle basis. Greater penetration and applications of various EPA Gas STAR technologies provide a proven avenue to reduce methane emissions.

Paper #4-3: Natural Gas End-Use GHG Reduction Technologies

This working paper identifies natural gas end-user technologies that could reduce greenhouse gas (GHG) emissions below 2030 projections on an economy-wide and sectoral basis. The research team that prepared this report distilled data from 35 publicly available academic and industry studies that quantified the volume and cost of projected GHG emissions. Quantitatively incomplete studies and studies that did not differentiate impacts on a technology-specific basis were excluded from consideration if researchers could not obtain additional data from study authors or independent industry experts. The final study sample set consisted of 15 studies detailing 15 end-user technologies in 32 cost-volume data points. For technologies where multiple data points were available, researchers computed weighted averages of cost, volume, and a proxy index for "uncertainty" (the variation in results across different studies).

Paper #4-4: Impact of EPA Regulations on the Power Sector

This paper specifically reviews existing literature related to the impact of upcoming EPA rules on coal-fired power plants and addresses the range of potential emissions reductions and increased natural gas demand associated with replacing the coal-fired generation with gas-fired generation.

Paper #4-5: Policy Options for Deployment of Natural Gas End-Use GHG Reduction Technologies

Given the abundance of natural gas supplies in the United States, natural gas can play a significant role in the energy consumption patterns of the country. Consistent with Secretary Chu's directive to the National Petroleum Council, this paper identifies policy options that allows for accelerated deployment of natural gas and associated technologies in various end-use sectors with the goal of reducing greenhouse gas emissions and maintaining energy and economic security. The paper finds that if the United

States wants to adopt an energy and environmental strategy that enhances the role of natural gas in the economy, it must work simultaneously and strategically on many policy fronts. In general, increased natural gas supplies, along with new environmental regulations, make natural gas an attractive option as a fuel in the end-use sectors, especially the electric power sector in the near- to midterm, particularly as a replacement fuel if there are significant coal plant retirements. Simple and seemingly attractive environmental policy approaches, such as adopting a price on carbon, must play a central role but will not by themselves realize the goals laid out by the Secretary for this study. Under a scenario requiring deeper, long-term emission reductions (e.g., 80% reduction of GHGs by 2050 from a 2005 baseline level), the contribution that natural gas would make to a lower carbon fuel mix may be less certain.

Macroeconomic Subgroup

Subgroup Topic Papers

Paper #5-1: Macroeconomic Impacts of the Domestic Oil and Gas Industry

This paper reviews recent studies and data sources regarding the impact that the domestic oil and gas industry has on U.S. gross domestic product, employment, labor income, and local, state and federal government revenue. In all of these categories, it is clear that the oil and gas industry is a significant contributor to the U.S. economy. In addition to supplying the critical feedstocks for many everyday consumer products, the oil and gas industry employs millions of Americans directly and supports the addition of millions of jobs needed to supply the industry and its employees with goods and services. Federal, state and local governments benefit from tax and royalty revenue generated by oil and gas activity in their respective jurisdictions.

Paper #5-2: Commodity Price Volatility

In this paper, we address commodity price volatility and the related effects on the broader economy, stock returns, and producers and consumers of oil and gas. We also deconstruct commodity price volatility to determine how commodity prices react to specific factors. Finally, we provide a brief overview on the correlation between oil and natural gas prices.

Paper #5-3: U.S. Oil and Gas Industry Business Models

Different countries have taken different approaches to the development of their natural gas and oil resources. In the United States, our system of private sector companies interact with private and public mineral owners, and the governmental bodies with regulatory authority, to determine who has the right to develop, produce, and market our natural gas and oil. The business model employed by natural gas and oil companies in the United States has adapted to the unconventional resource plays that, when compared to conventional resource development, are more broadly distributed geographically, have a greater areal extent, and are more wellbore, service sector and people intensive. This paper details this business model and explores the tools available to the Federal government to promote its policy objectives with respect to natural gas and oil development.

STUDY SURVEY DATA AGGREGATIONS

To ensure a broad review of current knowledge, the study groups examined a broad range of available analyses on North American oil and gas resources, supply, demand, and industry operations. To supplement these publicly available analyses, the NPC conducted a broad survey of proprietary energy outlooks. As an integral part of this process, the public accounting firm Argy, Wiltse & Robinson, P.C. received, aggregated, and protected the proprietary data responses. The aggregated data used by the study groups is available electronically on the NPC website (http://www.npc.org).