Quadrennial Technology Review 2015

Chapter 7: Advancing Systems and Technologies to Produce Cleaner Fuels

Technology Assessments

Bioenergy Conversion

Biomass Feedstocks and Logistics

Gas Hydrates Research and Development

Hydrogen Production and Delivery

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Offshore Safety and Spill Prevention

Unconventional Oil and Gas

U.S. DEPARTMENT OF ENERGY

Quadrennial Technology Review 2015

Offshore Safety and Spill Prevention

Chapter 7: Technology Assessments

Introduction and Background

The global oil and natural gas industry has responded to growth in international energy demand by developing new technologies for finding and producing oil and natural gas from deposits that are increasingly technically challenging to develop, including those found in the deeper water areas along continental shelves. The offshore environment is complex and challenging, characterized by meteorological, oceanographic, and hydrologic unknowns that require increased effort to reduce development risk. For these reasons, ensuring these valuable national resources are developed in a safe and sustainable way is a crucial research and technology development focus. This document provides a discussion of major challenges, an assessment of the state of the art, and key technology and research opportunities related to the safe and environmentally responsible development of the nation's offshore resources.

Offshore Oil and Gas Resource Base

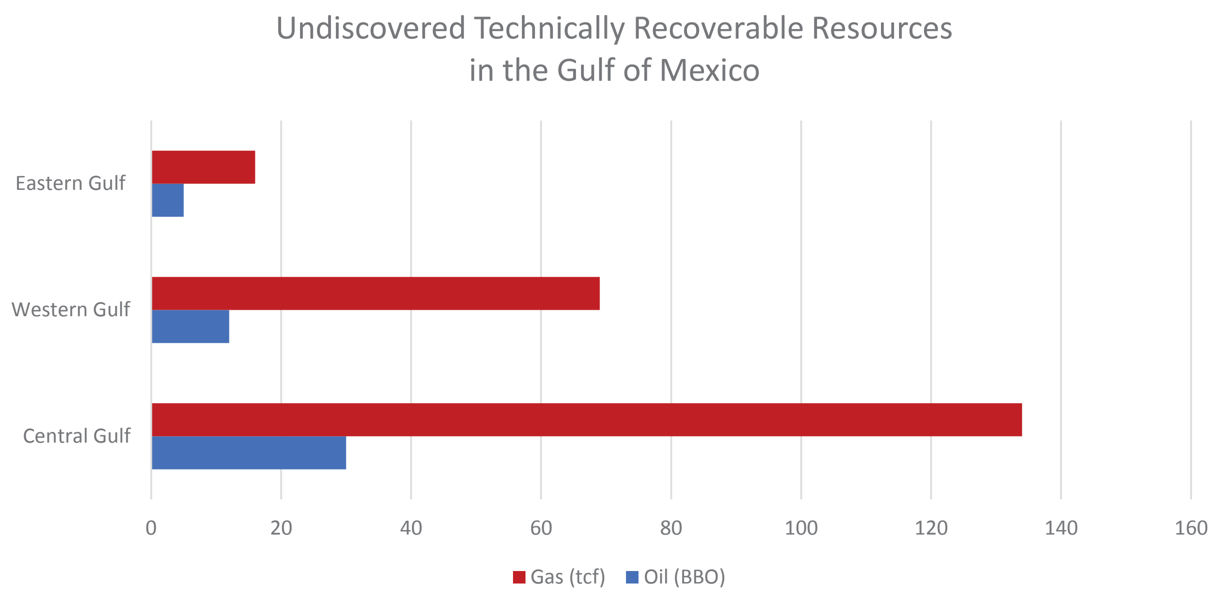
Offshore oil and natural gas resources, primarily from the Gulf of Mexico, have played a significant role in U.S. energy supplies for decades. As worldwide oil and natural gas demand grows, offshore resources will necessarily remain a key contributor to America's supply of oil for the foreseeable future. Federal offshore resources account for over 15% (about 5 billion barrels) of total proved domestic crude oil reserves.[1] In 2013, federal offshore production accounted for about 17% of total domestic crude oil production.[2] Also in 2013, federal offshore natural gas reserves made up over 2% (approximately 8 trillion cubic feet) of total U.S. dry natural gas proved reserves (approximately 338 trillion cubic feet)[3] and provided over 4% of total annual dry gas production.[4]

Gulf of Mexico

The Gulf of Mexico (GOM) is one of the most important locations for U.S. offshore resource production. As shown in Figure 7.F.1, the U.S. Department of the Interior's Bureau of Ocean Energy Management (BOEM) has made the following estimates for the undiscovered, technically recoverable resources in the GOM:[5]

- Central Gulf – more than 30 billion barrels of oil (BBO) and nearly 134 trillion cubic feet (tcf) of natural gas
- Western Gulf – more than 12 BBO and 69 tcf of natural gas
- Eastern Gulf – more than 5 BBO and 16 tcf of natural gas

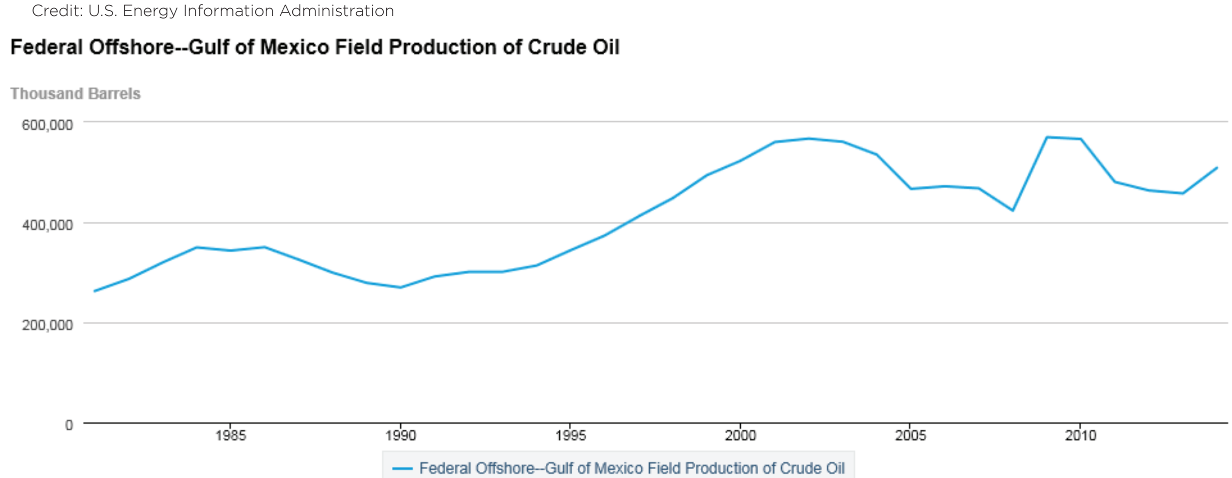
Figure 7.F.1 Undiscovered Technically Recoverable Resources in the Gulf of Mexico. Undiscovered technically recoverable resources are resources that are able to be produced with today's recovery technology, without regard to economic cost, primarily outside of known fields. In contrast, reserves are resources that are able to be produced from known reservoirs, with current technology and regulation, and under today's economic conditions, with reasonable certainty. Data from BOEM, Assessment of Undiscovered Technically Recoverable Resources, 2011.[5]



This area produces approximately 96% of all U.S. offshore oil[7] and about 93% of offshore natural gas.[8] Figure 7.F.2 shows the oil production from the Gulf of Mexico since 1980, indicating its historic importance in production. According to the U.S. Energy Information Administration (EIA), over 45% of total U.S. petroleum refining capacity is located along the coast of the Gulf of Mexico, as well as 51% of total U.S. natural gas processing plant capacity.[9]

Figure 7.F.2 Historical GOM offshore oil production[6]

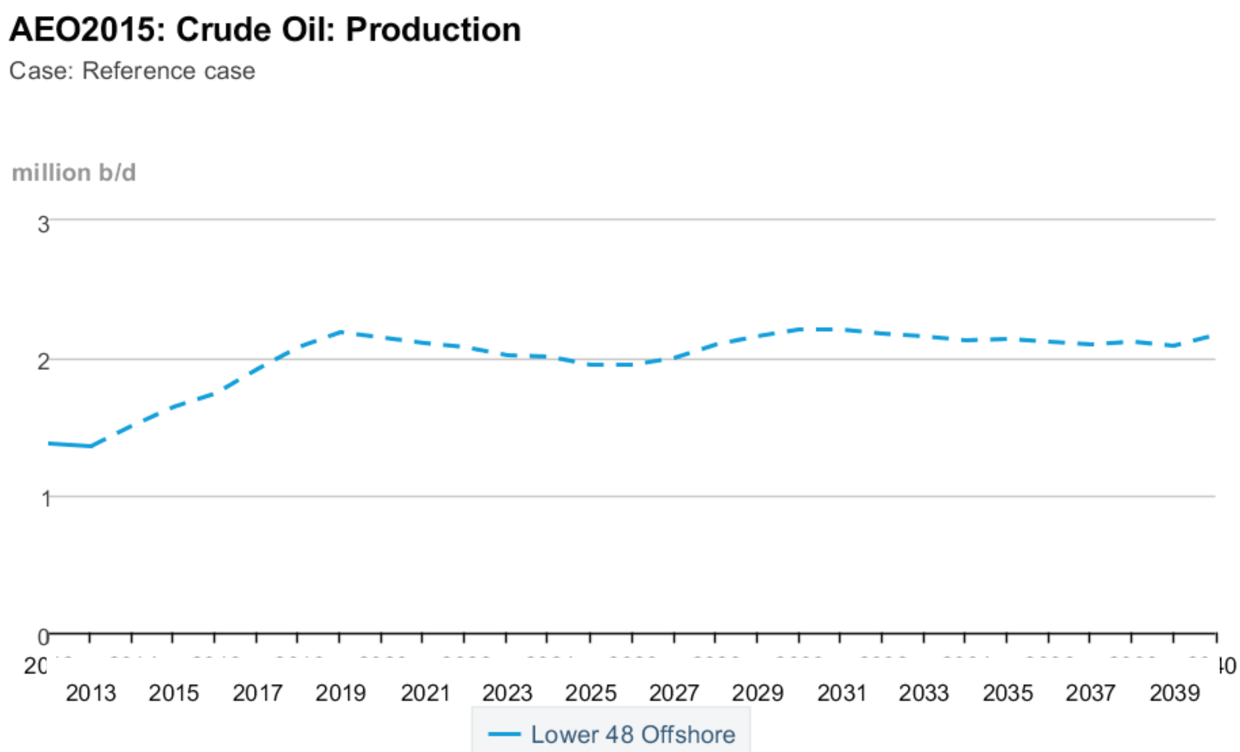
Credit: U.S. Energy Information Administration



As shown in Figure 7.F.3, the EIA Annual Energy Outlook 2015 (AEO2015) projects that continued development of crude oil resources in the GOM will remain an important component of domestic crude production.[10] In the offshore production areas of the lower 48 states, crude oil production is projected to fluctuate generally between roughly 1.4 million and 2.2 million barrels per day through 2040.[11]

Figure 7.F.3 Federal lower 48 offshore crude oil production projections.[12]

Credit: U.S. Energy Information Administration



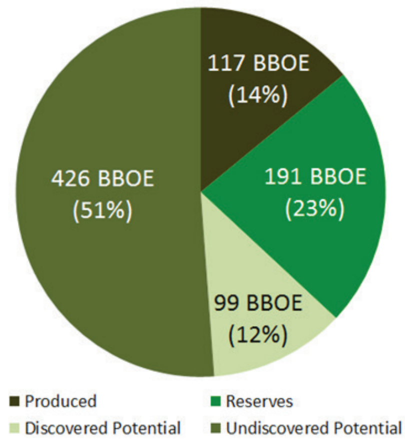
Arctic

The Arctic region is another area with potentially large oil and gas resources (Figure 7.F.4). The Arctic holds an estimated 90 billion barrels of the world's undiscovered conventional oil resources and about 30% of its undiscovered natural gas resources, according to the U.S. Geological Survey (USGS).[13] However, the Arctic environment is technically challenging and costly to develop.

A core component of the administration's *National Strategy for the Arctic Region (Strategy)* includes responsible development of Arctic oil and gas resources to ensure energy security.[14] This strategy notes the sizeable oil and natural gas resources and their integral role in meeting U.S. energy needs. Furthermore, the Strategy notes that continued responsible development of Arctic oil and gas resources aligns with the President's "all of the above"[15] energy approach to reduce reliance on imported oil and strengthen our energy security.

Figure 7.F.4 Global Arctic Conventional Endowment. Undiscovered Potential volumes are based on the USGS 2008 Circum-Arctic Resource Appraisal. Discovered Potential, Reserves, and Produced values are provided by Information Handling Services (IHS) and are approximate as of the end of 2013.[14]

Credit: National Petroleum Council



Note: BBOE (billion barrels of oil equivalent) is a unit of energy that combines oil and natural gas reserves and production into a single measure based on the energy released by burning one barrel of crude oil.

Technical Challenges

Given the growing importance of deepwater and ultra-deepwater production worldwide, it is imperative that U.S. producers and technology developers maintain a focus on technologies that can help to minimize environmental impacts as industry operators move into deeper and deeper water around the globe.

Gulf of Mexico

Deepwater production in the Gulf of Mexico began in 1979 with Shell's Cognac Field. Since then, industry has been leasing, drilling, and producing from increasingly deeper waters and more complex environments. Industry continues to pursue development of resources in deeper water, as evidenced by Shell's ongoing Stones Project, which is planned to produce from a record water depth of approximately 9,500 feet.[16] Technology innovation, was and continues to be a key factor in reducing risk so that offshore resources can be safely and reliably produced from increasingly challenging environments.

Water depths of greater than 1,000 feet are generally classified as "deepwater." Water depths of greater than 5,000 feet are classified as "ultra-deepwater" (UDW). Deepwater and ultra-deepwater environments create unique production challenges compared to those in shallower water, and require specialized technology in order to achieve safe and economically sustainable production, while minimizing environmental impacts.

While technology development has made it possible to produce oil and gas from deepwater and ultra-deepwater resources, technical challenges remain. The surface infrastructure must be able to withstand strong currents, storms, and hurricane forces. As operators drill down from the surface, they can encounter unpredicted geohazards, including faults and pressure differentials. Pressure management is important to prevent uncontrolled influx into the wellbore, while not damaging the formations. It is also important, but challenging, to acquire high-quality, fast, reliable data while drilling, so that an operator can know as early as possible when hazards are encountered. The rock formations through which an operator drills, including the final reservoir, could be under extremely high pressure and high temperature. The materials (metallic casing, seals, cement, etc.) used in the construction of the well must maintain integrity in the high-pressure, high-temperature subsurface environment to ensure zonal isolation between the wellbore and the surrounding rock formations. Finally, the people working on these drilling projects, especially those on the rig floor, must be able to correctly understand and quickly react to data received at the surface during any stage in the drilling process. While many challenges are similar both onshore and offshore, the relatively remote location, the ocean surface environment, and the necessity of placing equipment hundreds of feet below sea level mean special technology solutions are necessary for the offshore environment. The existence of these challenges, and the importance of solving them, was brought to the attention of all with the *Macondo* incident.

On April 20, 2010, a blowout occurred in the Gulf of Mexico. Results from the many committee meetings and hearings that followed the *Macondo* incident reinforced the idea that better technologies and safety practices will be required to reduce risk in both operations and facilities in the UDW environment.

The *Macondo* Incident

On April 20, 2010, the *Macondo* well-- located about 50 miles from New Orleans over 5,000 feet of water with a pay depth of over 18,000 feet subsea-- blew out, costing the lives of 11 men and spilling more than 4 million barrels of crude oil into the Gulf of Mexico.[17] The root causes identified by the President's Oil Spill Commission[18] were associated with zonal isolation during cementing and the failure to create a competent barrier to uncontrolled flow. Other risk factors contributing to this disaster were associated with well monitoring equipment on the *Deepwater Horizon*, including data displays, and the lack of attentiveness to the risk resulting from deviation from the original well construction design.

The President's Oil Spill Commission analyzed this blowout and noted a string of challenges and poor decisions that may have contributed to the blowout, including loss of control of the fluids entering the wellbore and decisions to deviate from the original drilling program.[19]

> *"The immediate causes of the Macondo well blowout can be traced to a series of identifiable mistakes made by BP, Halliburton, and Transocean that reveal such systematic failures in risk management that they place in doubt the safety culture of the entire industry."*
>
> **OIL SPILL COMMISSION REPORT [page vii]**[20]

The Ocean Energy Safety Advisory Committee (OESC) was chartered to advise the Secretary of the Interior on a variety of issues related to offshore energy safety.[21] The Ultra-Deepwater Advisory Committee (UDAC) advised the Secretary of Energy on the development and implementation of DOE's ultra-deepwater-related research and development program.[22] Both advisory groups issued recommendations related to the *Macondo* incident and the related findings of the President's Oil Spill Commission.[23]

Generally speaking, the UDAC recommended the Department of Energy focus on spill prevention technologies (including, for example, wellbore stability and advanced monitoring), safety and environmental issues (including, for instance, improving knowledge of behavior of materials in extreme environments to ensure zonal isolation), and risk assessment, which would include human-machine interactions. In the area of spill prevention, OESC made many similar and additional recommendations for necessary technology improvements, including—but not limited to—improving automated well safety systems, implementing best available and safest technologies (BAST), improving early kick detection, advancing monitoring of wellbore integrity, enhancing shearing technology, and improving BOP design. Advancing knowledge in these areas, among many others, may have helped prevent or mitigate the impacts of the *Macondo* incident. In response to the complex challenges that culminated in the *Macondo* incident, the related findings of the President's Oil Spill Commission, and the recommendations of advisory groups, the DOE refocused its ultra-deepwater research program from that of maximizing the value of these national resources and increasing energy security to instead focus on safety, spill prevention, and environmental sustainability of oil and gas development in ultra-deepwater.

OESC Recommendations

Historically, the OESC has issued recommendations in the following areas:[21]

- **Spill Prevention,** including improving automated well safety systems, implementing best available and safest technologies, improving early kick detection, advancing monitoring of wellbore integrity, enhancing shearing technology, improving BOP design, and several other recommendations.
- **Spill Containment,** including holding a workshop on system readiness for containment response.
- **Spill Response,** including evaluating the need for Arctic oil spill equipment deployment exercises, coordinating with the Interagency Coordinating Committee on Oil Pollution Research, and conducting and supporting oil spill response research and technology development.
- **Safety Management Systems,** including emphasizing measurement of the safety culture and reporting safety performance indicators, and reviewing inspection/audit practices for safety management systems.
- **The Arctic,** including developing specific regulations or standards for prevention, safety, containment, and response preparedness for the unique Arctic operating environment.

UDAC Recommendations

In general, UDAC's recommendations on the research focus of the Section 999 Ultra-Deepwater Research Program included the following:[22]

- **Spill Prevention**
  - Mitigate leakage in and around boreholes, and investigate long-term borehole stability, plugging, and abandoning technology, and long-term monitoring.
- **Health, Safety, and Environmental Issues**
  - Greater attention should be devoted to environmental issues, including how the environment affects infrastructure, and how infrastructure affects the environment.
- **Hazards, Risk Assessment, and Smart Systems**
  - Determine the present scope of systems that alert operating personnel to potential drilling hazards, including the human factors related to these systems, and continue work on hazards and risk analysis.
  - Add or improve the instrumentation at the wellhead and in the well to measure key parameters.

Arctic

Arctic oil and gas has the potential to play a key role in meeting future energy demand. Many of the same challenges and advances in technology for offshore Gulf of Mexico are applicable to the Arctic. However, the complex Arctic environment poses additional key challenges associated with the development of oil and gas resources. As the National Commission on the BP Deepwater Horizon Oil Spill and Offshore Drilling stated in its January 2011 final report:

> *"The Alaskan Arctic is characterized by extreme cold, extended seasons of darkness, hurricane-strength storms, and pervasive fog—all affecting access and working conditions. The Chukchi and Beaufort Seas are covered by varying forms of ice for eight to nine months a year. These conditions limit exploratory drilling and many other activities to the summer months. The icy conditions during the rest of the year pose severe challenges for oil and gas operations and scientific research. And oil spill response efforts are complicated year-round by the remote location and the presence of ice, at all phases of exploration and possible production."* [p. 302][24]

The 2015 National Petroleum Council (NPC) reviewed the relevant research and technology opportunities, and made recommendations for additional research and technology development.[25] According to the NPC, the presence of surface ice is the key environmental characteristic that distinguishes the Arctic from other operating environments. However, water depth and length of the open water season are also key characteristics that pose technical challenges. While a substantial amount of information that characterizes the ecology of the Arctic is available, additional information could be useful in other areas including ice and climate fluctuations and the transport behavior and environmental impacts of oil released under sea ice.[26]

NPC Recommendations

In the area of oil spill prevention and source control, the NPC made the following recommendations:[27]

- "Industry and regulators should work together with government agencies and other stakeholders to synthesize the current state of information and perform the analyses, investigations, and any necessary demonstrations to validate technologies for improved well control and containment.
  - The benefits and risks of advanced control and containment technologies should be assessed relative to the current practice of a Same Season Relief Well. Alternatives include capping stacks and sub-sea shut-in devices independent of the standard blowout preventer.
  - The DOE should work with industry and the DOI to perform this assessment, engaging the National Labs, the National Academies, and other stakeholders as appropriate. Assessment techniques could include those used in the nuclear, aviation, and petrochemical industries, such as precursor analysis and Quantitative Risk Assessment, where the DOE already has expertise.
  - Future regulation and permit requirements should be informed by the results of this analysis including required demonstrations and testing. DOI, DOE, and the National Laboratories should witness these demonstrations of improved well control and containment devices and include appropriate observers from the stakeholder community." [pp. 4-15, 4-16]

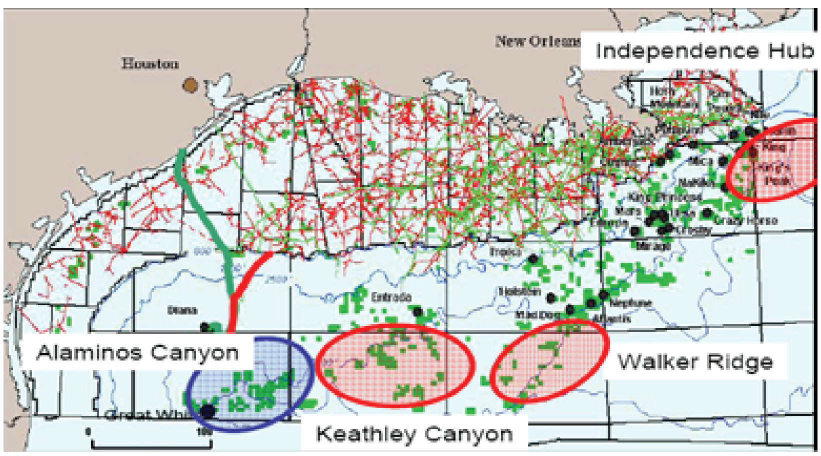
Other key challenges include improving the prediction of rapidly changing, extreme Arctic sea conditions and the performance of surface systems under those extreme conditions, sensing and imaging to detect integrity issues, improvements to integrity of materials used in the subsurface in Arctic conditions, remote communications, personnel safety, underwater profiling of ice features, ice management, and environmentally acceptable acquisition of Arctic offshore geophysical data.

Offshore Research and Technology Opportunities

While development is ongoing in many areas of the Gulf of Mexico, four key areas of activity in the deepwater Gulf of Mexico can be used to illustrate the range of research and technology challenges and opportunities in the offshore environment. These four areas, which are identified in Figure 7.F.5, include (1) Walker Ridge, (2) Keathley Canyon, (3) Alaminos Canyon, and (4) Eastern Gulf/ Independence Hub.

Figure 7.F.5 Key Areas of Activity in Deepwater Gulf of Mexico. These areas serve as examples of the range of technical challenges in offshore oil and gas production.[28]

Credit: Research Partnership to Secure Energy for America (RPSEA)



The challenges associated with all four areas include higher drilling costs and challenging economics. However, each area has additional unique technology challenges: Walker Ridge and Keathley Canyon have subsalt reservoirs, deeper wells, and tight formations; Alaminos Canyon has viscous crude and lack of infrastructure; and the Eastern Gulf/Independence Hub has high pressure, high temperature, carbon dioxide, and hydrogen sulfide. Based upon simulated generic fields in these key locations, unique design features that hinder technical and economic development in the offshore were identified.Technology challenges that were identified were associated with low permeability reservoirs; high viscosity oil; small reserve fields; high pressure/high temperature; environmental (safety barriers, validation, produced water); floating facilities; flow assurance; geoscience (subsalt imaging, characterization); severe metocean conditions; reservoir appraisal and surveillance; subsea facilities; and systems engineering and architecture. This illustrates the range and variability of challenges associated with offshore production of oil and natural gas.[29]

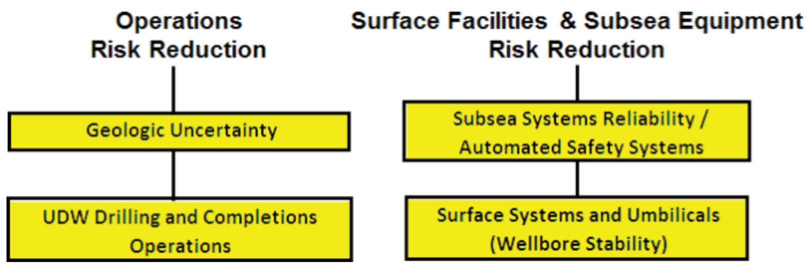
The key research and technology challenges associated with quantification and mitigation to reduce the risk of oil spills can be divided into four major areas (Figure 7.F.6):

- Characterization of the *geologic environment* with high quality data plus accurate modeling can allow for early response to geologic hazards. This knowledge will quantify and reduce the risk associated with unexpectedly encountering these hazards.
- Well construction materials, sensors, and other technologies used in *drilling and completing* offshore wells need to be optimized to reduce the risk of drilling in complex conditions. Research on these components can help quantify the risk associated with drilling and completing a well, while advances in technology can reduce risks and increase the long-term reliability of the well.
- *Equipment at the surface* must be able to withstand challenging conditions, including hurricane forces, currents, waves, and fires or explosions. Offshore facilities and systems need to be designed so

that they can handle these conditions and minimize the impacts of any worst-case incidents.

- In many cases, *subsea equipment* must be able to reliably handle seafloor conditions, operate independently, and be monitored and repaired quickly and with high resolution. Research and technology development in the performance and inspection of this equipment can help operators understand the risks, and identify and respond to damage, corrosion, and other issues in a proactive way.

Figure 7.F.6 Areas for Technology R&D for Offshore Safety and Spill Prevention at the Department of Energy



Overall, scientific research in the areas of *geologic uncertainty, drilling and completions, surface systems,* and *subsea systems* can reduce the risks associated with oil and gas exploration and production, thereby improving safety and minimizing environmental impacts.

Geologic Uncertainty

Enhanced understanding of the geological environment is needed in order to identify potential geohazards and develop technological countermeasures to hazardous precursors.[30] With a detailed knowledge of geologic formations and their rock properties, an operator can reduce the risk of encountering unexpected geologic hazards (such as pressure anomalies, salt formations, and faults), thereby increasing safety of offshore drilling activity.

Resources for profiling the geologic environment include studies and remote sensing surveys. These resources can provide information for determining "precursors" to potential drilling and production incidents that could result in oil spills or loss of life. These precursors can be geologic or hydrologic. Geologic precursors include, for example, weak formations that have an unusually low fracture gradient, which indicates a tendency for drilling mud loss to the formation. If new mud cannot be added to the system quickly enough, this mud loss has the potential to lower the bottom-hole pressure, which can destabilize wellbore integrity. Hydrologic precursors refer primarily to over-pressured zones where the fluid gradient (0.45 psi/ft.) approaches the overburden gradient (1.0 psi/ft.), which indicates a tendency for formation fluids to flow into the wellbore in an uncontrolled manner. Research opportunities include activities such as regional geologic studies (especially geohazards); advanced pre-drill seismic/sensing technology (especially "look ahead"); and combined reservoir and geologic studies to minimize geologic and operational exposure associated with exploration wells.

RDD&D Drivers and Current State-of-the-Art

Several trends reinforce the need for research in this area in order to anticipate potential geohazards. As was noted in a recent DOE research project[31] and in an analysis of GOM deepwater wells, industry drilled more wells than needed to produce a reservoir as frequently as—or more often than—it drilled fewer wells than required to produce a reservoir. This project, which developed and analyzed a database of deepwater and ultra-deepwater assets in the Gulf of Mexico, pointed to imperfect understanding of the complex reservoirs in the Gulf of Mexico as a major barrier to improving oil recovery from these wells. This limitation was recognized as a driver for improved reservoir understanding, through the use of additional seismic data acquisition and processing, detailed geologic studies, and advanced interpretation tools, as a mechanism to reduce risk by drilling fewer wells.

Industry is capturing more data at a faster rate, and this trend is expected to continue. As access to data increases in volume and speed, subsurface geologic uncertainty can be reduced. However, the access to this amount of data necessitates the development of methods, algorithms, and tools for interpretation. For that reason, a large potential exists to reduce risk with technology that improves the ability to interpret data in real-time. These types of drivers and trends support the need for research in the area of geologic characterization for spill prevention and risk reduction.

The current state of the art in seismic interpretation is limited to interpretation of signals of approximately 10Hz or less. Because of development costs, industry is targeting "elephant reservoirs" (over 500-million-barrel reserves with very high flow rate potential). Typically, these types of reservoirs do not *require* next generation seismic interpretation. However, new challenges, which result from issues such as reservoir compartmentalization from faulting and subsalt development, have created have created the need for advanced geologic interpretation techniques.

New data acquisition systems were recently demonstrated to increase vertical resolution from roughly 200 feet to 2 feet. One DOE project[32] is working toward harnessing this ability. If successful, geophysical interpretations would have the same resolution as well geophysical logs taken during drilling. The capability to collect pre-drill high resolution information is a step toward the development and use of next generation technology to avoid geologic hazards.[33]

RDD&D Challenges and Opportunities

As noted previously, it is necessary to develop technologies that identify precursors quickly so that risk of future incidents can be assessed and mitigated. In the area of geologic uncertainty, these technologies would include all pre-drill characterization studies and remote sensing technologies in addition to high-resolution, real-time sensing technologies during drilling.

Next generation seismic receivers (fiber optic and micro-electrical mechanical sensors), in limited prototype demonstrations, have the ability to detect very faint seismic signals at frequencies of one to two orders-of-magnitude greater than current systems. Such capability has also recently been demonstrated to be able to increase vertical seismic resolution from as much as 200 feet to 2 feet in specific areas. This would give a pre-drill seismic image resolution equal to that of post-drill wireline logs. As a result, the potential exists to resolve fine geologic/hydrologic hazards, such as faults and over-pressured zones, not previously able to be seen in pre-drill analyses. Unfortunately, industry business models do not include the use of such technology offshore because the reservoir targets are large and do not require improved seismic imaging. As a result, industry must deal with geologic hazards in real-time, counting on established practices to minimize impact. The ability to see geohazards prior to drilling into them, known as "detection ahead of the bit," has been a long sought objective. This is of interest for both economic development and detection of unknown hazards. The level of technology required, however, exceeds what is currently available. If this capability could be developed, it would significantly reduce risk in exploration drilling.

The focus of R&D activity in addressing geologic uncertainty is the area of next generation sensors and downhole measuring systems. These systems would preferably provide that preferably provide direct measurement of geology/hydrology, which would be an improvement to current sensors/systems that rely on interpretation of indirect responses. An example of this indirect measurement is the use of resistivity to identify saturation and more permeable zones. If these sensors can provide discrete, instantaneous measurements and could enable detection of trace amounts of hydrocarbon before an overpressured zone is encountered, a possible kick could be avoided. Some priority challenges and opportunities are listed in Table 7.F.1.[34]

Table 7.F.1 Challenges and Opportunities in Geologic Uncertainty[34]

Imaging: Improve understanding of subsurface hazards by new data acquisition technologies and remote sensing capabilities to provide higher resolution of subsurface detail prior to drilling and ahead of the bit during drilling

- There is not a well-developed ability to predict thin sandstone intervals that represent overpressured zones ahead of the bit. Without this ability, these zones remain hidden until they result in an influx of fluids into the wellbore, causing instability in the drilling mud's ability to act as a barrier. Solutions to this challenge could include downhole measurements, measurement while drilling (MWD), and increased characterization of sandstones. This ability could improve safety of operations.
- Arctic research has focused on metocean/ice issues. However, focus is needed on seismic source substitution due to the Marine Mammals Protection Act. Specifically, there is a need for technologies for passive acoustic monitoring that would get high-quality seismic data while remaining compliant with the Marine Mammals Protection Act.
- An opportunity for future seismic work is to use information from other domains (communications, navigations, radar, etc.). These domains have expertise and relatively mature techniques used to handle stochastic information and extract information from low resolution data to achieve high resolution interpretations. This could enable a significant technology leap forward by allowing reservoir dynamics interpretation using remote sensing.

Public (All Stakeholder) GIS/Database: Integrated subsurface information/models for improved prediction of potential hazards (e.g., NETL's EDX website[35])

- Mapping and modeling of sub-salts need to be improved to assist in determining if some areas are more prone than others to overpressure. The goal of this type of research would be to make sure data is widely available and used.
- Overburden characterization, including faulting and salts, is a key research need. It is not currently being done extensively due to cost, accountability, and time. In addition, it could be further described as a federal role in reference to the National Petroleum Council's recommendation for improved "pre-cursor" analysis. Such precursors represent the set of harbingers that indicate the potential for an event that could negatively impact safe operations.
- Additional research could investigate improving knowledge of the reference case of the seafloor prior to drilling. This would include the use of autonomous utility vehicles to record seeps and other ocean bottom activity.

Downhole Technology: Improved downhole geologic interpretation and data acquisition for better understanding of potential hazards during drilling.

- Besides digitizing, industry has not made strides in improving geophysical logging capabilities. Future research should include work to make sure logging technologies represent the in-situ stress state of the rock accurately and in a way that makes sense to the data interpreter. In addition, as pore pressure data is considered unreliable, it would be productive to identify areas in petrophysical technologies that should be targeted for improvement.
- There is a great opportunity to expand on geomechanics research. Specifically, the area of characterization of rock interactions with oilfield mud, chemicals, pressure, and temperature could be improved. At the microscopic and submicroscopic level, the interactions of fluids (and fluid additives) with rock affect near-wellbore chemistry and geomechanics over time. These effects need to be continually studied and updated, because the interactions affect every aspect of well efficiency, safety, control, and zonal isolation. These studies were part of the original scope to be accomplished with NETL's Ultra-Deep Drilling Simulator (UDS). In the field, next generation geochemical sensors now being considered by the oil and gas industry offer the potential for detailed geologic characterization of both formation and in-situ fluids downhole in real time.
- "Looking ahead of the bit" has remained the ultimate goal for mitigating risk of geohazards during drilling, in addition to guiding the bit to the targeted area of an unconventional reservoir. Work in this area is of mutual interest between government and industry.

Industry is often unable to invest in advanced technologies that do not fit with their projected business model. This represents a market failure and an opportunity to bring together industry, universities, national laboratories, and other researchers to address technical challenges and to provide solutions that reduce and mitigate risk.

Offshore Drilling and Completions Operations

Offshore drilling and completions operations[36] are complex processes with unique challenges. Research in this area points to the need to assess risks associated with innovative drilling and completions technologies and methods, and the need to reduce the risk of drilling in particularly complex conditions. In addition, this area highlights the need to improve the ability to collect and communicate data while drilling, which can provide the operator with early indications of possible issues.

This area also includes research associated with how people work and interact with technology—especially advanced technology—in safe operations (human factors and human-machine interface), as well as enhanced blowout preventer (BOP) technologies. Offshore drilling and completion operations research seeks to reduce operational risk by focusing on (1) “human machine interface” issues that involve improved decision-making by advanced downhole sensing technologies, advanced surface readout, and integration systems; and (2) improved operational methodologies based on improved understanding of equipment and materials (such as cement and other critical barriers). Additional research topics include early kick detection and best practices.

RDD&D Drivers and Current State-of-the-Art

Several trends reinforce the need for drilling and completions research in order to reduce and mitigate the risk of loss of well control.

Offshore operating environments are becoming more complex and technologically challenging due to the pursuit of targets in deeper formations and in deeper water. Specifically, these targets have higher pressures and higher temperatures downhole than faced before, and extremely low temperatures in Arctic waters. As the target environments become more complex (geologically, technologically), it is increasingly challenging and crucial to address the issues of remotely-located supplies and difficult “ship-to-shore” communications. Addressing these issues will be necessary to ensure all critical equipment and materials for operations are available when they are needed. In addition, the challenging locations increase the need for remote operation, remote sensing, and effective real-time communication. A related trend involves increasing the resolution of imaging data and the speed of its delivery. Efforts are increasing to further increase resolution, improve dynamic imaging, and develop real-time updates during drilling.

At the same time, the recent oil price decline has reduced private sector R&D investment with corresponding layoffs of workers and postponement of projects.

The cost of drilling and completion activities offshore has significantly increased over the years, due to the use of bigger drilling platforms required to drill in deeper waters. As a result, a focus for new innovation has been on improving operational efficiency by decreasing “nonproductive time” (NPT). NPT is defined as anything that does not deal directly with drilling and completing the well. Included in this category are all the required preparatory operations, such as pulling/changing out the riser following cementing in preparation for drilling the next smaller size hole, pulling and inspecting the BOP stack, and any other operation that delays completion of the well.

Innovation in reducing NPT is perhaps best shown in the development of “dual-activity” drill ships. Helix Well Control, Inc.’s Q4000 Discoverer-Enterprise (Figure 7.F.7) was the first drill ship to offer a dual drilling derrick capability, which allows simultaneous drilling operations to be performed and is reported to result in a 40%

increase in overall operational efficiency. Other innovations have been developed that increase both safety and operational efficiency, such as increased downhole sensing and communication speed—enabling the ability to collect and communicate data from within the borehole. Recent technology developments—many of which were supported by DOE funding, including, for example, advanced wired pipe technology (that allows high-resolution data collection from various points along the drill pipe)[38] have already advanced downhole sensing and communication capabilities. Additional examples include:

Figure 7.F.7 Helix Well Control, Inc. Q4000 Discoverer-Enterprise. This is the first drill ship to offer a dual-drilling capability.[37]

Credit: U.S. Coast Guard

- High-speed downhole data transmission—wired pipe
- Logging while drilling to replace wireline logging
- Best practices for use of cement offshore
- Feasibility studies of offshore reverse circulation cementing for safer operations
- Managed pressure drilling design and analytical tools to identify overpressured zones
- Intelligent production system for ultra-deepwater with short hop wireless power and wireless data transfer.[39]

RDD&D Challenges and Opportunities

Research and development in offshore drilling and completions operations emphasizes the need for capabilities such as getting downhole information to the surface at high speed with wide bandwidth to ensure adequate information transmission from multiple downhole sensor systems. Also, greater overall well control and integrity via cost-effective measurement of key hydrologic indicators along the drill pipe could ensure continuous evaluation of the mud well-control system throughout the wellbore. Finally, the topic addresses the human-machine interface and the development of effective countermeasures to deleterious human-factor-based events. Table 7.F.2 includes examples of the challenges and opportunities.[40]

R&D in these areas can improve reliability of downhole equipment and processes, as well as improve safety, reduce unexpected incidents, and improve process performance. Successful technology development in these areas could be carried over to other research areas to improve performance of the entire industry.

More specifically and as previously noted, there are a number of nascent technologies that have both economic and risk reduction benefits for offshore drilling and completions operations. The dual benefit of these technologies provides an opportunity for field demonstrations of offshore operational risk reduction through rapid deployment of these “common interest” technologies.

Table 7.F.2 Challenges and Opportunities in Drilling and Completions[40]

Wellbore Intervention/Remediation Technologies – Lifecycle of Well:

- Additional research could develop more effective technologies for well intervention during the life-cycle of the well, including remediation and plugging. An important potential focus of this research is developing technologies and processes to repair a poor cement job, especially small channels and micro-annuli.
- Another large R&D challenge is improving technology for completions. There is a need for a better methodology in completions to minimize intervention, so as to reduce threats to safety and the environment, as well as enhance economic effectiveness. This includes challenges related to erosion of sand in production fluids affecting flow control valves, high pressure/high temperature, and getting to a stable, steady-state flow.
- There are thousands of wells that need to be plugged, but it is difficult to accomplish cost-effectively and safely. In the past, wells were not designed with future plugging in mind. In addition, some of the records of shallow water wells are inadequate, and it can be difficult to even locate these wells. Finally, intervention technology will need to be advanced to enable industry to go back into old wells and stop or prevent leaks.

Wellbore Integrity – Designs, Materials, and Knowledge Base:

- Research in materials is important for improving wellbore integrity. This includes analysis of: design problems with changes in temperature, H_2S, CO_2, and other conditions; elastomers (advanced metallurgy research and advanced polymer research); replacement of casings; downhole tools; and better understanding of issues associated with high pressure/high temperature.
- Cement integrity is another key research area and challenge. Research opportunities in this area include: quality control and assurance; pressure testing; methodology for cement evaluation; direct method to measure cement integrity (to replace indirect measurements and assumptions); advanced cement mixing; reliable cement delivery; better ability to fix a cement job, downhole quality sensors for cement; and alternatives to cement.
- In the Arctic, identified R&D challenges include a lack of information and a difficulty of transfer of "lessons learned." Given that only about 100 wells have been drilled offshore Alaska, there is very little information about the existence and extent of geologic hazards. In addition, because most severe weather analyses focus on onshore phenomena with little offshore data acquisition, there is very little hazard information available regarding weather or current hazards.
- Additional research areas include 4D modeling and hydraulic fracturing offshore, where modeling, flowback fluid, and an understanding of the mechanisms, are large challenges.

Human-Machine Interface – Operational Issues/Technologies:

- Increased automation can reduce and/or assist personnel on the rig, which can reduce the potential for incident or injury. In addition, with fewer personnel, the size of the system can be reduced. To accomplish this, it would be necessary to have more sophisticated surveillance technology and real time data exchange to subject matter experts off-site. In addition, it will be necessary to differentiate between human judgment and data collection, so that automation may enable human judgment, not replace it. Solutions could come from the aviation industry, as they have a similar challenge of crew reduction.
  - Related to this challenge is the area of human factors. In this area, the time between detection and action needs to be reduced, and an automated response could help.
  - There is also a challenge of maintaining strong workforce competency into the future, particularly given the volatility of oil and gas prices, and competition for the best talent from other industries.

Sensor development is an area where there could be significant benefits from technology advances. Essentially all downhole sensors used today in drilling provide indirect measurements. For example, resistivity can be used to calculate an estimate of water saturation, and sonic travel time can be used to calculate formation density/integrity. The shortcomings of these methods are that resistivity and sonic travel time are affected by many factors; hence, interpretation is required. This interpretation often takes time. The time element is a large factor since the total operating costs of offshore rigs, especially deepwater rigs, are high and often increased with changes in weather and/or factors related to ocean currents. Interpretation is also open to error, especially if the tools are not properly calibrated before each use.

Geochemical sensors have recently been developed that can provide direct readings of the geochemicals present in the wellbore. These sensors have the ability to not only detect hydrocarbons in a stream, but also to differentiate the components (methane, ethane, propane, etc.) and their relative percentages. They could also be used to differentiate between sand and shale for better understanding of changes in geology. If such systems could be developed for tools used at the interface of the drill bit and the rock, it would be possible, for the first time, to fully characterize these aspects of the changing downhole environment in real time, and to assess corresponding potential hazards in real time.

The "human-machine" interface is another area with potential for huge gains in safety. This work would focus on human factors, such as training and competency, and improvements in interfaces, such as the manner in which data is displayed and interpreted. Existing downhole data could also be used to better indicate changes in borehole conditions to provide early detection of pressure anomalies before any visible indication is seen at the surface.[41]

Surface Systems and Umbilicals

Risk reduction associated with connecting the well to the surface facilities is needed, including analysis of cumulative fatigue in the wellbore system. This analysis can inform design inform design and maintenance of equipment and facilities (Figure 7.F.8). As industry moves into more challenging conditions, and as climate conditions change, the capability of offshore systems to deal with extreme conditions will likely need to increase.[42]

Improved understanding of these factors (the effects of cumulative fatigue and extreme environments) reduces the risk of oil spill incidents due to previously unanticipated extreme conditions. The term "wellbore stability" recognizes that offshore wells include an engineered system reaching from the ocean floor to surface facilities, supported by the drilling platform that undergoes continual stresses and corrosion during drilling. To ensure wellbore integrity throughout the well's lifecycle, analysis of cumulative fatigue in that system must be accounted for in design and maintenance.

RDD&D Drivers and Current State-of-the-Art

One major trend associated with these surface systems, and the flowlines and risers that connect them to the well, is increasing efforts to use existing infrastructure to drill more remote, less economic wells. For these long subsea tiebacks that connect new wells to existing facilities, improved electricity storage technology that has the potential to be used in high temperature, high pressure environments is needed. This could enable improved all-electric subsea systems, for which there is growing interest.

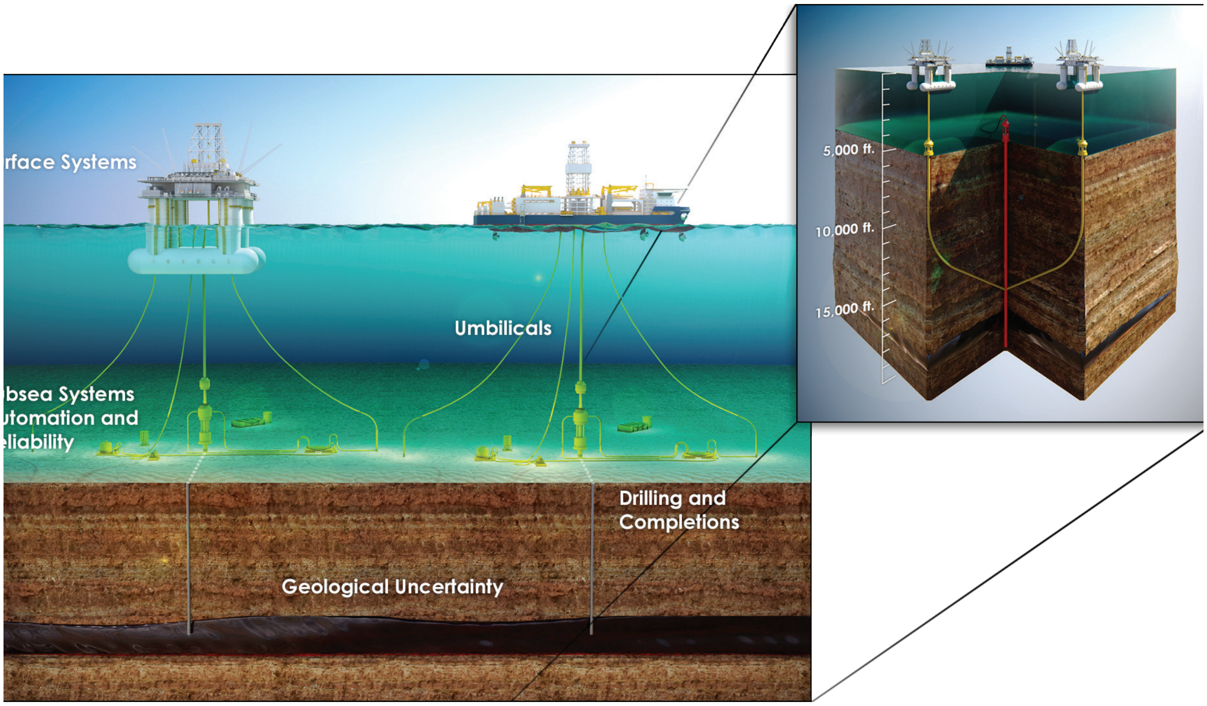
There is also a growing need to use smaller vessels for offloading and intervention, and use lighter-weight materials, including composite materials, in the construction of umbilicals. These lighter-weight materials would be designed to reduce the load on a surface vessel. In addition, lighter-weight materials are subject to less fatigue due to the load of their own weight (self-induced loads). So, with the use of lighter-weight materials, not only is the load on the surface vessel reduced, but also the load on the umbilical itself. The use of these materials can reduce fatigue and corrosion, which may lead to more reliable and safer umbilicals.

Cybersecurity is an important issue due to the increased interest in and development of automated systems and remotely operated controls. The growing use of these technologies leads to increased risk of loss of control of critical offshore operations. Therefore, there is an increasing need to mitigate risk and protect systems from cybersecurity failures due to unexpected events, including malicious cybersecurity threats.

Research to design lighter and cheaper risers and other umbilicals (power, control, chemistry) would pave the way for development of enabling technologies that are safer, more reliable, and cost-effective. Possible research topics include: subsea storage of chemicals and injection at the wellhead on the seafloor; ultra-high conductivity umbilicals;[44] and the delivery of power at the seafloor over long lateral distances. With regard to materials, current research includes a coiled and spoolable intervention riser made of composite carbon-fiber reinforced pipe.[45]

Figure 7.F.8 Diagram of systems for offshore oil and gas production. Among other things, this figure shows a floating platform, a drillship, and umbilicals. Umbilicals connect the surface facilities to the subsea system, transferring power, communication, and more.[43]

Credit: National Energy Technology Laboratory (NETL)



RDD&D Challenges and Opportunities

The surface system and umbilicals research area recognizes that, for offshore wells, the borehole (in the form of a drilling riser) is exposed to corrosion and unknown subsea current loads as it rises as much as 10,000 feet or more above the ocean bottom; and both the riser and all control umbilicals are supported by the surface facilities. Conventional ultra-high strength steel systems used to support such loads are at their design limits and subject to increased risk of failure due to corrosion and fatigue. In addition to known loads, recent metocean studies have revealed that there is still much to learn about subsea phenomena (such as loop current vortices) that have the potential to materially impact these systems and offshore operations in general. This research area includes such topics as more stable platform designs; safer facility designs that minimize consequences of explosion incidents; improved metocean 100-year design criteria; improved loop current and hurricane forecasting; lighter/stronger riser materials for reliability in 10,000-ft to 12,000-ft water depths; and riser inspection technologies and standards/best practices. Some specific priority research challenges and opportunities are included Table 7.F.3.[46]

Table 7.F.3 Challenges and Oppportunities in Surface Systems and Umbilicals[46]

Large-Scale System Safety/Integrity Designs and Technologies (riser/umbilical and topsides focus)
■ All-electric subsea systems would be more reliable and environmentally safer than existing hydraulic systems. Challenges for all-electric subsea systems include high energy and high power AC and DC systems, including for managing backpressure on the reservoir. There is an opportunity to transfer technology from onshore to offshore in three key areas: generation, power transfer and distribution systems, and switching and control.
■ Improved understanding of technology and system failure modes is needed, including for materials, to identify approaches to reduce the risk and associated safety and operational costs of such events. This would involve both laboratory testing and demonstrations.
■ Metocean studies are necessary for the Gulf of Mexico, the Atlantic, and the Arctic. The federal network of satellites and ocean-based sensor systems, together with the ability to gather data from the maritime industry and Department of Defense assets, can serve a key role in developing and analyzing metocean data in the GOM, Atlantic, Pacific, and Arctic. This information is critical for appropriate design criteria for large-scale systems.
Materials, including lighter weight composites and materials with improved safety and long-term durability
■ Improved technologies for power generation, transmission, and storage, and chemical transport and storage are needed for umbilicals and the seabed equipment. These technologies must have a low risk and consequence of failure. The development of a detailed technology roadmap for these systems could be an important next step for evaluating alternative systems.
■ R&D on lighter, stronger materials, particularly nonmetallic materials with high ductility to handle extreme stresses during events, will help lead to longer-term reliability and improved safety.
■ Additional avenues for research include lightweight risers and reduced size of vessels. With lightweight risers, intervention in very deepwater wells and high pressure/high temperature (HPHT) conditions would be vastly improved. There would be a need to prototype test any composite material in salt water and increase pressure capacity.
■ Federal laboratories have expertise in specialty steels which have not only improved strength, ductility, and corrosion-resistance, but also potential for development for specific offshore applications (e.g., long tubes for oilfield tubing, casing, and risers). This research needs to be re-invigorated or more broadly customized for deepwater oil and gas industry if performance requirements are to be met. In addition, federal laboratories have expertise in alternative materials (e.g., ceramic composites). Composites are discussed in the DOE Quadrennial Technology Review-Technology Assessment 6.E-Composite Materials.
Automation
■ Improving safety and productivity in long subsea tiebacks is important. If sensors and automation enabled remote operation without an on-board human presence, it would alleviate the need for HVAC, blast walls, and other infrastructure for the health and safety of people. However, such remote capabilities pose substantial technical and operational challenges that require extensive development and testing before implementation.

Research areas of potential interest for private/public partnership include cement, umbilicals, and risers. This is especially true for large-scale research projects. There may also be interest in collaborating on surface completion facilities (including "dry tree") research, enhanced/improved oil recovery, and safety- and health-related topics. Surface systems are an especially important topic because of the strong role of materials. Materials research and related improvements in technology can benefit all sectors of oil and gas.[47]

Subsea Systems Reliability and Automation

This area includes subjects such as analysis and improvement of the reliability of components within complex production systems operating autonomously on the ocean floor. These efforts serve the purpose of reducing the risk of spills (by identifying issues earlier, with greater accuracy, and a faster response time) and lessening the environmental impact should a failure occur.[48]

RDD&D Drivers and Current State-of-the-Art

Numerous drivers and trends point to the necessity of continued research and development in the area of subsea systems reliability and automation. A few of these trends mirror those identified in other research areas. For example, it was previously noted that recent low oil prices have led to less industry investment in research and development. Furthermore, adequate investment to address safety in these more complex conditions is difficult to obtain. This is also true in the area of spill prevention, as it is viewed as a low probability (but high consequence) research area. As a result, industry will continue to rely on evolutionary advances of prevention technologies and methodologies. This leads to slower maturation of technology. Finally, of all the phases of R&D, testing and qualification is the most expensive. Therefore, reduced industry investment associated with lower oil prices leads to a slower deployment of good ideas. A related trend is consolidation of the services support industry. This reinforces less industry investment. The investments that continue to occur are focusing on profit and improving current components, not “new” technology.

Another common trend is the increasing role of sensors and automation. Specifically, more information is being provided at a lower cost and greater distribution, which leads to the challenge of managing data and determining its significance. Worker experience in interpretation of automated data is becoming more crucial, especially remotely, as automation is moving personnel further from the platform. This field, coupled with education of the operators and workers, is an important area of research.

An important driver for research in this area is aging infrastructure. There is a lack of information on the current state of infrastructure, so additional analysis is required. Such an analysis should examine the extent to which extended life is possible using mitigation and maintenance methodologies without significant reinvestment or shut-in. In addition, there is an increasing threat of spills resulting from aging pipelines and umbilicals. This results in a need for re-engineering and accelerated inspection of old pipelines.

Another important trend is increased interest in the high-integrity pressure protection system (HIPPS), which was developed for protection of subsea pipeline after valve installation. This system can be helpful in pressure protection of existing low pressure pipelines when new high pressure pipelines are connected to the systems. However, operators currently have difficulty relying on HIPPS, so the system must be further developed. System acceptability will need to be cultivated with increased demonstrations, that show higher technology readiness levels. Advanced electric HIPPS technology can improve safety at a lower cost than current hydraulic-based HIPPS systems.[49]

RDD&D Challenges and Opportunities

The subsea systems reliability and automated safety systems research area is focused on subsea completions. Multi-well completions over tens of square miles often come to a single subsea processing point. So industry has coined the term “subsea factory” to incorporate all the design, reliability, automation, and power requirements that are needed to make such a system not only functional, but also reliable over a 20-year life cycle. The risk of significant undetected subsea oil and gas leaks increases with each mile of pipeline and each umbilical connection that is made. This research area includes such topics as advanced equipment packaging; improved sensor and system reliability for remotely operated vehicle (ROV) maintenance and intervention; ROV interface standardization; and advanced flow assurance understanding, especially under high pressure/high temperature (HPHT) conditions. Identified priority research challenges and opportunities are included in Table 7.F.4.[50]

The private sector focus is on decreased cost, increased production, and increased revenue. This motivates an emphasis on continuing with current technology and improving current assets. This tendency is accentuated by current low oil prices. These factors motivate a public role in research on safety, and on testing technology to “qualify” it and encourage field deployment. R&D could provide safer, more reliable, and more environmentally

Table 7.F.4 Challenges and Opportunities in Subsea Systems Reliability and Automation[50]

Advanced Equipment Packaging/Advanced ROV Interface Standardization:

- Subsea power generation is a key research area. Specifically, technologies such as fuel cells at hydrostatic pressure are an important potential approach.
- Technology opportunities for enhanced/improved oil recovery include low-salinity saltwater injection (where relatively fresh water is injected to displace saltwater in the reservoir, increasing oil recovery), submersible pumps or alternatives, HIPPS, and gas injection—particularly with CO_2. All of these opportunities require further research and testing.
- Additional research areas include dry tree systems, offshore marine operations (reducing time offshore and doing fabrication onshore), placing the drilling rig on the seafloor (which requires improvement in automation and robotics), sensors and measurement (including fiber optics), and residual oil zone mechanical completions (corrosion-resistance and material integrity).

Improved Sensor and System Reliability including ROV maintenance and intervention

- Cyber-terrorism and cyber failure is a major challenge in this area. With long supply chains, increased automation and interconnection, and remote control, securing the integrity of data is becoming more challenging. Ten years ago, in GOM, assets were distributed and not interconnected. Now, with extensive deployment and networking of IT, concerns about cyber failure and cybersecurity are growing, and the requirements for and effectiveness of redundancy in networked automated systems remain uncertain.
- Additional work on blowout preventers (BOPs) is a priority. Areas of research include instrumentation for smart BOP, assistance with testing, and all-electric BOPs.

Advance Flow Assurance Understanding, especially under extreme HPHT (xHPHT) conditions

- The "subsea factory" requires reliable flow assurance control, particularly for produced water. Research in this area could include water disposal, reinjection, subsea disposal, treatment of produced water, induced seismicity, and sensors, systems, and methodologies to detect and correct problems (oil in water).

responsible performance of subsea systems in harsh environments. Solving issues pertaining to the seafloor—including safety, inspection, spill prevention, subsea power, and robotics—may be beyond the expertise of most single technology sources, and may require the coordination of expertise across several public agencies with industry, universities, and national laboratories.[51]

Appendix A – Key Federal Engagements

Engagement	Years	Description
DOE Public-Private Partnership [EPAct 2005]	2007-2016	The Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Resources Research Program, launched by the Energy Policy Act of 2005 (EPAct), was a public/private partnership designed to benefit consumers by developing technologies to increase America's domestic oil and gas production. DOE contracted with the Research Partnership to Secure Energy for America (RPSEA) to facilitate this partnership.[52]
Ultra-Deepwater Advisory Committee (UDAC)	2007-2013	The UDAC was established to advise the Secretary of Energy on the development and implementation of programs related to ultra-deepwater natural gas and other petroleum resources, and review and comment on the program's annual plan. The UDAC consisted of special government employees, academia, environmental, and industry representatives.[53]
Interagency Coordinating Committee on Oil Pollution Research	2011-Present	Section 7001 of the Oil Pollution Act of 1990 (OPA 90) established the Interagency Coordinating Committee on Oil Pollution Research (ICCOPR). The purpose of the Interagency Committee is twofold: (1) to prepare a comprehensive, coordinated federal oil pollution research and development plan; and (2) to promote cooperation with industry, universities, research institutions, state governments, and other nations through information sharing, coordinated planning, and joint funding of projects.[54]
Ocean Energy Safety Advisory Committee (OESC)	2011-2013	The OESC was chartered on February 8, 2011, to advise the Secretary of the Interior, through the Director of the Bureau of Safety and Environmental Enforcement (BSEE), on a variety of issues related to offshore energy safety. Members are appointed by the Secretary of the Interior to represent the interests of the academic community, non-governmental organizations, offshore energy industry, and the federal government.[55]
BSEE-DOE Collaboration	2012-Present	DOE and Department of Interior/Bureau of Safety and Environmental Enforcement (BSEE) work together under a memorandum of collaboration to coordinate and collaborate on the implementation of recommendations by the President's Oil Spill Commission and the Ocean Energy Safety Advisory Committee.[56]
National Petroleum Council	2015	Secretary Moniz asked the NPC to conduct a study on the question, "What research should the Department of Energy pursue, and what technology constraints must be addressed to ensure prudent development of Arctic oil and gas resources while advancing U.S. energy and economic security and ensuring environmental stewardship?"[57]

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Acronyms

AC	Alternating Current
AEO	EIA's Annual Energy Outlook
BAST	Best Available and Safest Technologies
BBO	Billion Barrels Of Oil
BBOE	Billion Barrels Of Oil Equivalent
BOEM	United States Bureau of Ocean Energy Management
BOP	Blowout Preventer
BSEE	United States Bureau of Safety and Environmental Enforcement
CO_2	Carbon Dioxide
DC	Direct Current
DOE	United States Department of Energy
DOI	United States Department of Interior
DW	Deepwater
EDX	NETL's Energy Data Exchange
EIA	United States Energy Information Administration
EPAct	Energy Policy Act of 2005
FT	Feet
GIS	Geographic Information Systems
GOM	Gulf of Mexico
HIPPS	High-Integrity Pressure Protection System

HPHT	High Pressure/High Temperature
HVAC	Heating, Ventilation, and Air Conditioning
HZ	Hertz
ICCOPR	Interagency Coordinating Committee on Oil Pollution Research
IT	Information Technology
MWD	Measurement While Drilling
NASA	United States National Aeronautics and Space Administration
NETL	National Energy Technology Laboratory
NPC	National Petroleum Council
NPT	Non-productive Time
OCS	Outer Continental Shelf
OESC	Ocean Energy Safety Advisory Committee
PSI	Pounds per square inch
R&D	Research and Development
RDD&D	Research, Development, Demonstration, and Deployment
ROV	Remotely Operated Vehicle
RPSEA	Research Partnership to Secure Energy for America
TCF	Trillion Cubic Feet
UDAC	Ultra-deepwater Advisory Committee
UDS	NETL's Ultra-Deep Drilling Simulator
UDW	Ultra-deepwater
USGS	United States Geological Survey
xHPHT	Extreme High Pressure/High Temperature

Glossary

Arctic Region	All U.S. and foreign territory north of the Arctic Circle and all U.S. territory north and west of the boundary formed by the Porcupine, Yukon, and Kuskokwim Rivers; all contiguous seas, including the Arctic Ocean and the Beaufort, Bering, and Chukchi Seas, and the Aleutian Chain. [The Aleutian chain boundary is demarcated by the ‘Contiguous zone limit of 24-nautical miles.][58] *[As defined by the Arctic Research and Policy Act]*
Blowout	An uncontrolled flow of formation fluids, including fluids like water, oil, and gas, from the wellbore or into lower-pressured subsurface formations, that typically requires special tactics to be contained.[59]
Blowout Preventer (BOP)	A large valve at the top of a well that can be used to regain control of a well that has experienced a loss of control of formation fluids.[60]
Computational Fluid Dynamics (CFD)	The use of applied mathematics, physics, and computational software to calculate how a gas or liquid flows, as well as how the gas or liquid affects objects as it flows past. Computational fluid dynamics is based on the Navier-Stokes equations. These equations describe how the velocity, pressure, temperature, and density of a moving fluid are related.
Conventional oil and natural gas production	Oil and natural gas produced from a formation that allows for the hydrocarbon to readily flow into the wellbore.[61]
Crude Oil	A liquid mixture of hydrocarbons found in underground reservoirs and as it passes through surface separating facilities.[62]
Deepwater	Water depths of greater than 1,000 feet.
Deepwater Horizon	A member of Transocean’s fleet of offshore drilling rigs. The $560-million-dollar semisubmersible rig, under lease to BP, which was working on BP’s 18,000-foot-deep Macondo well when it blew out and escaping methane gas exploded.[63]

Drilling — The act of boring a hole (1) to determine whether minerals are present in commercially recoverable quantities and (2) to accomplish production of the minerals (including drilling to inject fluids).

- Exploratory. Drilling to locate probable mineral deposits or to establish the nature of geological structures; such wells may not be capable of production if minerals are discovered.
- Developmental. Drilling to delineate the boundaries of a known mineral deposit to enhance the productive capacity of the producing mineral property.
- Directional. Drilling that is deliberately made to depart significantly from the vertical.[64]

Energy Data Exchange Website — https://edx.netl.doe.gov/

Faults — A fracture along which the blocks of crust on either side have moved relative to one another parallel to the fracture.[65]

Flow Assurance — The plans and strategies used to ensure that oil or gas moves without disruption from the reservoir to the point of sale.[66]

Fracture Gradient — The pressure required to fracture a rock formation at a specific depth.[67]

Geohazard — Features including faults and pressure differentials that may result in an unexpected influx into the wellbore.

Geomechanics — The study of how rocks, stresses, pressures, and temperatures interact, which can be used in oil and gas development.[68]

Hydraulic Fracturing — Fracturing of rock at depth with fluid pressure. Hydraulic fracturing at depth may be accomplished by pumping water, chemicals, and a proppant into a well at very high pressures.[69]

Hazardous Precursors — See precursors.

Joint Industry Project — A method of addressing a complex project by collaboration between several interested parties (companies, government entities, universities, etc.).

Kick — The flow of fluid into the wellbore during drilling, caused by lower pressure in the wellbore than in the formation.[70]

Kick Detection — The process of identifying when a well being drilled is taking on a kick from hydrocarbon, gas, or water from the surrounding rock formations.

MetOcean — METeorological and OCEANographic.

Modeling — The act of constructing a model.

Petrophysics	The study of the properties and the interactions of petroleum systems.
Precursors	A state (event, data point, etc.) that precedes a potential drilling and/or production incident that could result in an oil spill or loss of life.
Quantitative Risk Assessment (QRA)	A method for calculating risk typically to human health or the environment for comparison with established risk criteria.[71]
Relief Well	A well drilled to intersect a well that has experienced a blow-out as a method to obtain control of the fluid flow.
Remote Sensing	The process of measuring, observing, or analyzing features below the surface, including on the seafloor or below ground surface, using technologies like radar and satellite photography.[72]
Reservoir	A porous and permeable underground formation containing an individual and separate natural accumulation of producible hydrocarbons (crude oil and/or natural gas) which is confined by impermeable rock or water barriers and is characterized by a single natural pressure system.[73]
Same Season Relief Well	A relief well drilled in the same season as the exploration well itself.
Seismic Low Frequency (10Hz or less)	Referring to the frequency of the seismic pulse utilized in active seismic interpretation methods.
Subsea Factory	A collection of equipment placed on the seafloor that allows for remote-controlled production of hydrocarbons offshore.[74]
Swellable Packer	A device that can be placed downhole in a wellbore and expands to create an annular seal.[75]
Seismic Data	Information about the transmission of P-waves and S-waves that is used for the understanding of formation characteristics, like fluid content and composition.[76]
Sub-Salts	A play in which the targeted oil or gas- bearing formation exists below a salt layer.[77]
Tight Formations/ Tight Rock	Rock formations with very low permeability, typically including, but not limited to, shale formations.
Unconventional Natural Gas	Oil and natural gas that is produced using methods other than that for conventional production. The interpretation and use of this term changes based on available technologies, the economic environment, and other complex factors.[78]
Umbilicals	The connection between surface and subsea equipment that can transfer power, communications, or materials.

Ultra-Deepwater	A water depth of greater than 5,000 feet.
Wellbore Integrity/ Stability	The ability of well materials (cement, metals, etc.) to ensure wellbore control and maintain zonal isolation between the wellbore and the surrounding formations.