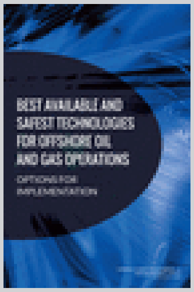

Best Available and Safest Technologies for Offshore Oil and Gas Operations: Options for Implementation

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BEST AVAILABLE AND SAFEST TECHNOLOGIES FOR OFFSHORE OIL AND GAS OPERATIONS

OPTIONS FOR IMPLEMENTATION

Committee on Options for Implementing the Requirement of Best Available and Safest Technologies for Offshore Oil and Gas Operations

Marine Board

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NATIONAL RESEARCH COUNCIL
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RAYMOND A. WASSEL, Project Director

Preface

Section 21(b) of the Outer Continental Shelf Lands Act (OCSLA)[1] mandates that the Secretary of the Interior[2]

> shall require, on all new drilling and production operations and, wherever practicable, on existing operations, the use of the best available and safest technologies which the Secretary determines to be economically feasible, wherever failure of equipment would have a significant effect on safety, health, or the environment, except where the Secretary determines that the incremental benefits are clearly insufficient to justify the incremental costs of utilizing such technologies.

In the aftermath of the Macondo well blowout and *Deepwater Horizon* explosion in 2010, various analyses of the causes of the incident (for example, NAE and NRC 2012) identified the need for government agencies to incorporate more sophisticated approaches for assessing and managing risks associated with offshore activities. Accordingly, the Bureau of Safety and Environmental Enforcement (BSEE)[3] considered ways of enhancing the approach it uses in implementing the best available and safest technologies (BAST) mandate. The director of BSEE asked the National Academy of Engineering (NAE) and the National Research Council (NRC) to form a committee that would provide a range of options for improving the implementation of BAST. The committee was also asked to review options and issues that BSEE is already considering. However, the committee was not asked either to recommend a specific BAST implementation approach or to

[1]Public Law 95-372, as amended on September 18, 1978.

[2]The mandate is also directed to the secretary of the department in which the Coast Guard is operating.

[3]On October 1, 2011, BSEE became the federal entity within the U.S. Department of the Interior responsible for safety and environmental oversight of internal processes of offshore oil and gas operations.

carry out an in-depth evaluation of BSEE's past BAST approach. (The committee's statement of task is provided in Appendix A.)[4] In response, NAE and NRC assembled a committee of 13 members providing expertise in petroleum engineering, marine systems, system safety, risk analysis, testing and evaluation of new technologies, and human factors. In addition, the committee provided experience in regulatory and corporate decision making concerning the identification, development, and deployment of advanced technologies (see Study Committee Biographical Information at the end of this document). The diverse background of the committee membership proved to be valuable, as the committee had to rely heavily on its collective judgment and experience in providing its recommendations in this report.

In accordance with its task statement, the committee did not recommend a specific BAST implementation approach. In accordance with its best judgment, the committee took an integrated approach in recommending actions to enhance BSEE's fundamental capabilities for supporting any of the identified options. On the basis of conversations with the sponsor at its first meeting, the committee considered the specific options listed in its statement of task to be illustrative of the complexity of BAST implementation and not to define the set of topics to be considered in its report. Therefore, the committee used its discretion within the parameters of its scope of work to focus on the set of options to be discussed fully and analyzed within its report. The committee principally focused on developing options with regard to BSEE's plans for an independent Ocean Energy Safety Institute (OESI), which would provide technical support for BAST implementation. General plans for OESI were outlined by BSEE officials at the committee's first meeting.

As part of its information-gathering activities, the committee held three public sessions in 2013 to receive presentations from BSEE; other federal agencies involved in BAST-type approaches; and industry associations, individual companies, and other organizations involved in offshore drilling and production operations. On March 11, the committee heard from Michael Else and Joseph Levine (BSEE), Kevin Culligan (U.S. Environmental Protection Agency), Holly Hopkins (American Petroleum Institute), Alan Spackman (International Association of Drilling Contractors), and Thomas Moroney (Shell). On May 13, the committee heard from Homayoon Dezfuli (National Aeronautics and Space Administration), Lirio Liu (Federal Aviation Administration), James Simons (National Highway Traffic Safety Administration), and Brian Sheron (U.S. Nuclear Regulatory Commission). On May 30, the committee heard from Fred Florence (National Oilwell Varco), John Hensley (Petrobras), Robert Judge (GE Oil and Gas), Rod Larson

[4]The committee issued a letter on April 15, 2013, which commented on BSEE's preliminary plans for implementing the BAST requirement, as presented to the committee on March 11, 2013.

(Oceaneering International), Roald (Ro) Lokken (ExxonMobil), Richard Mercier (Offshore Technology Research Center), Keith Seilhan (Stone Energy), Mel Whitby (Cameron Drilling Systems), and Charlie Williams (Center for Offshore Safety).

Donald C. Winter, *Chair*
Committee on Options for Implementing the Requirement of Best Available and Safest Technologies for Offshore Oil and Gas Operations

Acknowledgments

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise in accordance with procedures approved by NRC's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report: R. Lyndon Arscott, International Association of Oil and Gas Producers; Benton F. Baugh, Radoil, Inc.; Michael R. Bromwich, The Bromwich Group; Patricia M. Jones, University of Illinois at Urbana–Champaign; Alexander MacLachlan (DuPont, retired); Keith Seilhan, Stone Energy; Allen Verret, Offshore Operators Committee; and David Wisch, Chevron Energy Technology Company.

Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by Robert A. Frosch (NAE), Harvard University, and Susan Hanson (NAS), Clark University. Appointed by NRC, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

Raymond Wassel managed the study under the guidance of the committee and the supervision of Stephen Godwin, Director, Studies and Special Programs, Transportation Research Board (TRB). Norman Solomon edited the report; Radiah Rose prepared the prepublication manuscript, under the supervision of Javy Awan, Director of Publications, TRB. Ricardo Payne and Timothy Devlin arranged meetings and provided logistical communications to the committee.

Abbreviations

ALARP	as low as reasonably practicable
API	American Petroleum Institute
ASRS	Aviation Safety Reporting System
BAST	best available and safest technologies
BOEM	Bureau of Ocean Energy Management
BOP	blowout preventer
BSEE	Bureau of Safety and Environmental Enforcement
DOI	U.S. Department of the Interior
E&P	exploration and production
FAA	Federal Aviation Administration
FFRDC	federally funded research and development center
GOM	Gulf of Mexico
HFE	human factors engineering
HSE	health, safety, and environment
IP	intellectual property
JIP	joint industry project
NAE	National Academy of Engineering
NASA	National Aeronautics and Space Administration
NRC	National Research Council
NTNU	Norwegian University of Science and Technology
NTSB	National Transportation Safety Board
OCS	outer continental shelf
OCSLA	Outer Continental Shelf Lands Act
OESI	Ocean Energy Safety Institute
OGP	International Association of Oil and Gas Producers
R&D	research and development
SEMS	Safety and Environmental Management Systems
SINTEF	Stiftelsen for Industriell og Teknisk Forskning
TA&R	Technology Assessment and Research
UARC	university-affiliated research center
USCG	United States Coast Guard

Contents

BEST AVAILABLE AND SAFEST TECHNOLOGIES FOR OFFSHORE OIL AND GAS OPERATIONS

OPTIONS FOR IMPLEMENTATION

Summary

In the Outer Continental Shelf Lands Act (OCSLA),[1] Congress directs the Secretary of the Interior to regulate oil and gas development activities in federal waters. The act mandates that the Secretary[2]

> shall require, on all new drilling and production operations and, wherever practicable, on existing operations, the use of the best available and safest technologies which the Secretary determines to be economically feasible, wherever failure of equipment would have a significant effect on safety, health, or the environment, except where the Secretary determines that the incremental benefits are clearly insufficient to justify the incremental costs of utilizing such technologies.

In the aftermath of the Macondo well blowout and *Deepwater Horizon* explosion in 2010, the Department of the Interior (DOI) sought to improve the approach it uses for implementing the mandate for best available and safest technologies (BAST).[3] Accordingly, the director of the Bureau of Safety and Environmental Enforcement (BSEE)[4] asked the National Academy of Engineering and the National Research Council to form a committee that would provide a range of options for improving the implementation of BAST. The committee was also asked to review options and issues that BSEE is already considering. However, the committee was not asked either to recommend a specific BAST implementation approach or to carry out an in-depth evaluation of BSEE's past BAST approach. On the basis of conversations with the sponsor at its first meeting, the committee considered the specific options listed in its statement of task to be illustrative of the complexity of BAST implementation and not to define

[1] 43 U.S.C. Sec. 1331 ff.

[2] The mandate, carried in amendments to the OCSLA enacted on September 18, 1978 (P.L. 95-372), is also directed to the secretary of the department in which the Coast Guard is operating.

[3] The Technology Assessment and Research Program was established by DOI in the 1970s to ensure that industry operations on the outer continental shelf incorporated the use of BAST.

[4] On October 1, 2011, BSEE became the federal entity within DOI responsible for safety and environmental oversight of internal processes of offshore oil and gas operations.

the set of topics to be considered in its report. Therefore, the committee used its discretion within the parameters of its scope of work to focus on the set of options to be discussed fully and analyzed within its report. The committee principally focused on developing options with regard to BSEE's plans for an independent Ocean Energy Safety Institute (OESI), which would provide technical support for BAST implementation (see discussion later in the text). General plans for OESI were outlined by BSEE officials at the committee's first meeting.

In the summary, the committee provides several recommendations for BSEE to consider in developing a basis for effective BAST implementation regardless of how it decides to carry out its mandate. They are amplified and expanded in the chapters.

IDENTIFICATION OF TECHNOLOGIES

Candidate technologies[5] for BAST can come from many sources, the major one being the offshore oil and gas industry. Discoveries of deepwater hydrocarbon reservoirs, favorable economics of high-producing deepwater wells, and the advancement of field-ready deepwater-capable technologies help drive exploration and development activities in deepwater basins. The offshore drilling and production environment poses technical challenges, which become more demanding as activities move into deep water or formations involving high pressures or high temperatures or into harsh environments such as the Arctic. As technologies mature, industry competition drives novel technology into use, creating an inherent "push" dynamic of new candidate technologies, including those enhancing mechanical integrity and consequently improving safety. Thus, many of the innovations eventually providing BAST candidates are inevitably motivated by R&D efforts in pursuit of improved mechanical integrity and productivity gains.

Other factors that can give rise to BAST candidates include a robust safety reporting system that documents incidents (near misses) as well as accidents, the identification of the potential impacts of human error, and risk assessments. Such factors provide "technology pull" by highlighting areas where candidate technologies would materially improve safety in outer continental shelf operations. Given the variety of factors, the committee believes that a portfolio of efforts is needed by BSEE to find and solicit advances in candidate technologies and to provide leadership and support for safety-related research within industry.

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[5]The committee interpreted "technology" broadly to encompass not only equipment directly involved in drilling and operating wells but also support systems (e.g., marine systems), safety systems (e.g., explosive gas detectors and blind shear rams), control and display systems (e.g., real-time operations centers), and human factors considerations.

EVALUATION OF TECHNOLOGIES

BSEE's evaluation of BAST candidates will need to consider the overall complexity of the entire engineered system in which the technologies will be used and the interactions of system components, humans, and the geologic environment in which the engineered system operates. The behavior of complex systems is generally harder to predict than is that of an individual component before it is integrated into the system. Altering one or more components of a complex system can have unintended consequences that result in reduced reliability or failures elsewhere. Although many engineering reliability and risk analysis methods have been developed to help anticipate and reduce failure risks in technological systems, none completely overcomes the complexity and uncertainty inherent in managing new technology risks in oil and gas exploration and production. In addition, current technology cannot fully or accurately predict all geologic aspects. Therefore, important uncertainties will inevitably remain in characterizing the offshore environment and the performance of technologies deployed in that environment.

ECONOMIC ANALYSES

Assessments of the economic impacts of implementing BAST necessarily consider costs associated with candidate technology acquisition and sustainment (operations and maintenance) and the potential costs of disruptions to drilling and production operations that may be caused by the introduction of immature technologies or technologies not fit for their intended purpose. The latter concern is raised often by industry.

Although the BAST mandate does not require quantitative benefit–cost assessments, the Secretary of the Interior may choose to undertake such an assessment to compare the incremental benefits with the incremental cost of implementing the technology. Benefits may include reduced accident probabilities, improved accident impact mitigation, and any ancillary benefits associated with the new technology (such as a reduction in unplanned outages). The committee notes the extreme difficulty of constructing quantitative estimates of reductions in the likelihood of an offshore accident or likely reductions in their severity as the result of a safer technology installation. The scarcity of data with regard to low-probability and high-impact offshore accidents makes it exceptionally difficult to quantify risks and thereby ascribe dollar values to safety technologies.

TECHNOLOGY DEVELOPMENT AND MATURATION

In funding new offshore technology research, the federal government invests on behalf of the public, and industry invests on behalf of its shareholders. While federal funding comes from many sources, the total has been, and probably will continue to be, limited in comparison with that of industry. These budget levels lend themselves more to basic research, where the costs are modest compared with those required to mature engineered systems for deployment, and there can be great leverage in funding early and basic technology development.

In carrying out its BAST responsibilities, BSEE should consider the acquisition and maintenance of an in-depth understanding of existing industry and government capabilities for development, evaluation, and testing of technologies to be a priority *(Recommendation 1)*. Resources in industry, government, and academia as well as joint and international facilities need to be assessed. A census of these capabilities will include what exists, who has access to it, what organizations and people have the knowledge and skills to carry out testing and development activities, and where the gaps are. BSEE could then knowledgeably set priorities between basic and applied research and steer funding toward BAST research that can have the greatest impact.

The Secretary of the Interior will make the final determination that a specific technology meets the requirements for BAST and mandate its use. However, a strong business case for the adoption of new safety technologies could result in a greater industry focus on technologies for BAST and shorten their development and deployment times. **Although industry may develop a business case for potential technologies, including those considered for BAST, BSEE should consider using legislative or regulatory incentives (see Chapter 3) to speed the deployment of new safety technologies *(Recommendation 2)*.**

PERSONNEL SKILLS AND EXPERIENCE

Building new and necessary competencies within BSEE will be an enormous challenge. Historically, BSEE has relied heavily on operating and service companies to perform the bulk of the technical work associated with the development of new offshore exploration and production capabilities. As BSEE's approach to BAST implementation evolves, it will need access to staff and others with knowledge of and experience with the specific systems and technologies being developed, as well as a working knowledge of how they are incorporated into the complex systems used offshore. For both the technology assessments and the economic analyses, BSEE will need to obtain senior staff with the requisite skills for understanding the complexities and uncertainties and the ability to communicate them effectively to senior DOI officials.

BSEE has embarked on an aggressive hiring and training campaign in the past 2 years, but it cannot realistically be expected to match industry in technical depth or breadth. Compensation limits imposed by the federal government will make it difficult to compete with industry for the best graduates and experienced staff. However, BSEE can take advantage of industry expertise in many alternative ways (see Chapter 4). **In view of the challenges associated with technology assessments and economic analyses and of the role played by expert judgments, BSEE should seek access to the requisite expertise, including a**

multidisciplinary group of individuals with economic, engineering, and scientific skills; access to experts with unique technical skills; and the ability to request independent reviews *(Recommendation 3)*.

OCEAN ENERGY SAFETY INSTITUTE

In May 2013, BSEE announced a competitive request-for-proposal process to establish an independent OESI to enhance safe and responsible operations across the offshore oil and gas industry. OESI is intended to be used to support technology assessment and facilitate BSEE's implementation of BAST.

The committee considers OESI to be a suitable vehicle for supporting BSEE by identifying, evaluating, and maturing new technologies that would materially improve offshore operations safety. If properly organized, staffed, and supported, OESI could go a long way toward solving problems associated with a government agency competing with industry for top talent and expertise. While the direction proposed in the BSEE announcement of OESI is good, the scale and structure of the institute identified in the solicitation will need to be significantly expanded to address fully the challenges posed offshore. With industry spending several billion dollars per year on drilling, development, and production activities, technology moves ahead constantly. OESI could be an important adjunct to BSEE, providing knowledgeable, independent assessments of safety-related technology maturity, suitability (fitness for purpose), and cost. OESI could serve BSEE as a competent, trusted, conflict-free agent if it is given the appropriate resources.

Alternative Structures

Structural options used at the federal level to perform functions not dissimilar to OESI are the federally funded research and development center (FFRDC), the university-affiliated research center (UARC), and grants. An FFRDC can recruit personnel whose skills and commensurate market value place them out of reach of the civil service pay structure. It also provides long-term technical continuity for the agency. The primary disadvantage of an FFRDC is that it requires some degree of annual funding stability. A UARC is a government research center that operates similarly to an FFRDC, but with management provided by a university. A UARC has education as an important part of its charter. The advantages of a UARC are essentially the same as those of an FFRDC. Its most significant disadvantage is the potential conflict between educational interests and the near-term needs of the sponsoring federal agency. Grants provide a means for an organization to have requested services performed over a set time period. Grantees are usually selected as a result of a competitive bidding process in response to a grantor's proposal solicitation. A university, a nonprofit organization, or a commercial entity can receive a grant.

The committee is supportive of the initial formation of OESI through a grant process. However, the initial funding is limited and will severely restrict what can be accomplished in the near term. As initially described, OESI does not allow for the creation and growth of the institutional knowledge and memory that will be required to steer and promote the necessary BAST development. A technical core within OESI will be needed that follows industry developments over many years and is able to recognize and respond to trends and developments in a timely manner. The regular recompeting of OESI would make this difficult, since it conflicts with the objective of growing a stable core of technical and managerial expertise. **BSEE should consider expanding OESI's charter to allow it to evolve into an FFRDC or a UARC, since such a structure would provide a more stable approach and foundation for long-term operation *(Recommendation 4)*.** With any of these options, a governance board will likely be not only desirable but also necessary, and the quality of the board will likely determine the organization's effectiveness, regardless of structure. Inclusion of representation from BSEE and other parts of DOI, industry, academia, and standards organizations would be important for the board. The board would be responsible for identifying opportunities for testing and research and for setting priorities and recommending funding levels associated with the activities of the institute. In addition to the governing board, a research committee, chaired by the lead scientist or engineer of OESI, could be an important vehicle for steering the technical resources of the institute and maintaining relationships with industry and other government agencies (see Chapter 4).

Funding Levels

BSEE indicated in its proposal announcement that up to $5 million will be made available over 5 years to launch OESI. The committee believes that this funding level is not adequate for producing meaningful BAST results other than planning and that it could limit the ability to attract and retain key personnel. **BSEE should consider OESI structures that facilitate the retention of knowledge and experience *(Recommendation 5)*.** On the basis of consideration of similar past efforts with regard to technology identification and assessment (as evidenced by existing FFRDCs and UARCs), OESI will face key challenges that are typical at the start-up of this type of organization. It will need a funding commitment that is consistently in the range of several million dollars per year to attract and grow the skills and competencies required, to monitor and keep pace with industry technology developments, and to shape and support as necessary the research programs to assess and mature beneficial technologies.

Location

A body of knowledge and experience is available to a nascent OESI, largely developed within the oil and gas industry and nurtured within the technical departments of operating companies, service companies, and equipment manufacturers. **The geographic center of this industry is in the greater Houston area along the Texas Gulf Coast. BSEE should consider locating OESI in that area to encourage the free flow of technology from industry to the institute and to afford access to the large pool of industry retirees, who could form a cadre of institute employees and consultants *(Recommendation 6)*.** This would also facilitate temporary assignment of industry personnel to OESI (and vice versa) for technology transfer purposes and the growth of broad OESI capabilities, including those necessary to aid BSEE in implementation of BAST.

TESTING FACILITIES

Because of the size and complexity of many systems that would incorporate BAST, facilities for testing BAST before deployment offshore tend to be large and costly. Hence, the efficient and effective use of existing capabilities is important to industry in minimizing the costs of proving that a BAST candidate is ready to be deployed offshore. **BSEE should consider creating and maintaining a compendium of worldwide test facilities for determining where best to test introductions into the BAST family *(Recommendation 7)*.** Such a compendium can be created effectively through international cooperation and agreement on how these facilities can be used. It would need to include such items as capabilities, potential effectiveness, location, and availability and to be periodically updated. The effort could begin by creating the U.S. portion of the compendium for use by U.S. industry, and BSEE could take the lead in promoting the implied international cooperation. The compendium process should proactively seek and discuss industry test plans to exploit opportunities for using these facilities more effectively for BAST introduction. This approach could also identify alternative courses of action with regard to the effective use of existing facilities in the United States or overseas and the development of industry- or government-sponsored facilities and complement the current company-centric approach. Any such review of suitable facilities should identify the staff with the expertise to use them.

CHIEF ENGINEER

Complementary to the establishment of OESI, BSEE should consider hiring a highly reputable chief engineer or chief scientist with technical expertise in offshore drilling, exploration, and production to work within the bureau *(Recommendation 8)*. BSEE currently has limited technical staff separate from those with regulatory and oversight responsibilities. BSEE needs to have a small number of technical staff, supervised by a trained and experienced engineer of the caliber of the chief engineer within an operating or service company, who can interface with OESI, understand technologies and their applications, interface with his or her counterparts within industry, and provide critical judgment of industry plans and activities to senior and management staff within BSEE and DOI.

PARTICIPATION OF STAKEHOLDERS

In BAST implementation, many challenges will arise in creating the structures and conditions that will reliably bring the best technologies to the attention of both operators and the regulator and allow the regulator to assess fully the net benefits of applying these technologies in offshore operations. To make informed decisions, BSEE needs to understand the concerns of a range of organizations and individuals with regard to the decisions being made.

BSEE should foster the meaningful involvement of all stakeholders, including industry, environmental organizations, and members of the general public, in providing input to OESI management on long- and short-term areas of focus of its initiatives *(Recommendation 9)*.

1

Introduction

The first offshore wells were drilled along the California coast at the beginning of the 20th century. Land drilling rigs constructed on piers stretching out from the beach into water a few tens of feet deep were used. Since then, the oil and gas industry has greatly extended its operating envelope as it pursues profitable accumulations of hydrocarbons. While the onshore oil and gas business garners most media attention today, as companies large and small develop new resources in shale formations, the offshore industry presses ahead, drilling deeper wells, in deeper water, with new multibillion-dollar development projects announced each year. A recently released study by Wood McKenzie estimates[1] that over the next decade, deepwater activity alone will grow by a compound rate of 9 percent per year, with worldwide spending in 2022 estimated at $114 billion, up from $43 billion in 2012.

To ensure that oil and gas development efforts in federal waters are conducted in a safe manner, Congress has authorized the Department of the Interior to regulate such activities. The Outer Continental Shelf Lands Act (OCSLA) was originally enacted in 1953 and virtually rewritten by the OCSLA Amendments of 1978.[2] Much has transpired since then in exploration technologies and development of oil and gas resources, as well as in the regulatory mechanisms used to control such activities. Nonetheless, many of the challenges associated with implementing the requirement to use the best available and safest technologies (BAST) in such activities remain unchanged after 35 years. A committee of the Marine Board of the National Research Council (1979) first examined the issues associated with the implementation of BAST. In its report, the 1979 committee gave highest priority to government development of "the technological capability to assess and evaluate OCS [outer continental shelf] technologies." It further noted that "the government will require additional expertise for the implementation of

[1]http://www.ogj.com/articles/2013/06/wood-mackenzie-study-sees-deepwater-surge.html?cmpid=EnlEDJune272013. Accessed September 25, 2013.

[2]Public Law 95-372, as amended on September 18, 1978.

the BAST requirement" (NRC 1979, 37). This was at a time when the deepest production platform in U.S. waters was around 1,000 feet and exploration drilling was being conducted by early versions of floating drilling vessels, a far cry from the technology embodied in dynamically positioned rigs such as the *Deepwater Horizon*, capable of drilling in waters up to 8,000 feet deep.[3]

It is therefore not surprising that the Ocean Energy Safety Advisory Committee, a federal advisory group, recommended establishment of an Ocean Energy Safety Institute (OESI), whose functions would include providing support to the Bureau of Safety and Environmental Enforcement (BSEE) in carrying out technology assessment and facilitating BAST implementation.[4] BSEE has, subsequently, initiated a solicitation for the operation and maintenance of an OESI.[5] This committee concurs with the observations and recommendation of the 1979 committee concerning the critical need to augment the regulator's technical capabilities for implementing BAST. Furthermore, this committee notes the difficulty of hiring personnel with both the required expertise in the technologies utilized in the industry and experience in their application offshore. This difficulty becomes particularly acute when the hiring process is constrained by government compensation limits.[6] Therefore, the committee considered the need for BSEE to utilize an outside resource, such as OESI, to assist in implementing BAST successfully, and it supports BSEE's movement in that direction (see Chapter 3).

After the committee began its work, BSEE indicated that OESI would be the primary vehicle for improving BAST implementation.[7] The committee subsequently focused its efforts on assessing the current challenges in implementing BAST and on identifying alternative approaches that may be utilized by BSEE, with the assistance of OESI, in achieving the statutorily required objectives. The committee also assessed the implications for OESI's structure and necessary capabilities.

To support the deliberations and guide the development of its recommendations, the committee made certain interpretations of the wording in Section 21(b) of OCSLA (see Preface) to ensure that the intent of Congress was met, notwithstanding the material changes in the nature of offshore operations since

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[3]http://www.deepwater.com/fw/main/Deepwater-Nautilus-58C15.html?LayoutID=17. The *Deepwater Horizon* was similar to the *Deepwater Nautilus*. Accessed September 25, 2013.

[4]http://www.bsee.gov/uploadedFiles/BSEE/About_BSEE/Public_Engagement/Ocean_Energy_Safety_Advisory_Committee/OESC%20Recommendations%20January%202013%20Meeting%20Chairman%20Letter%20to%20BSEE%20012513.pdf. Accessed September 25, 2013.

[5]http://www.grants.gov/search/search.do?oppId=235604&mode=VIEW. Accessed September 25, 2013.

[6]http://www.opm.gov/policy-data-oversight/pay-leave/pay-administration/fact-sheets/maximum-gs-pay-limitations/. Accessed September 25, 2013.

[7]Joseph Levine, BSEE, briefing to the committee, March 11, 2013.

the act was passed. The following are among the key definitions and assumptions made by the committee:

- "Safest" technology is interpreted as technology that can reduce the risks to workers, the public, and the environment to a point that is consistent with the principle of ALARP (as low as reasonably practicable).[8]
- In this context, the committee took a total system perspective on safety, encompassing occupational safety, process safety, and the safety of supporting elements such as marine systems, in recognition that emphasis should be afforded to aspects of offshore operations that are unique to the industry.
- Noting that the majority of the lives lost in the offshore industry were not due to process safety failures,[9] the committee interpreted "technology" broadly. In the committee's view, the term encompasses not only equipment directly involved in drilling and operating wells but also support systems (e.g., marine systems), safety systems (e.g., explosive gas detectors and blind shear rams), control and display systems (e.g., real-time operations centers), and the human factors considerations that are often central to the causes of major disasters such as the Macondo well blowout.[10] The safe functioning of offshore operations depends on the culture of the organizations involved, which includes interactions among human, organizational, and technological components.
- Practicability is interpreted as encompassing the concepts of technology availability and economic feasibility.

OCSLA recognizes the importance of economic factors but fails to give any guidelines for cost–benefit determinations. OCSLA simply states that the Secretary of the Interior shall require the use of BAST "except where the Secretary determines that the incremental benefits are clearly insufficient to justify the incremental costs of utilizing such technologies."[11] In Chapter 3 the committee discusses the considerations to be included in such cost determinations: the expenses associated with both the acquisition and the sustainment (operations and maintenance) of candidate technologies and potential disruptions to drilling operations caused by the introduction of new technologies that can have significant cost implications.

The challenge of implementing BAST is further complicated by the diversity of drilling and production operations within BSEE's purview. The diversity of operations includes deepwater exploration and development as well as the

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[8]The ALARP principle is becoming generally recognized worldwide. See, for example, http://www.hse.gov.uk/risk/theory/alarpglance.htm. Accessed September 25, 2013.

[9]http://www.oilrigdisasters.co.uk/; http://www.cdc.gov/mmwr/preview/mmwrhtml/mm6216a2.htm. Accessed September 25, 2013.

[10]http://www.nap.edu/openbook.php?record_id=13273&page=3. Accessed September 25, 2013.

[11]OCSLA Section 21(b).

collection and treatment of oil and gas obtained from wells located in shallower water of the outer continental shelf. To provide the desired risk reduction benefit, the candidate technologies must be "fit for purpose"—that is, they must be suitable for the specific intended application.[12] The technologies that are universally applicable as "best available and safest" are likely to be limited.

Chapter 2 addresses various processes BSEE might use for identifying BAST candidate technologies. Chapter 3 provides options for evaluating and developing candidate technologies and discusses economic considerations. Chapter 4 discusses the implications these functions would have for the requisite capabilities of both OESI and BSEE. Finally, Chapter 4 addresses the potential roles for both industry and the public in the BAST process.

[12]The term refers to one of the criteria used by industry to evaluate technology. For example, see Richard Mercier, Offshore Technology Research Center, presentation to the committee, May 30, 2013.

2

Processes for Identifying Technologies

The discovery of new sources of best available and safest technologies (BAST) candidate ideas serves the motivations of both industry and the Bureau of Safety and Environmental Enforcement (BSEE). In this chapter, a number of key advanced technology sources are examined. Ideas and technologies can be introduced (or pushed) through company-sponsored or collaborative research and development, regardless of the original research objective (productivity, expanded drilling regimes, etc.). In addition, potential technology solutions for safety issues can be identified (or pulled) through analyses of drilling systems and systematic assessments of safety incidents and near misses.

TECHNOLOGY PUSH

A combination of factors drives exploration and development activities in drilling and production. They include deepwater discoveries of hydrocarbon reservoirs, favorable economics of high-producing deepwater wells, and the advancement of field-ready deepwater-capable technologies.[1] Offshore exploration, development, and production, particularly in deep water, pose demanding technical challenges, among them high-temperature, high-pressure well characteristics. In addition, low temperatures and high ambient pressures at the sea floor present demanding conditions for the operation of production facilities. As technologies mature, the industry deploys novel technology into production, creating an inherent "push" dynamic of new candidate technologies, including those that enhance safety.

The industry trend to pursue exploration and production activities in deeper waters can be tracked in overall oil and gas production statistics. In 2007, federal offshore tracts accounted for roughly 27 percent of all oil and 14 percent of all natural gas produced in the United States. In 1985, Gulf of Mexico (GOM) deep-

[1] http://www.bsee.gov/Exploration-and-Production/Development-and-Production/Gulf/Gulf-of-Mexico-Deepwater-Information.aspx. Accessed September 25, 2013.

water production accounted for just 7 percent of all offshore production. By 2011, deepwater production accounted for 78.6 percent of oil and 46.8 percent of all GOM offshore gas production.[2] The investments required to construct these deepwater wells have favored economies of scale, with larger offshore drilling and exploration companies, supported by equipment manufacturers and service providers, supplying technologies that increase the productivity and safety of operations.

Generally, such research and development (R&D) activities are developed and sponsored in-house. Successful ideas progress through a series of technology readiness levels before being deployed. However, outer continental shelf (OCS) activities generally demand large capital outlays, and operators sometimes amortize R&D risks, pool resources, and shorten time-to-field by cooperating with each other on joint industry projects (JIPs).[3] JIPs can take various forms and afford the additional benefit of fostering best-practice sharing and acceleration of candidate technologies. JIPs offer the advantages of providing a multiparty collaborative approach and an intellectual property regime that promotes broader cross-industry collaborative candidate technology R&D.

The industry, with the large operating companies in the lead, is providing the most significant injection of new ideas, capabilities, and funding for bringing these ideas to field-ready status. There are many examples of evolutionary or revolutionary "step-change" ideas and technologies that have enabled the deepwater trend. Two examples of safety-enhancing technology are three- and four-dimensional seismic imaging and remote monitoring. In the first, seismic imaging enables more accurate "well-specific" planning to advance drilling techniques for deeper and safer casing programs. Remote monitoring serves as an example of broadly applicable technology that affords greater operational efficiencies and enhanced safety through real-time, 24-hour monitoring of topside and subsea systems from onshore facilities.

As illustrated by the previous two examples, many R&D efforts that provide BAST candidates are initially primarily motivated by productivity gains.[4] Active efforts by the industry in the OCS have triggered increased spending on technologies and approaches that could be candidate technologies or systems for BAST. Since the Macondo well blowout, the industry has increased its focus on safety-enhancing R&D. One major deepwater equipment supplier of blowout preventers estimates that its percentage of BAST-specific R&D has risen as high as 25 percent.[5]

[2]http://www.data.bsee.gov/homepg/data_center/production/production/summary.asp. Accessed September 25, 2013.

[3]http://www.offshore-mag.com/articles/print/volume-70/issue-50/drilling-_completion/dual-gradient-drilling.html. Accessed September 25, 2013.

[4]Bob Judge, GE Oil and Gas, presentation to the committee, May 30, 2013.

[5]Bob Judge, GE Oil and Gas, presentation to the committee, May 30, 2013.

In accordance with industry practice, proven candidate technologies join other BAST innovations and techniques already published in a particular operator's general practices documents. To be included, technologies must have matured and demonstrated positive effects on safety, earning their way into the company's modus operandi. A company's *general practices* represent a summary of the company's best and safest well-specific or broadly applicable technologies and systems that are considered field-proven.[6] ExxonMobil estimates that 10 to 15 percent of these practices involve BAST-related technologies.[7]

Government-sponsored R&D, including government-reimbursed R&D and government-sponsored small-company targeted R&D, is not prevalent within industry. BSEE, via its Technology Assessment and Research (TA&R) efforts, typically has a budget of $1.5 million to $2.0 million per year and covers a variety of research topics.[8] In contrast, private industry funding of related offshore R&D is orders of magnitude higher. The details of R&D spending categories by individual companies are not available, but public records show that ExxonMobil, Shell, Chevron, and ConocoPhillips combined have annual worldwide expenditures for all types of R&D of about $3 billion.[9] The amount spent on offshore and deepwater R&D is not ascertainable, but the importance of the offshore opportunities in each of these companies' portfolios suggests a significant percentage. **While the committee recognizes the safety-enhancing contributions of the TA&R program,[10] its impact is limited by budgetary constraints. BSEE should consider focusing its TA&R efforts on basic and forward-looking collaborative R&D initiatives, where limited funds can provide better leverage. These efforts should seek to include smaller participants, such as engineering houses and smaller independents. These types of funding activities would allow BSEE to leverage the development of candidate technologies through company-sponsored research or collaborative research and development *(Recommendation 2-1)*.**

Understandably, most R&D efforts within the industry are closely guarded. However, there is ample opportunity for BSEE to find avenues of common interest, specifically with regard to sources of candidate safety-enhancing technologies.

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[6]Roald Lokken, ExxonMobil, personal communication, May 30, 2013.

[7]Roald Lokken, ExxonMobil, personal communication, May 30, 2013.

[8]http://www.bsee.gov/Research-and-Training/Technology-Assessment-and-Research/tarprojectcategories/index.aspx. Accessed September 25, 2013.

[9]http://www.rdmag.com/articles/2012/12/industrial-r-d%E2%80%94energy, http://www.statista.com/statistics/245897/research-and-development-costs-of-exxon-mobil, http://www.reports.shell.com/investors-handbook/2011/projectstechnology/rdexpenditure.html. Accessed September 25, 2013.

[10]http://www.doi.gov/deepwaterhorizon/loader.cfm?csModule=security/getfile&PageID=33598. Accessed September 25, 2013.

The decades-long story behind oil and gas production from shale formations in the United States is an example of government and industry each doing what it does best.[11] Although it is concerned with promoting production technology, the example has relevance to the development of technologies that focus on safety. Driven by declining U.S. gas production concerns in the 1970s, early basic research in shale fracturing was done by the U.S. Bureau of Mines and predecessors of the U.S. Department of Energy (DOE) and the National Energy Technology Laboratory, which led to the first demonstration of massive hydraulic fracturing in horizontal wells. Nearly a decade later, a joint DOE–private industry venture completed the first multistage fracking job in a horizontal well. Joint industry funding through the Gas Research Institute led to completion of the first successful wells in the Texas Barnett Shale, which after several years of further development led to the first commercial production and the "gas boom" that followed. In short, basic research was carried out by federal agencies and national laboratories in response to a national need. A commercial opportunity was recognized by an oil company, and the technology was adapted through joint public–private research and then developed and deployed successfully with industry funding. In addition, early production was aided by favorable tax treatment.

When the early-stage research was initiated (early 1970s) and the tax credit was established in law (1980), there was no expectation that the two would combine to help create the resource boom of today. They were both small elements of larger programs that did not attempt to forecast the future of technology and pick winners.

BSEE should consider applying the model for promoting oil and gas production from shale formations with regard to BAST offshore *(Recommendation 2-2)*. Modest government research budgets can be greatly leveraged by focusing on basic research and early technology development. With the level of spending by industry on offshore exploration and production, the skills and expertise that will apply new technologies to industry challenges will be developed within the operating companies, service companies, and equipment manufacturers. The operating and service companies are expected to be aware of ongoing research around which they will develop commercial models and a value proposition for their further development and deployment.

Two other organizational models deserve discussion as potential mechanisms for R&D activities for developing BAST candidates.

1. DeepStar, created in 1991 by Texaco to prepare the industry for the move into deep water, continues to be a premier JIP for deepwater subsea technology development. Its membership has changed over the years, but it currently has 11

[11]See "Where the Shale Gas Revolution Came From," http://thebreakthrough.org/index.php/programs/energy-and-climate/where-the-shale-gas-revolution-came-from. Accessed September 25, 2013.

participating members and 75 or more contributing members.[12] In 2013, some 30 projects with a value of about $7.5 million were overseen by separate technical committees—Geoscience, Reservoir, Flow Assurance, Subsea Facilities, Floating Facilities, Drilling and Completion, Metocean, and Systems Engineering.[13] DeepStar is managed by Chevron, with technical input and future scenario guidance from an overview committee made up of technology managers and leaders from the participating companies.[14]

2. The Research Partnership to Secure Energy for America (RPSEA) operates under the guidance of the Secretary of Energy. It is a consortium that includes representatives from industry, academia, and research institutions. RPSEA has developed a broad-ranging and comprehensive advisory structure that includes program-level and technical-level advisory panels, with industry—large and small companies—and environmental groups represented. The annual budget of approximately $30 million is split about evenly between onshore studies and ultradeepwater studies. The offshore research emphasizes the understanding of system risk and risk reduction by using real-time information and the development of advanced technologies.[15]

BSEE should consider the DeepStar and RPSEA models in multiparty collaboration for insights into how best to utilize the Ocean Energy Safety Institute and the TA&R efforts in implementing BAST *(Recommendation 2-3)*.

TECHNOLOGY PULL

After most major offshore incidents, such as the losses of the *Piper Alpha* and the *Deepwater Horizon* (Macondo well), extensive investigations are conducted to identify the causes that led to the catastrophes and thereby suggest corrective actions to avoid similar events in the future. These investigations, as well as the systematic analyses of operations and near misses,[16] often provide insight into safety issues that warrant focused attention. Such focus areas can serve to "pull" technology applications that can enhance safety and serve the objectives of BAST. The committee notes that the range of such technologies can be broad, from advanced instrumentation to human factors, an area often underappreciated in importance.

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[12]http://www.deepstar.org/attachments/wysiwyg/3140/DeepStar_Supplement_2013-FINAL(1).pdf. Accessed September 25, 2013.

[13]http://www.deepstar.org/PhaseXIOverview/. Accessed September 25, 2013.

[14]http://www.deepstar.org/attachments/wysiwyg/3140/DeepStar_Supplement_2013-FINAL(1).pdf. Accessed September 25, 2013.

[15]http://www.rpsea.org/attachments/contentmanagers/3234/2012%20Annual%20Plan%20Final%208-9-12.pdf. Accessed September 25, 2013.

[16]http://www.gulfpub.com/product.asp?PositionID=&ProductID=2745. Accessed September 25, 2013.

Human Factors

Lessons Learned from Accidents

The *Piper Alpha* and Macondo well offshore disasters are cases in point for which human factors were identified in the accident chain of events. For example, an analysis done by Paté-Cornell (1993) of the *Piper Alpha* accident concluded that most significant causes were "rooted in the organization, its structure, procedures and culture." Similarly, there was common agreement across Macondo well blowout study reports with regard to human factors, including (*a*) pressure to complete well abandonment operations quickly at the risk of safety, (*b*) conduct of simultaneous operations accompanied by poor work team communications, (*c*) misinterpretation of well pressure test data, and (*d*) failure to follow best practices for well drilling and abandonment procedures (*Deepwater Horizon* Study Group 2011; NAE and NRC 2012).[17] Offshore accident data also show evidence of human errors, including the use of an unsafe procedure (37 percent), unsafe acts (44 percent), improper equipment design (8 percent), and other errors (11 percent) (Christou and Konstantinidou 2012).

In other words, offshore oil and gas accidents often were caused by mistakes made in the organizational decision processes and the failure to follow best practices or standard procedures—the causes were, in fact, human failures. The facts concerning offshore disasters and accident statistics support the idea of paying closer attention to organizational and human performance factors as essential in the effective implementation of the BAST regulatory oversight, rulemaking, and approval processes. Such consideration would also help achieve the objectives of BSEE's Safety and Environmental Management Systems regulations to manage the overall safety and environmental aspects in offshore oil and gas operations.[18]

Areas of Human Factors Concern

First, it is believed that the offshore oil and gas industry will experience substantial growth in the application of remote sensing and control systems used to observe well conditions. These control and display systems are complex in operation and maintenance. Some pose a possibility of human error due to complicated control and display interfaces that have a high potential for erroneous user inputs and misinterpretation of data displays. Operators will base critical risk decisions on data obtained from remote sensing and display systems. As in the case of the Macondo well blowout, decisions based on well measures (pres-

[17] http://www.gpo.gov/fdsys/pkg/GPO-OILCOMMISSION/content-detail.html. Accessed September 27, 2013.

[18] http://www.bsee.gov/Regulations-and-Guidance/Safety-and-Environmental-Management-Systems---SEMS/Fact-Sheet.aspx. Accessed September 25, 2013.

sure and chemical composition of well fluids) can have serious consequences for health, safety, and the environment if they are wrong (*Deepwater Horizon* Study Group 2011).

Second, advanced computer-driven algorithms that sometimes include artificial intelligence (intelligent agents) are increasingly used to reduce operator workload and to improve task efficiency. The introduction of high levels of automation historically has led to some operator complacency (because of the assumption, based on the high reliability typically observed in automation, that the automation is working as intended, when it sometimes does not) and to operator confusion concerning system operating modes and automated functions (Parasuraman and Riley 1997).

"Human factors" are factors or variables in the human–system interface that affect the performance of individuals, work crews, and organizations in a work environment. The intent of human factors engineering is to reduce the frequency of human error by systematic design and management processes at all levels of personnel performance. The following factors are taken into consideration:

- Individual worker—personnel qualifications, training, and experience;
- Environment and equipment design—worker task complexity, work space design and working conditions, workload and fatigue, local supervision (Salvendy 1997; Wickens et al. 2004; International Association of Oil and Gas Producers 2011);
- Crew or team—crew composition (mix of skill sets, national origin, language, and culture), workplace supervision, on-the-job communications and task coordination, team or crew resource management training (Helmreich and Merritt 2000; Bjellos 2012); and
- Organization—leadership style, commitment to safe operations versus production, adequacy of resources (time and materials), working conditions, organizational and safety cultures[19] (Ciavarelli 2007; Roberts 1993; Weick and Sutcliffe 2007; NAE and NRC 2012; TRB 2012). An emphasis on safety culture by an organization's leadership recognizes inherent operational risks and takes appropriate measures to ensure the safety of key operations.

As part of BAST implementation, BSEE should appropriately consider human factors aspects given their impact on recent offshore disasters worldwide. All too often there is a tendency to focus on component technologies (*Recommendation 2-4)*.

[19]On May 10, 2013, BSEE issued a safety culture policy statement. https://www.federalregister.gov/articles/2013/05/10/2013-11117/final-safety-culture-policy-statement. Accessed September 25, 2013.

Reporting Near Miss and Accident Data

Christou and Konstantinidou (2012), in their extensive review of offshore accidents, stated that there is a critical need for a robust safety reporting system that documents incidents (near misses) as well as accidents. The reporting system should maintain a database for analysis of trends and for use by industry in conducting risk management activities leading to BAST candidate identification. The following are some of the main hazards and risks that should be addressed:

- Unintended release of hydrocarbons,
- Loss of well control,
- Failure of a safety-critical element,
- Vessel collisions or near collisions,
- Helicopter misses and crashes,
- Fatal accident or serious injury,
- Evacuation of personnel in response to non-weather-related events,
- Release of hazardous materials beyond some specified de minimis level, and
- Damage to the environment apparent in the short term.

The authors identified common sources of worldwide data available now. Among them are

- Health and Safety Executive, United Kingdom;
- SINTEF (Stiftelsen for Industriell og Teknisk Forskning), Norway; and
- International Association of Oil and Gas Producers.

The National Aeronautics and Space Administration's (NASA's) Aviation Safety Reporting System (ASRS) is an example for BSEE to consider in creating a nonpunitive system for workers to report safety incidents (near misses) anonymously. ASRS has served in alerting members of the aviation community to events that might compromise safety for more than 35 years. The idea is based on the fact that there are many more close-call incidents than accidents, and the type and frequency of incidents provide a valuable database for judging risks associated with the safety of flight and related aviation activities (ASRS 2013). All major aviation organizations can use ASRS as a universal nonpunitive close call or near-miss reporting system. ASRS is sponsored by the Federal Aviation Administration (FAA) (regulator) but administered by NASA as a third-party "neutral" organization that protects the identity of individuals reporting and retains confidentiality of the data.[20] The following are key functions and uses of ASRS:

[20]L. Connell, Aviation Safety Reporting System (ASRS): Program Brief. Prepared for the committee, 2013.

- Alert bulletins and "for your information" notices serve as a "front line" for alerts concerning safety issues or hazards that affect many aviation users.
- Safety reports are from pilots, air traffic controllers, flight attendants, maintenance technicians, and others describing aviation safety events.
- Quick response studies support government organizations such as FAA, the National Transportation Safety Board, and Congress during rulemakings, procedure and airspace design efforts, and accident investigations and in other ad hoc circumstances.
- Operational research: ASRS has conducted and published numerous research studies since the program's inception. ASRS research has always been designed to examine human performance issues in real-world operations.
- Database search requests: Information in the ASRS database is available to interested parties at no cost under Freedom of Information Act provisions.

BSEE executed an agreement with the U.S. Department of Transportation's Bureau of Transportation Statistics (August 2013) to develop a confidential near-miss reporting system for use on the outer continental shelf.[21,22]

Additional and New Data Sources

The offshore oil and gas industry has long depended on sophisticated computational processing and storage systems. The role of seismic imaging and its continued enhancements have provided evidence that "more data are better" (Mayer-Schönberger and Cukier 2013, Chapter 5). The adoption of multiphase subsea meters is one deepwater OCS trend contributing to exponential data growth faced by operators. In this example, images and detailed characterization of the hydrocarbon flow at the seabed level join traditional discrete-data-emitting temperature and pressure sensors.

Remote monitoring and capturing of housekeeping data enable probability modeling to improve estimates of mean time between failures of safety-critical equipment.[23] Similarly, new sources of subsea telemetry enable better at-seabed, closed-loop processing, which allows faster-acting pressure control equipment to increase safety through an enhanced seabed infrastructure.[24] These can serve as sources of BAST candidates.

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[21]http://www.rita.dot.gov/bts/bts_bsee. Accessed November 11, 2013.

[22]The prepublication version of this report, which was issued in October 2013, indicated an agreement had been reached between BSEE and NASA to create a safety reporting system. However, information received after the prepublication report was issued indicated that BSEE executed an agreement with the Bureau of Transportation Statistics to develop a safety reporting system.

[23]http://www.barringer1.com/pdf/Chpt1-5th-edition.pdf. Accessed September 25, 2013.

[24]http://www.gereports.com/ge-oil-gas-launches-smartcenter-for-subsea-wells. Accessed September 25, 2013.

The recent advent of high-speed, subsea-to-shore communication networks and sophisticated sensor packages has helped bring about the establishment of real-time operations centers (RTOCs) by the majors, independents, and providers of deepwater equipment. RTOCs can also be applied to well-specific situations: "In the Gulf of Mexico, a fit-for-purpose use of RTOCs means there is a focus on the prevention of nonproductive time—trouble associated with well control, lost circulation, borehole stability."[25]

Many of these facilities will also provide scenario-planning simulation capability. This will afford trainees the ability to simulate actuation of topside and seabed equipment or respond to simulated emergencies and see effects at a system level. **BSEE should consider the use of RTOCs and simulators to assess decision capabilities under stress *(Recommendation 2-5)*.** (Also see NAE and NRC 2012, 156, Summary Observations 4.12 and 4.13.) The aviation industry, for example, has used recent advancements in desktop and full-scale simulators to provide realistic simulations. They allow a failure to be simulated in a matter of days after an incident.

Risk Assessment

Risk assessment highlights areas where candidate technologies for BAST would materially improve OCS operation safety. Although many variants exist, risk assessments largely fall into either matrix-based approaches or probabilistic risk-based approaches.[26] Generally, OCS operators rely on matrix-based risk assessments that examine the likelihood and severity of failures.[27] These matrix-based approaches are adapted to "broad technology," "category-specific," and "well-specific" scenarios because they are more easily applied in the context of inherent uncertainties and system dynamics faced in real-life drilling and other OCS operations.

New data sources offer the ability to grow data sets significantly and potentially provide additional quantitative sources to enhance risk assessments. Normalized and aggregated cross-industry data would provide empirical and quantitative inputs critical to the development of better baselines for in-use BAST. **BSEE should consider supporting efforts that provide normalized approaches across certain technology classes to obtain inputs for development of better baselines *(Recommendation 2-6)*.** As the Macondo experience suggests, data concerning risk assessment and the use of particular technologies

[25]http://www.drillingcontractor.org/remote-operations-centers-earning-keep-through-drilling-optimization-247-support-%E2%80%98remanning%E2%80%99-6816. Accessed September 25, 2013.

[26]Charlie Williams, Center for Offshore Safety, presentation to the committee, May 30, 2013.

[27]Charlie Williams, Center for Offshore Safety, presentation to the committee, May 30, 2013.

are lacking. BSEE can raise the overall value of risk assessments by considering explicit requirements for data reporting. Broader industry participation in risk assessment normalization and standardization would amplify technology development by exposing BAST deficiencies.

Additional Sources from Other Industries

Many technologies used within the oil and gas industry have been developed elsewhere. **BSEE should consider engaging adjacent industries to accelerate the discovery and enhancement of candidate technologies *(Recommendation 2-7*).** ("Adjacent industries" are industries facing challenges similar to those of the oil and gas industry.) The U.S. aviation industry's top 10 R&D spenders invested $18 billion in 2010 and 2011 combined.[28] Leveraging just a portion of this investment through BSEE-sponsored cross-industry cooperation is one way to access a larger candidate technology R&D pool. For example, advancements in avionics can benefit subsea and topside controls, and well-proven and broadly applicable technologies such as data recorders may have applicability in the OCS (also see NAE and NRC 2012, 156, Recommendation 4.9). Further aviation-specific examples of potential candidate sources include telemetry, closed-loop automation, advanced materials, coatings, advanced testing, safety systems, and modeling techniques.

The U.S. mining and pipeline industries offer technologies that could be used within the oil and gas industry. Mining and offshore drilling face many similar challenges, including uncertainties in geology, highly capable pumping technologies, and gas detection equipment.[29] Other adjacent industries focused on inspection technologies and software could also help in better utilization of new data sources discussed previously and require further investigation through a BSEE-led process of rigorous discovery.

The committee notes that there are significant challenges in adapting technologies from adjacent industries. To be effective, BSEE will need to engage stakeholders in oil and gas and targeted adjacent industries to drive cooperation. BSEE leadership will have to determine the best approach for each interindustry engagement, which might include interindustry JIPs and engagement of national laboratories, academia, and government agencies (e.g., NASA, FAA).

Fostering an understanding of the technologies available and used within adjacent industries offers another potential source of candidate technologies. Given the capital- and resource-intensive nature of OCS-related R&D, even accelerated efforts involve multiyear R&D sponsorship from participating parties.

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[28]http://www.rdmag.com/articles/2012/12/industrial-r-d%E2%80%94aerospace/defense/security. Accessed September 25, 2013.

[29]As a further example of OCS and mining technology leverage, seabed mining equipment has been developed by combining technologies from both industries. See http://www.nautilusminerals.com/s/resourceextraction.asp. Accessed September 25, 2013.

The committee believes that a portfolio of efforts is needed for BSEE to find and solicit advances in candidate technologies and systems. Such efforts can accelerate the introduction of candidate technologies and lead to a key role for BSEE in influencing technology development. For example, BSEE could engage in multiparty collaborations and could focus TA&R efforts on basic and forward-looking collaborative R&D initiatives, where limited funds can provide better leverage. As discussed in the next chapter, better exploitation of these sources of ideas and technologies demands significant additional BSEE resources (including in-house technical domain and program management and personnel training) so that results can be achieved and a higher level of engagement with industry can be sustained.

3

Processes for Evaluating and Developing Technologies

New best available and safest technologies (BAST) will come from many sources, as described above. As new technologies are identified that could be deployed as BAST, the Bureau of Safety and Environmental Enforcement (BSEE) will bear the responsibility for evaluating their potential to increase safety offshore. To do so will require testing, modeling, and analysis that characterize the efficacy of the new technologies and their impact on offshore systems. BSEE will need access to people with the right experience and skills so that the agency understands not only the technologies being evaluated but also how they are incorporated into the complex systems used in offshore exploration and production.

EVALUATION METHODOLOGIES

Candidate technologies will need to be evaluated in many ways. As standalone technologies, the performance of the mechanical and material components themselves is often easiest to characterize fully. **This characterization will often come from the original source of the technology, but in the event that it is incomplete or missing, BSEE should be prepared to perform the necessary tests or to utilize external laboratories and technical resources to have this work done.**

Just as important, BSEE should take a system-level view of any technology and its impact on safety that considers not only the individual technology but also the overall complexity of the integrated drilling or production system and the interactions of individual components, subsystems, and systems, including human factors. Such evaluations must recognize the complexity and implications of the limited understanding of the geologic environment in which the engineered and human systems are embedded and operating (*Recommendation 3-1*).

The performance and failure modes of individual components can be straightforward and easy to assess. The behavior of complex systems, however, can be much harder to predict, and unintended consequences of altering one component of a system can lead to failures elsewhere. In addition, the interfaces of individuals, work crews, and organizations with technology are key determinants of system-level safety. BSEE has the responsibility for evaluating technologies given this complexity and for recommending as BAST those that materially improve offshore safety and whose incremental costs can be justified given the effect on safety, health, and the environment.

A concept such as "technology readiness level" (TRL) can be useful in assessing the maturity of technologies and could be of value to BSEE in the development and assessment of BAST.[1] TRL is typically assigned on a numeric scale. For example, a TRL of 1 may designate basic research, while a TRL of 9 may indicate technologies that have been tested within operating systems and are fully operational. In the middle range, a TRL of 5 through 7 can indicate demonstration projects of varying complexity and maturity. **BSEE should consider using a metric such as TRL, with levels established on the basis of explicit criteria, in categorizing BAST and communicating with industry on technology maturation *(Recommendation 3-2).***

Reliability and Risk Analysis

Whenever a technology component is introduced into oil and gas operations, the question of how it will affect systemwide reliability and safety arises. For proposed new technologies, trustworthy answers may be difficult or impossible to obtain before the decision is made whether to deploy the technology. Although many methods of engineering reliability and risk analysis have been developed to help anticipate and reduce risks of failures in technological systems, none completely overcomes the complexity and uncertainty inherent in managing risks of new technologies in oil and gas exploration and production.

Electronic, hydraulic, mechanical, software, hardware, and human components and subsystems interact at multiple points in the normal control and safe operation of a drilling rig, production platform, or other offshore facility. They may also interact in different, unexpected ways during an accident (e.g., due to common-mode failures), so it is necessary to consider not only whether new technologies introduced into one subsystem will perform as planned within that subsystem but also how they might interact in unintended ways with other subsystems, especially during emergencies. Perrow's theory of "normal accidents"[2] suggests that the complexity and tight coupling of interactions among these sub-

[1]http://www.hq.nasa.gov/office/codeq/trl/trl.pdf. Accessed September 25, 2013.
[2]http://press.princeton.edu/titles/6596.html. Accessed September 25, 2013.

systems can be expected to cause accidents that cannot easily be foreseen or prevented.

Methods of risk analysis can help to anticipate and prevent at least some accident scenarios, and full advantage of this limited help should be taken. The following are examples:

- *Risk matrices, priority lists, rankings, ratings,* and *scores* are often used to document expert opinions and perceptions about the frequencies and severities of types of accidents and accident precursors. Although their validity may be difficult to establish in the absence of data, such qualitative and semiquantitative methods can at least help those who use them to remain mindful of the risks that have been identified.
- *Fault tree analysis* can help to reason systematically about how undesirable end states (e.g., failure of an electronic control module) might occur. It reasons backward from supposing that such a "top event" happens to identify combinations of events and conditions that could cause the event. This can help to identify potential failure paths and suggest countermeasures to prevent them in systems with well-understood components and possible causes of failure.
- *Event tree analysis* helps to reason forward systematically from the assumed occurrence of one or more initiating events (e.g., failure of a component, fire in a control room) to their possible consequences, again identifying paths that lead to catastrophic outcomes.
- *Bayesian networks, influence diagrams,* and *probabilistic expert systems* provide a flexible set of software and computational tools for identifying possible (and, data permitting, most likely) failure paths in complex systems. They are able to integrate expert judgments, statistical analyses, and probability models (e.g., for component reliabilities and failures).
- *Stochastic simulation models* of systems operations and rare failure events can help to quantify the time until (or between) different kinds of failures, including cascades of events leading to catastrophic outcomes—if useful input data are available on conditional failure rates and dependencies. For new technologies, such data are usually not available, and even methods such as accelerated life testing cannot easily furnish dependable surrogate data for large, complex systems.
- *Design of experiments and testing protocols:* Statistical and operations research methods have been developed to optimize sequential and adaptive testing protocols for reliability systems (e.g., by testing first the components of a series system with the greatest failure probability per unit of testing cost, to minimize the expected cost of determining whether the series system will perform when needed).
- *Statistical risk models* and *data analysis* can be applied to accident precursors and near misses to help make best use of experience as it accumulates and provide early warnings of potential failure modes.

All of these methods can offer some insight into system safety associated with particular technologies, but the limitations inherent in each cannot be overstated. The offshore operating environment, particularly during the exploration phase, cannot be fully or accurately characterized or modeled, and all of the methods described above are limited by significant uncertainties in the characterization of the subsurface environment. Other analytic approaches emphasize the importance of human and organizational factors and safety culture in complex sociotechnical systems (e.g., Qureshi 2007). However, the major insights from these approaches are most applicable to assessment of ongoing operations rather than to incorporation of new technologies.

An incomplete understanding of potential interactions of new components or subsystems with the larger systems and operating environments into which they are integrated will also limit the effectiveness of all of these methods of risk analysis. Substituting a new, possibly safer, technology for an established one raises the possibility that partly known old risks are simply exchanged for less well-known new ones. Important concerns have arisen in other areas of risk analysis—for example, green chemistry (where some believe that regulatory programs intended to prevent the use of old chemicals suspected of possibly harming health have led to the "regrettable substitution" of new chemicals that harm health),[3] pharmaceutical safety [where some observers have expressed concerns that bans on the use of animal antibiotics, intended to reduce the spread of resistant organisms, have instead led to more animal and human illnesses and to increases in therapeutic antibiotic use for both animals and people (Hayes and Jensen 2003)], and complex engineering systems (e.g., Chernobyl, where testing of shutdown power to the main circulating pumps contributed to loss of control of the reactor).[4]

The practical lesson from much of applied risk analysis is that models and methods such as those just mentioned can help to reduce some risks, especially risks that can be identified by systematic consideration of possible event sequences and behaviors of well-understood systems, but they cannot eliminate all of the major uncertainties that surround introduction of new technologies into complex, tightly coupled systems. In characterizing the offshore environment and technologies deployed in that environment, important uncertainties will inevitably remain.

Economic Analyses

BSEE is required to assess the economic impacts of alternative options for BAST. Quantitative economic analyses of safety technologies for offshore drill-

[3]http://www.nytimes.com/2013/03/31/us/osha-emphasizes-safety-health-risks-fester.html?pagewanted=all&_r=0. Accessed September 25, 2013.

[4]http://www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Chernobyl-Accident/#.UfdWcJXn-Uk. Accessed September 25, 2013.

ing are considerably more challenging than are similar efforts in other domains, such as transportation, where large numbers of accidents afford well-established statistical data. The scarcity of data with regard to low-probability, high-impact offshore accidents makes it exceptionally difficult to quantify risks and therefore ascribe dollar values to safety technologies.

The economic test established in the statute is consistent with these analytic realities. The statute establishes a cost test for evaluating a technology option, mandating "the use of the best available and safest technologies which the Secretary determines to be economically feasible, wherever failure of equipment would have a significant effect on safety, health, or the environment. . . ."

In carrying out the economic feasibility analysis—the test that is required under this provision—the committee notes that BSEE will need to consider three types of costs:

- Capital or initial acquisition costs of the technology,
- Operating and maintenance costs associated with the technology, and
- Potential impacts on the reliability and efficiency of the drilling and production systems.

The assessment of the capital and operating costs of candidate technologies will be relatively straightforward. However, many of these technologies will be fairly new, and therefore the uncertainties in these cost estimates will be greater than uncertainties in estimates for technologies that have longer track records. The data limitation with respect to newer technologies is even more of an impediment in assessing potential impacts on reliability and efficiency. Estimates of the costs of a disruption or degradation of operations will inevitably be coupled with considerable use of "best engineering judgment" and qualitative assessments concerning the likelihood of these effects occurring.

Although the impacts on reliability could be treated as an operating cost, separating them is useful because of their economic importance. The committee heard from several industry representatives that adverse impacts on reliability and resultant shutdowns in operations can impose large costs.[5] This factor therefore weighs heavily in industry considerations with regard to the required introduction of new technologies and practices into offshore drilling and production operations that may not be fit for purpose. BSEE will need to decide how much weight to give this factor in its own economic feasibility deliberations.

In those instances where the Secretary uses her or his discretion to proceed to the second step described in the statute to determine whether the "incremental benefits are clearly insufficient to justify the incremental costs,"[6] BSEE will need to develop an assessment of the incremental benefits of a proposed technology and compare them with the incremental costs. Benefits could include

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[5]Presentations to the committee on May 30, 2013, at its meeting in Houston, Texas.
[6]Section 21(b), Public Law 95-372, as amended on September 18, 1978.

- Reduced risk of accidents,
- Mitigation of impacts if an accident were to occur, and
- Any ancillary benefits associated with the new technology (such as a reduction in unplanned outages).

The committee notes the extreme difficulty of constructing quantitative estimates of the reduced risk of offshore accidents or likely reductions in their severity as the result of the installation of a safety technology. For example, in a benefit–cost analysis, a key benefit of a better safety technology would be the product of two factors: the cost of an accident if it were to occur and the reduction in the probability of it occurring if the new technology is adopted. A simplistic example is a new technology that would reduce the risk of a $1 billion accident by 10 percent. The benefit would be valued at $100 million. Quantifying the two factors would be exceedingly difficult. First, the costs of a hypothetical accident would be difficult to predict beyond qualitative statements that the type of accident prevented would probably result in small, medium, or large costs. Attaching a number to the second factor—how likely is it that an accident would occur without the new technology and how much less likely would it become if the technology is adopted—is equally problematic if not more so. The previous section on probabilistic risk assessment provides insights into how difficult these types of determinations will be. **In view of the challenges associated with technology assessments and economic analyses and of the role played by expert judgments, BSEE should seek access to the requisite expertise, including a multidisciplinary group of individuals with economic, engineering, and scientific skills; access to experts with unique technical skills; and the ability to request independent reviews *(Recommendation 3-3)*.**

The committee also notes that, since the economic analyses will tend to be qualitative, the acquisition by BSEE of senior staff with the skills for both understanding these complexities and uncertainties and effectively communicating them to senior U.S. Department of the Interior (DOI) officials will be important.

It would be unfortunate if the regulatory and permitting processes become bogged down by the unrealistic expectation that economic analyses will create a "bright line" for decision makers with regard to what constitutes BAST. Additional data and analyses will provide valuable insights and help BSEE evaluate the roles of qualitative and quantitative risk assessment approaches in narrowing the range of risk possibilities and making BAST determinations. Recognition of the need to apply sound judgment will be needed.

Personnel, Skills, and Experience

Building new and necessary competencies within BSEE will be an enormous challenge. Historically, the regulator has relied heavily on operating companies to provide the bulk of technical work. As BSEE enhances its role in the evaluation of BAST, it will need access to personnel with experience not comparable with that of personnel in its predecessor agencies. Potential solutions will be discussed in Chapter 4. For the evaluation of BAST, the key will be to have access to staff with knowledge of and experience with the specific systems and technologies being developed as well as a working knowledge of how the technology is used and the environment in which it will be deployed. BSEE will need to know what working on an offshore facility or onshore in a real-time operations center is like so that it can bring the necessary judgment into the BAST evaluation process.

In addition, BSEE will need to know where available skills and expertise are in industry, academia, and government. Within the federal government, there are significant resources in the national laboratories that can be utilized through cooperative agreements, but BSEE needs to know who these people are to access them when needed. As BSEE builds closer technical relationships with industry and academia, it can also become aware of centers of expertise that can be called on. This and other personnel issues will be discussed in more detail in Chapter 4.

In November 2010, Secretary of the Interior Ken Salazar proposed the formation of an "Ocean Energy Safety Institute" (OESI) in partial response to the *Deepwater Horizon* oil spill to assist BSEE by facilitating R&D, training, and implementation of operational improvements in offshore drilling safety and environmental protection. BSEE has initiated a solicitation for the operation and maintenance of an OESI that is intended to be a source of technical support to BSEE for BAST implementation. The committee considers this to be a suitable vehicle for identifying, evaluating, and maturing new technologies that would materially improve safety in offshore operations. If properly organized, staffed, and supported, OESI could be a key source of advice to BSEE for BAST development and evaluation and could help in solving problems associated with a government agency competing with industry for top talent and expertise.

Other government agencies and departments have effectively used different models to manage new and developing technologies, such as federally funded research and development centers and university-affiliated research centers. These models will be addressed in some detail in Chapter 4.

TECHNOLOGY DEVELOPMENT AND MATURATION

Through several decades of offshore exploration and development, technology has been critical in enabling industry to move into progressively more complex and challenging environments. Basic and applied research has resulted in key advances in exploration, production, and safety technologies incorporated into offshore operations today.

In carrying out its BAST responsibilities, BSEE should consider the acquisition and maintenance of an in-depth understanding of existing industry and government capabilities for development, evaluation, and testing of technologies to be a priority *(Recommendation 3-4)*. Resources in industry, government, and academia as well as joint and international facilities need to be assessed. An accounting of these capabilities will include what exists, who has access to it, what organizations and people have the knowledge and skills to carry out testing and development activities, and where the gaps are. This knowledge will allow BSEE to set priorities between basic and applied research as well as steer funding toward work on BAST that can have the greatest impact.

Roles and Processes

Investment in technology maturation, whether for operational or safety systems, has in the past come predominantly from industry. It has been carried out in operating and service company research centers, in joint industry projects (e.g., DeepStar, Gas Research Institute), and through company-sponsored research at universities. Over the past two decades, industry research has shifted more to technology development and deployment targeting specific assets or asset classes (deep water, tight formations) and away from basic research, leaving a gap that can be filled by government-sponsored research.

In considering the development and maturation of BAST, multiple paths and processes are likely. Technologies and research necessary for the development, maturation, and approval of BAST will vary with the technologies involved. Different approaches (subject to the availability of funds) could be established for different categories of technologies, such as the following:

- High-priority critical technologies [e.g., blowout preventer (BOP)[7] and wellhead instrumentation];
- Long-term technology development goals;
- Out-of-the-box ideas that lend themselves to a model similar to the Defense Advanced Research Projects Agency;
- Big-picture questions that might be addressed with an X-Prize model; and
- Small, short-term seed funding of novel ideas from many quarters [e.g., U.S. Department of Defense Small Business Innovation Research (SBIR) model].

Whatever the categories, they will require different levels of funding and management support, will vary between basic and applied research, and will operate over different time frames. BSEE will need a knowledgeable advisory group to allocate its own limited resources effectively and manage the flow and maturation of ideas coming from these different processes.

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[7]See Chapter 3 of NAE and NRC 2012 for recommended improvements to BOP systems.

The amount of money available for government-sponsored research is small compared with industry R&D spending. These smaller budget levels lend themselves to basic research, where the costs are modest compared with maturing engineered systems for deployment, and there can be great leverage in funding early and basic technology development. Historically, this has been the principal area of government-funded research investment in oil and gas as well as in other areas of science and technology; the typically much larger investments required to mature technologies can be made by companies with a commercial interest in their success and deployment.

There are significant potential roles here for OESI in advising BSEE: to steer federal spending in safety-related research toward early-stage technology development and to make that research known to industry so that BAST can be matured and deployed. Applied research and development is largely conducted by private interests, to whom an assessment of risks associated with their investments is of critical importance.

Available Resources and Incentives

In funding research for new technology offshore, the federal government invests on behalf of the public, and industry invests on behalf of its shareholders. While federal funding comes from many sources [e.g., the Department of Energy (DOE), DOI], it has been limited compared with that of industry, and the committee believes that this may well continue to be so.

In the case of BAST, the Secretary will make the determination that a specific technology meets the requirements for BAST and mandate its use. However, a stronger business case for the adoption of new safety technologies could result in a greater industry focus on technology for BAST and shorten their development and deployment times. **Although industry may develop a business case for potential technologies, including those considered for BAST, BSEE should consider using legislative or regulatory incentives to speed the deployment of new safety technologies *(Recommendation 3-5)*.** Broad and focused incentives collectively would afford BSEE influence on technology development paths across “broadly applicable,” “category-specific,” and “well-specific” areas. Examples of incentives, some of which have been applied in the past, are the following:

- Favorable tax treatment for investments in research in safety technologies (e.g., a research tax credit model);
- Placement of permits at the front of the queue for wells and facilities that incorporate new safety-enhancing technologies or that are used to develop or demonstrate new technologies, or the incorporation of “best value” concepts in leasing and permitting (this would require close cooperation between BSEE and operators during the well planning and deployment phases);

- X-Prize-type incentives for members of academia and other independent entities to develop deepwater candidate technology (e.g., the Wendy Schmidt Oil Cleanup X Challenge);[8]
- Modest royalty relief for projects that incorporate new technologies (as has been done in the past to motivate industry to develop marginal deepwater fields);[9]
- Awards within DOE, DOI, and other federal agencies for valuable federal, state, and local government employee contributions to outer continental shelf BAST;
- A BAST prize cosponsored by DOI and industry through the Offshore Technology Conference or a similar visible venue; and
- The establishment of an SBIR program or a small business technology transfer program, which could help broaden participation to smaller industry participants.[10]

Favorable treatment might be extended to low-risk operating environments where new safety technologies could be deployed first with minimum risk to gain valuable operating data and experience.

Organization and Facilities

As discussed in Chapter 2, there are several examples of organizations that address exploration and production technology development and maturation. The oil and gas industry has successfully used joint industry projects, public–private partnerships, and academic consortia to address many technology challenges. In the past when new technology development was critical for the success of a major project, operating companies have formed alliances with equipment manufacturers to develop and test the necessary technology and move it quickly through maturation to deployment.

In considering technology resources, test facilities merit special attention. Because of the size and complexity of many BAST systems, such as existing and future BOPs, test facilities tend to be large and costly. Hence, the efficient and effective use of existing capabilities is important to industry in minimizing the costs of proving that BAST systems are ready to be deployed for uses offshore.

BSEE should consider creating and maintaining a compendium of worldwide test facilities for determining where best to test introductions into the BAST family *(Recommendation 3-6)*. Such a compendium can be created effectively through international cooperation and agreement on how these

[8]http://www.iprizecleanoceans.org/. Accessed September 25, 2013.
[9]30 CFR 203 Subpart A—Relief or Reduction in Royalty Rates.
[10]http://www.acq.osd.mil/osbp/sbir/about/index.shtml. Accessed September 25, 2013.

facilities can be used. It would need to include such items as capabilities, potential effectiveness, location, and availability and would need periodic updating. The effort could begin with creation of the U.S. portion of the compendium for use by the U.S. industry, and BSEE could take the lead in promoting the implied international cooperation. The compendium process should proactively seek and discuss industry plans for using test facilities more effectively for BAST introduction. BSEE should strive to gather information from any relevant existing compilations.

The compendium of available facilities should be accompanied by a review that identifies the staff with the expertise to use them. As BSEE builds closer technical relationships with industry and academia, it can become aware of centers of expertise that can be called on. OESI could have the role of compiling a characterization of offshore skills and competencies and maintaining it on an ongoing basis.

BSEE should consider testing for new BAST capabilities by using combinations of scale models and full-size prototypes, systems, subsystems, and modeling and simulation. Such testing should be done in static and dynamic environments *(Recommendation 3-7)*. Testing on a given BAST will likely involve a combination of verification (i.e., whether it meets its design intent and specification) and validation (i.e., whether it satisfies the needs and intent of the customer, including necessary margins). In addition, specific reliability testing will likely be required to show that a given BAST meets its reliability objectives.

Facilities for the integrated and full-scale wet testing of offshore technologies will have special challenges given the scale of offshore systems. Individual companies may have difficulty in justifying the expense, so such large test facilities might be operated by industry consortia or might be U.S. government facilities, if funding permits.

The essence of the above is that several types of tests are required to ensure that a potential BAST is certified for deployment.

Simulation of actual application environments will be difficult. Therefore, modeling and simulation will be important adjuncts to mechanical and electrical testing. However, modeling and simulation are useful only when the model's predictive capability has been verified by test and operational data. In complex offshore systems, data adequate for full evaluation of models and simulations are unlikely to exist. Therefore, judgment will be required in assessing the maturity of BAST, which will again necessitate access to personnel with the right skills and experience.

In the specific area of offshore safety, the post-Macondo creation of the Marine Well Containment Company[11] and the Helix Well Containment Group[12] may offer models that can be followed in other areas where significant invest-

[11]https://marinewellcontainment.com/. Accessed September 25, 2013.
[12]http://www.hwcg.org/. Accessed September 25, 2013.

ment is needed that will have a broad impact on industry's license to operate.[13] In both cases, industry has been successful in focusing significant resources on a critical and complex problem and in building industrywide solutions and capability without government assistance.

With the above background, it is the committee's view that BSEE needs a trusted agent to assist BSEE in evaluating test plans and assessing the effectiveness and reliability of new systems before recommending certification that any new BAST is ready for operational use. This function could logically be accomplished under the expanded role being suggested for OESI, which will be discussed in Chapter 4.

[13]NTL No. 2010-N10. Statement of Compliance with Applicable Regulations and Evaluation of Information Demonstrating Adequate Spill Response and Well Containment Resources. http://www.bsee.gov/Regulations-and-Guidance/Notices-to-Lessees-and-Operators.aspx. Accessed September 25, 2013.

4

Implementation Mechanisms

In this chapter, the implications of the necessary capabilities of the Bureau of Safety and Environmental Enforcement (BSEE) for the development and evaluation of best available and safest technologies (BAST) are discussed. The roles of industry and the public in the BAST process are addressed.

BSEE ORGANIZATION AND BAST

The legal authority for implementing the federal offshore law, the Outer Continental Shelf Lands Act (OCSLA), including the BAST requirement, resides with the Secretary of the Interior, who, in turn, has delegated much of the authority for promoting safety and environmental enforcement to BSEE. Within that bureau, the Office of Offshore Regulatory Programs develops and maintains up-to-date regulations, policies, standards, and guidelines for BAST practices that govern industry's offshore operations nationwide. It oversees BSEE's compliance activities and ensures appropriate and effective enforcement actions.[1] The current organization chart of BSEE is shown in Figure 4-1.

Since BSEE and the Bureau of Ocean Energy Management (BOEM) are charged with overseeing the industry's energy exploration and production in the OCS, they must grasp emerging technologies for exploration, development, and production. In the committee's view, BSEE needs an agent that is competent and trusted (i.e., free of conflict) and that has the resources to assess new exploration technologies and their system applications. The agent would have the responsibility of evaluating design, test protocols, and test results on behalf of BSEE to certify new BAST items having health, safety, and environment ramifications. The Ocean Energy Safety Institute (OESI) could augment BSEE in this regard.

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[1]BSEE Leadership. http://www.bsee.gov/About-BSEE/BSEE-Leadership/Index.aspx. Accessed September 25, 2013.

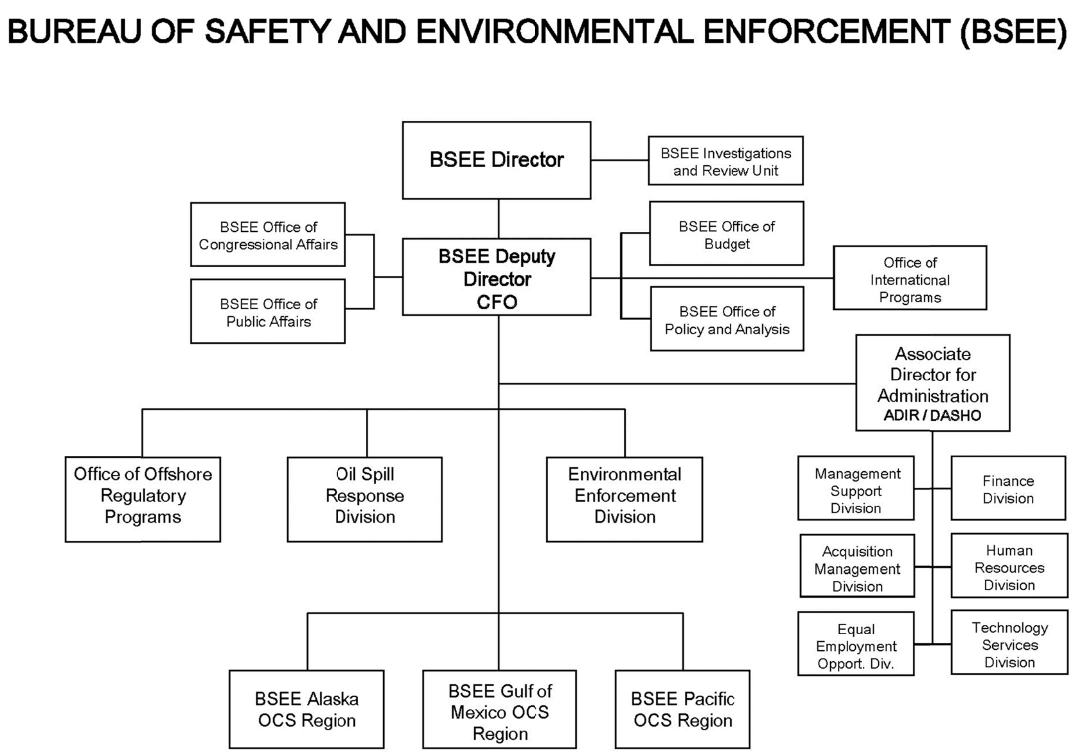

FIGURE 4-1 Organization of BSEE. (ADIR = Assistant Director for Information Resources; CFO= Chief Financial Officer; DASHO = Designated Agency Safety and Health Official.) Source: http://www.bsee.gov/About-BSEE/index.aspx. Accessed September 27, 2013.

Ocean Energy Safety Institute

In May 2013, BSEE announced a competitive request-for-proposal process to establish an independent OESI to support BSEE by enhancing safe and responsible operations across the offshore oil and gas industry, thus fulfilling a major recommendation of the Ocean Energy Safety Advisory Committee.[2] BSEE announced that it would seek proposals "for the establishment of an Institute that will facilitate research and development, training of federal workers on identification and verification of Best Available and Safest Technology (BAST), and implementation of operational improvements in the areas of offshore drilling safety and environmental protection, blowout containment and oil spill response. OESI will be a collaborative initiative involving government, academia and scientific experts. The recipient institution(s) receiving the award will be responsible for managing OESI, providing input on yearly objectives, conducting certain work to further the attainment of those objectives, and being a focal point for collaboration on issues within the OESI mandate."[3]

As identified in the program announcement by BSEE, "the primary mission of the OESI is to provide a forum for dialogue, shared learning, and cooperative research among academia, government, industry and other non-governmental organizations, in offshore energy-related technologies and activities that ensure safe and environmentally responsible offshore operations" (BSEE and BOEM 2013, 2). In the committee's view, one of the major challenges for OESI will be to provide knowledgeable independent assessments concerning technology maturity, suitability (fitness for purpose), and cost. In addition, OESI will face key challenges that are typical at the start-up of this type of organization, such as hiring the initial staff and receiving sustained funding to allow it to mature.

Up to $5 million (over 5 years) will be made available to launch OESI. "This funding is intended to pay for the startup costs of the OESI, which will include the salaries of up to three staff, workshops and forums, and research and related activities" (BSEE and BOEM 2013, 3). The project is intended for state and county government agencies and for public and state-controlled institutions of higher education. Federal entities are allowed as partners (BSEE and BOEM 2013, 6).

A key question is whether the substantial expectations for OESI can be met with the proposed funding level. In examining the OESI concept, the committee discussed options for alternative structures, lessons learned from similar organizations, and the importance of the location of the institute.

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[2]http://www.bsee.gov/uploadedFiles/BSEE/About_BSEE/Public_Engagement/Ocean_Energy_Safety_Advisory_Committee/OESC%20Recommendations%20January%202013%20Meeting%20Chairman%20Letter%20to%20BSEE%20012513.pdf. Accessed September 25, 2013.

[3]http://www.grants.gov/search/search.do?mode=VIEW&oppId=235604. Accessed September 25, 2013.

However it is organized, OESI should serve BSEE as a technical center that captures and preserves knowledge and experience to improve offshore operations. It should become the knowledge repository and "corporate memory" that BSEE can use as offshore operations expand and technologies are developed and introduced. In this context, the staff and organization of OESI must be reasonably stable over the decades-long periods that characterize offshore operations and facility lifetimes. The committee believes that this should be taken into account if hosting and management of OESI are recompeted on a regular basis.[4]

Options for Alternative Structures

The committee supports BSEE's formation of OESI and offers the following comments concerning structure and governance options and potential impact on the intent and capabilities of OESI.

Three organization options that have been used at the federal level to perform functions not dissimilar to OESI are the federally funded research and development center (FFRDC), the university-affiliated research center (UARC), and grants. The committee did not consider the option of a government-owned or government-operated (GO/GO) laboratory because of BSEE's expressed preference in its request for proposal for a third party to establish an independent OESI. GO/GO laboratories are predominantly staffed by federal employees.

Federally Funded Research and Development Center

An FFRDC is sponsored and funded by a government agency such as the Department of Defense, the Department of Transportation, or the Department of Energy (DOE). Its purpose is to fulfill special long-term research and development needs that are not met effectively by in-house staff or a project-specific contractor. The primary focus areas for existing FFRDCs are (*a*) systems engineering and integration centers, (*b*) study and analysis centers, and (*c*) research and development centers (including national laboratories).

The agency sponsoring agreement is spelled out in Federal Acquisition Regulation 35.017-1. The agreement identifies the purpose and mission of an FFRDC. It provides for the orderly termination or nonrenewal of the agreement. It directs how any retained earnings may be used, and it prohibits an FFRDC from competing against any non-FFRDC (except to operate an FFRDC). The agreement also determines whether the FFRDC can accept work from organizations other than the sponsor.

There are approximately 40 FFRDCs today. Examples include the Aerospace Corporation, Rand Corporation, and Sandia National Laboratories. The government agency's annual funding for each of these FFRDCs can range from

[4]Presentation, Joseph Levine, BSEE, March 11, 2013.

a few million dollars to over $2 billion, depending on the size and scope of the agreements. Specifically, Sandia's budget on behalf of DOE exceeds $2 billion.

In general, FFRDCs are stand-alone entities with their own personnel pay and benefits packages. However, the senior management structure for the operation may be changed periodically by the sponsoring agency via a competitive process.

There are several advantages for an agency in sponsoring an FFRDC. The FFRDC will develop a comprehensive knowledge of the sponsor's needs. It can adapt its resources to current needs and can respond quickly when conditions change. It is required by federal regulation to be free of organizational conflicts of interest and therefore can maintain its objectivity (GAO 2008). An FFRDC is not bound by the federal government's personnel hiring and compensation practices. Therefore, it can recruit personnel whose skills and commensurate market value place them out of reach of the civil service pay structure (Howieson et al. 2013, 13).

The ability to provide long-term technical continuity for the agency is also important. In general, FFRDCs have broad access to both government and commercial proprietary information to supplement their own inherent capabilities. The primary disadvantage for the sponsoring agency is that it must provide a degree of annual funding stability to maintain and effectively use these advantages.

University-Affiliated Research Center

A UARC is a government research center that is affiliated with a university. It operates similarly to an FFRDC, but education is an important part of its charter. The management structure is provided by the university.

A UARC's advantages are essentially the same as those of an FFRDC. Its most significant disadvantage is that the focus on the sponsoring government agency can be constrained by university interests. Specifically, the focus on education can affect the type of work that the UARC can undertake and complicate issues such as acquiring proprietary technology.

There are approximately 15 UARCs today sponsored by the Department of Defense and the National Aeronautics and Space Administration (NASA). Examples include the Georgia Tech Research Institute and the Johns Hopkins University Applied Physics Laboratory. Federal funding for UARCs varies in amount. The UARC at the University of California, Santa Cruz, funded by NASA Ames, has an annual budget of about $23 million.[5]

Grants

Grants provide a means for an organization to have requested services performed over a set period. Grantees are usually selected on the basis of a compet-

[5]http://uarc.ucsc.edu/about/. Accessed September 25, 2013.

itive proposal bidding process in response to a grantor's request-for-proposal solicitation. Universities, nonprofit organizations, and commercial entities can receive grants, as can state and local governments. Grants can take the form of research grants, education grants, training grants, or facilities grants. Grantees must follow the terms and conditions of the grant agreement and periodically provide progress and financial reports.

For government agencies, grants provide capabilities and expertise needed to support agency programs. They also provide a major source of funding for educational institutions and nonprofit organizations. One disadvantage is that grant funding availability is limited and not of long duration, so bidders are not motivated to make long-term investments in personnel or equipment. The recent BSEE announcement seeking proposals from qualified organizations or institutions to enter into a cooperative agreement for 5 years with funding of up to $5 million for the operation of OESI (BSEE and BOEM 2013) is an example of a potential grantor's request-for-proposal solicitation.

The committee supports the initial formation of OESI through a grant process. **However, BSEE should consider expanding OESI's charter to allow it to evolve into an FFRDC or a UARC, since such a structure would provide a more stable approach and foundation for long-term operation *(Recommendation 4-1)*.** As mentioned previously, one of the challenges for OESI will be to provide knowledgeable independent assessments with regard to technology maturity, suitability (fitness for purpose), and cost.

Regardless of the structure or governance model selected for OESI, extensive study of similar organizations reveals that their success hinges most critically on "high-quality technical expertise and a trusting relationship between laboratory leaders and their sponsor agencies" (Howieson et al. 2013, 14), which ultimately reflects the quality of the governing board rather than the specific model chosen.

Lessons from Other Organizations

The way in which private organizations that support regulators are structured and function can provide valuable lessons and examples to BSEE. Classification societies provide classification and statutory services to the maritime industry and regulatory bodies with regard to maritime safety and pollution prevention. The life-cycle process of classification (i.e., design evaluation, construction, and in-service evaluation and monitoring throughout service life) are applicable to critical equipment such as blowout preventers as well as other equipment or systems related to BAST.

SINTEF (Stiftelsen for Industriell og Teknisk Forskning, the Foundation for Scientific and Industrial Research) is the largest independent, noncommercial research organization in Scandinavia. Its proximity to a university environment enables SINTEF to have joint use of university laboratories and equipment and to have access to university research and faculty personnel, including those who are retired. See Appendix B for additional discussion of classification societies and SINTEF.

The committee did not consider classification societies or SINTEF as possible models for OESI because the U.S. government is limited in its ability to create private enterprises such as these. FFRDCs and UARCs are the most similar types of organization in the U.S. system. Some FFRDCs and UARCs have evolved into broader, private nonprofit enterprises, but only after they were formed by using the prescribed mechanisms for U.S. government investment.

Governance

Under any of the options for structuring OESI, a governance board will likely be not only desirable but necessary, and its quality will likely determine the organization's effectiveness.

The governance structure of OESI should be consistent with its mission. According to the program announcement, "this project will be a collaborative venture with the Recipient, including substantial involvement of the BSEE and BOEM. OESI will be a collaborative initiative involving government, academia and scientific experts. The recipient institution(s) receiving the award will be responsible for managing OESI, providing input on yearly objectives, conducting certain work to further the attainment of those objectives, and being a focal point for collaboration on issues within the OESI mandate" (BSEE and BOEM 2013, 2). As noted above, the initial funding of OESI is intended for qualified county or state agencies and public or state-controlled institutions of higher education, which will have implications for its governance.

BSEE could view the initial grant as "seed money" that will enable the institute to evolve into a more robust organization with the involvement of industry participants as well. This is anticipated in the program announcement, which requires the recipient's proposal to "include a strategy that will allow the institute to continue to fulfill its mission and should consider industry participation as well as any other potential opportunities for funding" (BSEE and BOEM 2013, 5). In addition, administration of OESI by a governance body that monitors the focus, quality, and value of the institute's work would be consistent with the governance practices of an FFRDC or a UARC.

The committee envisions that the staff of OESI will include members from the recipient's organization and from BSEE. In addition, the institute may be able to leverage the technical expertise and experience of industry by involving secondees from industry who would support the research and development activities of the personnel of the institute. Secondees would be expected to rotate back to industry after an engagement with the institute for periods ranging from several weeks to more than a year. Such industry involvement is important in ensuring that OESI is able to prioritize and focus on the key technological and regulatory gaps as well as risks and challenges related to offshore oil and gas exploration and production technology. Industry involvement would also ensure that OESI remains current with the evolving technology.

BSEE should consider establishing two governing committees to provide oversight and guidance for (*a*) coordination of OESI in terms of its overall policy and direction and (*b*) a guarantee of the quality of the academic and scientific research programs that it pursues *(Recommendation 4-2)*. The first might be termed a governance board or a board of advisers. It would include representatives from the primary stakeholders associated with the institute: BSEE and BOEM (the federal agencies), industry, academia, and standards organizations. The governance board would be responsible for identifying opportunities for testing and research and for setting priorities and recommending funding levels associated with the activities of the institute.

The second committee might be called the research committee, engineering committee, or science advisory board. It would be chaired by the lead scientist or engineer of the institute. Such a committee, which would be separate from the governing board, could be important in steering the technical resources of OESI and maintaining relationships with industry and other government agencies. Its membership would include team leaders of research activities related to such areas as innovations in drilling and production equipment, safety systems, oil spill response, and the identification and verification of BAST. The committee would provide technical oversight of the conduct of engineering and research projects and ensure the relevance and the quality of these efforts in supporting deepwater and Arctic exploration and development.

OESI should give high priority to developing its relationships with operating and service companies, equipment manufacturers, academia, other federal departments, and national laboratories that may be the source of technology or resources *(Recommendation 4-3)*. The oil and gas industry maintains facilities and laboratories that can be of great value to OESI.

Location

A body of knowledge and experience is available to a nascent OESI, but it is largely developed within the oil and gas industry and nurtured within the technical departments of operators, service companies, and equipment manufacturers. The committee believes that consideration should be given to locating OESI in an area near offshore drilling and exploration activities, such as the Gulf States region. This would facilitate attracting retirees and others with industry experience and assist in the ongoing dialogue with industry.

The geographic center of this industry is in the greater Houston area along the Texas Gulf Coast. BSEE should consider locating OESI in that area to encourage the free flow of technology from industry to the institute and to afford access to the large pool of industry retirees, who could form a cadre of institute employees and consultants *(Recommendation 4-4)*. This would also facilitate the temporary assignment of industry personnel to OESI (and vice versa) for the purposes of technology transfer and the growth of broad

OESI capabilities, including those necessary for aiding BSEE in the identification, maturation, and implementation of BAST.

The location of other government-sponsored technology efforts close to industry has proved to be successful (e.g., NASA's Jet Propulsion Laboratory in Pasadena, California). The movement of staff between the institute and industry also follows successful past models; similar movements between the oil industry and government agencies occur in Great Britain.

PEOPLE AND SKILLS

Industry skills and expertise are developed and grown in the operating companies, service companies, and equipment manufacturers, as is evidenced by the level of spending by industry in offshore exploration and production. BSEE has embarked on an aggressive hiring and training campaign in the past 2 years, but it cannot realistically be expected to match industry in technical depth or breadth. However, as it continues with its recruiting program to attract new science, geoscience, and engineering graduates into government service, there are many ways in which BSEE can take advantage of the expertise built by industry:

- Develop and grow its new-hire training program and take advantage of industry training to ensure that its staff is as technically comparable with industry peers as possible.
- Pursue involvement of industry retirees, who represent a robust technical resource. Many retirees immediately go back to work for other companies, but some are looking for a career change and should be pursued by both BSEE and OESI. Developing ongoing and active relationships with companies and professional organizations will expose BSEE and OESI to this resource and will provide these industry retirees with new opportunities.
- Consider models for cross-postings of BSEE and OESI technical staff to and from industry. Cross-postings are carried out successfully in other federal agencies with safety oversight responsibilities in technically demanding fields. The Federal Aviation Administration is one example.[6] This can be effective in striving for technical parity with industry and in developing mutual respect between BSEE, OESI, and industry. Regulators in Europe have used this method successfully.
- Develop models for recognizing long-term exemplary safety contributions by individuals. For example, working with the professional organizations, BSEE or OESI could establish criteria for recognizing "safety fellows" within industry, government, and academia. Such an award, if treated as a significant accomplishment by BSEE and industry, would emphasize the importance of individual contributions to offshore system safety.

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[6]http://www.faa.gov/about/plans_reports/media/2013/AVS_FY2013_Business-Plan_12-12-10.pdf. Accessed September 25, 2013.

Given the competitive nature of the oil and gas industry and industry staffing needs, BSEE may be limited in its ability to attract and retain technical staff. Federal resourcing criteria will make it difficult to compete with industry for the best graduates and experienced staff; therefore, BSEE needs to be open to new resourcing models. Flexibility afforded through OESI could be valuable in creating these new models, and OESI could provide the "home" for many technical staff, cross-posted industry staff, and consultants.

Complementary to the establishment of OESI, BSEE should consider hiring a highly reputable chief engineer or chief scientist with technical expertise in offshore drilling, exploration, and production to work within the bureau *(Recommendation 4-5)*. BSEE currently has limited technical staff separate from those with technical degrees but with regulatory and oversight responsibilities. BSEE needs a small number of technical staff, supervised by a trained and experienced engineer of the caliber of the chief engineer within an operating or service company, who can interface with a (remote) OESI, understand technologies and their applications, interface with his or her counterparts within industry, and provide critical judgment concerning industry plans and activities to senior and management staff within BSEE and the Department of the Interior. A BSEE chief engineer should have qualifications and a résumé comparable with those of a chief engineer or discipline chief within a major oil or service company. In addition, BSEE would benefit from an in-house capability of providing the director with an assessment of technical issues such as BAST that is independent of oversight and regulatory responsibilities. Such capability could be achieved, for example, by creating the position of chief scientist or chief engineer and filling it with a highly reputable expert who could communicate effectively with industry, OESI, and the director.

Role of Stakeholders

As indicated above, BSEE will be the prime agent in defining how the industry and other interest groups engage in the implementation of the safety and environmental provisions of the OCSLA, including the application of BAST.

In the definition and implementation of BAST, BSEE has the opportunity to engage the expertise of industry in the shared goal of delivering safe and economic energy to the nation.[7]

In addition, technology-focused input from a variety of other stakeholders would add a dimension and a perspective that could be beneficial to BSEE in establishing a clear, balanced, effective, and meaningful BAST standard.

All interested parties understand that, in the aftermath of the Macondo well blowout, BSEE has engaged in reviewing, revising, and strengthening its

[7] http://www.bsee.gov/uploadedFiles/BSEE/BSEE_Newsroom/Speeches/2013/BSEE-and-USCG-OTC-Presentation-2013.pdf. Accessed September 25, 2013.

safety and environmental regulations, particularly those affecting deepwater exploration and production.[8] In the implementation of BAST, there will be many challenges in creating the structures and conditions that will reliably bring the best technologies to the attention of both operators and the regulator and that will allow the regulator to assess the net benefits of applying these technologies in offshore operations. To make fully informed decisions, it is important for BSEE to understand the concerns of a range of organizations and individuals who have an interest in the decisions being made. The establishment of OESI opens an opportunity for cooperative efforts among BSEE, industry, and other stakeholders on technology development initiatives. **BSEE should foster the meaningful involvement of all stakeholders, including industry, environmental organizations, and members of the general public, in providing input to OESI management on long- and short-term areas of focus of its initiatives *(Recommendation 4-6)*.** A recent example of broad involvement of all stakeholders in an agency–industry conference was shown in the June 2013 National Energy Board of Canada Safety Forum.[9]

Suggested Mechanism for BSEE to Obtain Input and Guidance

In the implementation of BAST, BSEE has an opportunity to redefine the relationship between it and industry more as a partnership—one that recognizes that the final authority remains with the federal agency but in which the agency acknowledges that industry has much technological expertise to offer. The committee believes that a proper arms-length relationship between the regulator and the regulated is consistent with a well-managed joint endeavor. It should be a professional relationship based on a clear understanding of the roles and drivers that benefit both the government (safety and environment) and the offshore industry. BSEE's unique position as regulator and permit issuer gives it an opportunity to set the stage for mutually beneficial interactions with, and within, industry and other interested and engaged entities. In addition to the formal processes suggested below, BSEE is encouraged to initiate a regular cycle of discovery, including visits to involved companies of all types to meet with engineers, product leaders, and those deploying technology in situ.

BSEE, either directly or through OESI, should consider the following interactions primarily with industry; other stakeholders would be engaged as appropriate:

- Forums would consider and evaluate best practices in a system safety context. They reflect what an operator or other members of industry consider to

[8] http://www.bsee.gov/uploadedFiles/BSEE/BSEE_Newsroom/Speeches/2012/Speech-OTC%20Breakfast%20Keynote-05-01-2012.pdf. Accessed September 25, 2013.

[9] http://www.neb-one.gc.ca/clf-nsi/rsftyndthnvrnmnt/sfty/nbsftyfrm2013/prgrm-eng.html. Accessed September 25, 2013.

be best practice and will aid in the overall understanding of the development and implementation of BAST.

- Workshops would evaluate technology readiness in given areas of current and future needs. They could help in accelerating efforts to adopt candidate technologies.[10]
- Low-likelihood, high-consequence scenario planning should receive consideration. The question of what should be done in the extremely rare event with high consequence deserves the attention and leadership of BSEE, with the support of technical leaders from industry. Such planning should not exclude the assessment of likelihood of occurrence, but neither should it become an esoteric exercise in competing risk assessment approaches, such as quantitative risk assessment, probabilistic risk assessments, and risk matrices.
- Cold-eye assessment is a concept under which those with expertise are brought in to evaluate a situation. In this application, BSEE could empanel experts to aid in its reviews of topics for which its internal expertise is not sufficient. A deepwater operation plan with new and unusual technology features might be an example of such a situation. Other examples could be related to longer-term evaluations of specific or general technology assessments.
- Industry, through its many associations and joint industry projects, has ongoing suites of programs to evaluate current technology status and future needs. Recognizing that budget funds are limited, BSEE should evaluate options and explore opportunities to join selected studies as full paying members or, as sometimes is offered, as an observer.

COMMITTEE'S NET ASSESSMENT

Having considered options for the establishment and evaluation of BAST, the committee recognizes that there will be many challenges in creating the structures and environment that will reliably bring the best technologies to the attention of both operating companies and the regulator and that will allow the regulator to assess fully the net benefits of applying these technologies in offshore operations.

OESI, as currently proposed by BSEE, is the beginning of a process that could provide BSEE with the tools and expertise to evaluate systems and technologies and identify those materially improving safety in offshore operations.

While the direction proposed in the BSEE announcement of OESI is good, the scale and structure of the institute will need to expand to address the challenges posed in the offshore environment. More than 3 years since Macondo, industry activity has increased to the point where approximately 70 drilling rigs were active in the U.S. Gulf of Mexico in July 2013, and a steady stream of large development projects are ongoing or planned.[11] With industry spending

[10]BSEE, 1st Domestic and International Standards Workshop, November 14-15, 2012.
[11]http://www.rigzone.com/data/utilization_region.asp. Accessed September 25, 2013.

several billion dollars per year on drilling and development activities (see Chapter 1), technology moves ahead constantly, and OESI will be important in enabling BSEE and the regulatory environment to keep up.

However, to be effective, the scale of OESI will need to be much greater than that described in the initial announcement. OESI will need to be located where it can readily access experienced staff and interact with industry. **BSEE should consider OESI structures that facilitate the retention of knowledge and experience *(Recommendation 4-7)*.**

The committee believes that the funding level proposed in the BSEE announcement is not adequate for achieving these ends. As discussed earlier in this chapter, various structures can be used in building OESI. However, examination of similar efforts in technology identification and assessment undertaken in the past indicates that the funding commitment to OESI will need to be consistently in the range of several million dollars per year to attract and grow the skills and competencies required, to monitor and keep pace with industry technology developments, and to shape and support the research programs to assess and mature beneficial technologies.

The committee is also concerned that OESI, as initially described, does not allow for the development of the institutional knowledge and memory that will be required to steer and promote the necessary technology development for BAST. A technical core within OESI that follows industry developments over many years and is able to recognize and respond to trends and developments in a timely manner will be needed. The regular recompeting of OESI could make this difficult, particularly at the budgetary level announced, because growth and retention of a stable core of technical and managerial expertise that will be necessary over the decades-long time scales that are common in the offshore industry will not be possible. Complementary to the establishment of OESI, BSEE would benefit from having its own in-house highly reputable chief engineer or chief scientist with technical expertise in offshore drilling and exploration.

In sum, the committee believes that for the effective implementation of BAST, the technical expertise and resources in BSEE and OESI need to evolve along the lines indicated by the body of recommendations in this report.

References

Abbreviations

ASRS	Aviation Safety Reporting System
BOEM	Bureau of Ocean Energy Management
BSEE	Bureau of Safety and Environmental Enforcement
GAO	U.S. Government Accountability Office
NAE	National Academy of Engineering
NRC	National Research Council
TRB	Transportation Research Board

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Appendix A

Statement of Task

An ad hoc committee will identify options the Department of Interior's Bureau of Safety and Environmental Enforcement (BSEE) could use for improving the implementation of the "best available and safest technologies" (BAST) requirement in the Outer Continental Shelf Lands Act. As the committee develops options, it will review those options and issues that BSEE itself already is considering; examples of which include the feasibility and appropriateness of establishing a formal industry committee to make BAST determinations about new and improved technologies; whether it will need to develop test protocols for every technology it evaluates in order to fairly compare competing technologies; how to determine economic feasibility in a manner that is independent of industry; whether it should rely on the development of consensus standards; and whether it should initiate a more vigorous process with various possible improvements to blowout preventers. The committee will identify a range of options and the pros and cons of each, but it will not recommend a specific BAST implementation approach.

Following its initial meeting, the committee will prepare a brief report commenting on existing BSEE proposals to implement BAST. In developing its final report at the conclusion of its study, the committee will include consideration of the following:

- Other relevant safety requirements that bear upon technologies for offshore oil and gas operations;
- Relevant reports of previous NRC committees and other organizations;
- The potential role of neutral third parties in making BAST assessments;
- The role of human factors in the safe use of technologies by industry; and
- Resource requirements of federal agencies for BAST implementation.

Appendix B

Lessons from Other Organizations for Best Available and Safest Technologies Implementation

CLASSIFICATION SOCIETIES

Classification societies have played an integral role in the development of safety in shipping and maritime commerce over the past 150 to 250 years (Evangelista et al. 2013; Watson et al. 2010). How a classification society is structured and functions can provide valuable lessons and examples of an organization working collaboratively with, yet independently of, the industry it regulates.

The internationally recognized classification societies are the 13 members of the International Association of Classification Societies (IACS), which collectively class more than 90 percent of all commercial tonnage in international trade.[1] IACS, a nongovernmental observer at the International Maritime Organization (IMO), is the voice for its member classification societies at IMO. Classification societies are nongovernmental and are generally organized as nonprofits that operate worldwide. They are funded by the fees they collect in performing classification services. Classification societies establish and apply technical standards, also known as class rules, for the design, construction, and survey of marine-related facilities, including ships and offshore structures. The rules are issued and published by the classification society. A vessel that has been designed and built to the appropriate rules of a classification society may apply for a certificate of classification from that society. The society issues the certificate

[1]IACS members are as follows: American Bureau of Shipping, Bureau Veritas, China Classification Society, Croatian Register of Shipping, Det Norske Veritas, Germanischer Lloyd, Indian Register of Shipping, Korean Register of Shipping, Lloyd's Register, Nippon Kaiji Kyokai, Polish Register of Shipping, RINA, and Russian Maritime Register of Shipping. See http://iacs.org.uk/Explained/members.aspx. Accessed September 25, 2013.

on satisfactory compliance with society rules and the completion of the relevant surveys (IACS 2011).

Class rules are developed to assess the structural strength and integrity of the hull structure and the reliability and the function of the propulsion, steering, electrical, and mechanical systems. Class rules are developed and updated by technical committees consisting of eminent industry representatives from around the world who are experts in their field. The classification process consists of the following:

- Technical review of design drawings and related documents by class engineers to verify compliance with applicable class rules;
- Attendance at the shipyard by class surveyors during construction of the vessel or offshore structure and at relevant production facilities of key components to verify that the construction and products are in accordance with class rules;
- Issuance of a classification certificate when the preceding steps have been satisfactorily completed; and
- Once a vessel or offshore structure is in service, the performance by class surveyors of periodic surveys on board to verify that it is maintained to the applicable class rules over the lifetime that the vessel or structure remains in class.

Classification societies maintain an extensive database of damage and failure data from surveys performed on their classed vessels in service, which serves as a basis for developing and updating class rules. They also maintain an in-house research and development staff to conduct studies on maritime-related topics in support of class rules that exist or are under development. Classification societies have their own in-house training centers, where engineers and surveyors undergo regular training and certification to maintain their knowledge of the latest rules and regulations as well as state-of-the-art technology developments.

Although classification societies are nongovernmental organizations, flag state administrations—such as the U.S. Coast Guard; Transport Canada; the U.K. Maritime and Coastguard Agency; and those of Panama, Liberia, and others—under whose laws the vessel or structure is registered will delegate the inspection and survey of the vessel or structure to classification societies.

In summary, classification societies have long been viewed as independent and trusted agents by the industry they serve, including government regulatory agencies. Classification societies have no conflict of interest with the parties that they serve, such as builders, operators, charterers, marine underwriters, and financial institutions. The technical development of the classification rules is done in a transparent fashion with industry input. Classification certifies adherence to the class rules over the service life of a vessel or offshore structure.

Some lessons learned from classification societies have applications to the Bureau of Safety and Environmental Enforcement or the Ocean Energy Safety Institute (OESI) in enhancing safety in offshore drilling and production, including best available and safest technologies (BAST). One example is the life-cycle process of classification (i.e., design evaluation, construction, and in-service evaluation and monitoring throughout service life), which is applicable to critical equipment such as blowout preventers and other equipment or systems related to BAST. Another example is the development and maintenance of a worldwide incident or failure database or safety reporting system. Such a system for BAST could capture data that provide a basis for technology improvements and development, BAST performance evaluation, safety and reliability analysis, and standards improvement and development, among others. Such a database is useful for compiling data not only from the outer continental shelf (OCS) but also from other areas of offshore drilling and exploration (e.g., offshore Brazil, Africa, Norway, the United Kingdom). One of the specified tasks for OESI is to "develop and maintain a domestic and international equipment failure reporting system and database of critical OCS equipment failures related to control of the well" (BSEE and BOEM 2013, 4).

SINTEF

SINTEF (Stiftelsen for Industriell og Teknisk Forskning) was established in 1950 as a private, nonprofit research group. It is organized in the form of a foundation with a number of subsidiary companies. SINTEF operates in partnership with the Norwegian University of Science and Technology (NTNU) in Trondheim and collaborates closely with the University of Oslo and other national and international research institutions. SINTEF also receives funding from the Research Council of Norway,[2] which defines and invests in short- and long-term strategic research topics for the nation. NTNU personnel work on SINTEF projects, while many SINTEF staff members teach at NTNU. The partnership involves the extensive joint use of laboratories and equipment, with many of the staff employed by both NTNU and SINTEF. SINTEF conducts technological and industrially oriented research to meet the need for research and development in the public and private sectors. It is organized into eight research institutes, among them the Petroleum Research Institute and the Norwegian Marine Technology Research Institute (MARINTEK). MARINTEK is a supplier of research and development services for industry and the public sector in the field of marine technology for companies in the shipping, marine equipment, ocean energy, and offshore oil and gas industries. MARINTEK's facilities include several laboratories. Among them are the Ship Model Tank for hydrodynamic performance investigations of ships in waves; the Ocean Basin Laboratory for testing and verification of marine and offshore structures in various ocean and wind environments; and the Energy–Machinery Laboratory for testing of experimental equipment, instrumentation, and data acquisition systems. MARINTEK works extensively with national and international oil companies, equipment

[2] http://www.forskningsradet.no/en/Home_page/1177315753906. Accessed September 25, 2013.

suppliers, and engineering companies worldwide on projects related to oil and gas fields in the Gulf of Mexico, Brazil, West Africa, the North Sea, Southeast Asia, and Australia.[3]

Lessons from SINTEF are applicable to OESI. For example, SINTEF's proximity to a university environment (i.e., NTNU) ensures the availability of personnel with a strong scientific background for research projects. Many retired NTNU professors are also employed by SINTEF. Proximity to a university allows joint use of university laboratories and equipment and access to university research and faculty personnel, including retirees. Opportunities arise for a broad network of knowledge and research through international cooperation and collaboration with industry and other research organizations. For example, SINTEF Petroleum Research helped in the development of an advanced three-dimensional oil drilling simulator for a major oil company. Its purpose is to improve the safety and efficiency of drilling operations. The development efforts were carried out in collaboration with several other Norwegian companies.[4] In view of SINTEF's approach, OESI would focus not only on technology developments and research for the OCS but also on such activities in other offshore environments. Working with university research and faculty personnel can also foster international cooperation, given the nature of their own international network and their cooperation with peers.

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Abbreviations

BOEM	Bureau of Ocean Energy Management
BSEE	Bureau of Safety and Environmental Enforcement
IACS	International Association of Classification Societies

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Study Committee Biographical Information

Committee on Options for Implementing the Requirement of Best Available and Safest Technologies for Offshore Oil and Gas Operations

Donald C. Winter, *Chair,* is an Independent Consultant and Professor of Engineering Practice in the Department of Naval Architecture and Marine Engineering at the University of Michigan. He served as the 74th Secretary of the Navy from January 2006 to March 2009. As Secretary of the Navy, he led America's Navy and Marine Corps team and was responsible for an annual budget in excess of $125 billion and almost 900,000 people. Previously, Dr. Winter held multiple positions in the aerospace and defense industry as systems engineer, program manager, and corporate executive. He served as chair of the National Academy of Engineering and National Research Council Committee on the Analysis of Causes of the *Deepwater Horizon* Explosion, Fire, and Oil Spill to Identify Measures to Prevent Similar Accidents in the Future. He received a doctorate in physics from the University of Michigan. Dr. Winter is also a graduate of the University of Southern California Management Policy Institute; the University of California, Los Angeles, Executive Program; and the Harvard University Program for Senior Executives in National and International Security. In 2002, he was elected a member of the National Academy of Engineering.

Paul M. Bommer is a Senior Lecturer in Petroleum Engineering in the Department of Petroleum and Geosystems Engineering at the University of Texas at Austin. He is a major contributor to publications of the University of Texas Petroleum Extension Service, including books on oil well drilling and fundamentals of petroleum. Dr. Bommer was a member of the National Oceanic and Atmospheric Administration–U.S. Geological Survey Flow Rate Technical Group concerning oil rate estimates escaping from the BP Mississippi Canyon 252-001

(Macondo) well. In 1979, he cofounded Bommer Engineering Company, which is an oil and gas consulting company specializing in drilling and production operations and oil and gas appraisals. He is a registered professional engineer in the state of Texas. Dr. Bommer served as a member of the National Academy of Engineering and National Research Council Committee on the Analysis of Causes of the *Deepwater Horizon* Explosion, Fire, and Oil Spill to Identify Measures to Prevent Similar Accidents in the Future. He received a PhD in petroleum engineering from the University of Texas at Austin.

Robert Brenner joined the Nicholas Institute for Environmental Policy Solutions at Duke University as a senior fellow in October 2011. At the institute, he assesses the cost-effective technologies, policies, and regulatory approaches that can be used, in conjunction with the Clean Air Act, to meet air quality goals for multiple pollutants and sources. Before joining Duke, Mr. Brenner served in the U.S. Environmental Protection Agency (EPA) for 32 years. In August 2011 he retired from his role at EPA as Director of the Office of Policy Analysis and Review in the Office of Air and Radiation, where he was focused on finding innovative, cost-effective ways to implement the Clean Air Act, particularly through the use of market-based approaches such as emissions trading and other economic incentives. Before starting with EPA in 1979, Mr. Brenner worked at Princeton University's Center for International Studies. He holds a bachelor's degree and a master's degree in economics and public policy from Princeton University.

Anthony P. Ciavarelli is President and Chief Scientist of Human Factors Associates, Inc., which provides advice to various industries on organizational and operational safety improvement. He is also a retired Professor of Applied Psychology, Naval Postgraduate School, where he taught and conducted research on human factors and training technology. He served as Associate Provost for Instruction at the Naval Postgraduate School from 1999 to 2001, where he was responsible for supervising curriculum updates, faculty development, and faculty academic services. Dr. Ciavarelli has a broad technical background that includes training requirements analysis, system engineering development, and human–machine interface design gained over more than 20 years in the aerospace and defense industries. He is an experienced human factors engineer and research psychologist and conducted research in military aircrew training and human performance assessment before joining the faculty at the Naval Postgraduate School in 1989. Dr. Ciavarelli was initially assigned to the School of Aviation Safety (Naval Postgraduate School), where he taught human factors and air safety for 15 years and conducted research designed to improve individual, team, and organizational performance. He was awarded tenure in 1996 and promoted to full professor in 1999. His most recent human research is focused on identifying organizational factors in accident causation. He and a research team from the Naval Postgraduate School and the University of California, Berkeley, developed a web-based Organizational Safety Climate Assessment

System that is now in use in Naval Aviation and U.S. Marine Corps ground forces to assess leadership commitment to safety, safety program effectiveness, and safety culture. He has developed similar online organizational surveys for a variety of civilian aviation organizations and for use in aerospace and medical applications. Dr. Ciavarelli received an EdD from the University of Southern California in education, and he has a master's degree in experimental psychology from California State University at Los Angeles.

Louis Anthony (Tony) Cox, Jr., is President of Cox Associates, an applied research company specializing in quantitative health risk assessment, causal modeling, probabilistic and statistical risk analysis, data mining, and operations research based in Denver, Colorado. Since 1986, Cox Associates mathematicians and scientists have developed and applied computer simulation and biomathematical models, statistical and epidemiological risk analyses, causal data mining techniques, and operations research and artificial intelligence risk and decision models to improve health, business, and engineering risk analysis and decision making for public- and private-sector clients. Dr. Cox holds a PhD in risk analysis and an SM in operations research, both from Massachusetts Institute of Technology's (MIT's) Department of Electrical Engineering and Computer Science. He has an AB from Harvard University and is a graduate of the Stanford Executive Program. He is a member of the National Research Council Board on Mathematical Sciences and Their Applications and is Honorary Full Professor of Mathematics at the University of Colorado at Denver, where he has lectured on biomathematics, health risk modeling, computational statistics, and causality. Dr. Cox is on the Faculties of the Center for Computational Mathematics and the Center for Computational Biology at the University of Colorado at Denver and is Clinical Professor of Preventive Medicine and Biometrics at the University of Colorado Health Sciences Center, where he has focused on uncertainty analysis and causation in epidemiological studies. He was elected to the National Academy of Engineering in 2012.

James S. Dyer holds the Fondren Centennial Chair in the McCombs School of Business at the University of Texas at Austin. In 1999, he received the College of Business Administration Foundation Advisory Council Award for Outstanding Research Contributions. He served as chair of the Department of Information, Risk, and Operations Management from 1988 to 1997. He was the Philip J. Rust Visiting Professor of Business at the Darden Business School at the University of Virginia in 1999. Dr. Dyer is the former president of the Decision Analysis Society of the Operations Research Society of America [now the Institute for Operations Research and the Management Sciences (INFORMS)]. He received the Frank P. Ramsey Award for outstanding career achievements from the Decision Analysis Society of INFORMS in 2002. He was named a fellow of INFORMS in 2006 and received the Multiple Criteria Decision Making Society's Edgeworth-Pareto Award in 2006. Dr. Dyer has consulted with a number of companies concerning the application of decision and risk analysis tools to a variety of practical problems, including the Jet Propulsion Laboratories, the Rand Corporation, and the Department of Energy. He has published three books and more than 60 articles on risk analysis and investment science. His recent articles focus on decision making, including a multiattribute utility analysis for the disposition of weapons-grade plutonium in the United States and Russia. He received a BA with honors, Phi Beta Kappa, in physics with minors in mathematics and philosophy and a PhD in business quantitative methods and management from the University of Texas at Austin.

Thomas R. Kitsos served as the Executive Director of the U.S. Commission on Ocean Policy (USCOP) from 2001 to 2004. In 2005, Dr. Kitsos retired from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce, as the Associate Deputy Assistant Administrator for Ocean Services. He is currently a private consultant on national ocean policy, advising the Joint Ocean Commission Initiative, the follow-up, foundation-supported organization composed of the members of USCOP and the privately funded Pew Ocean Commission and dedicated to promoting ocean policy reform proposals recommended by the two commissions. His earlier experience included 6 years at the Department of the Interior (DOI), where his primary responsibilities were in the area of energy development on the outer continental shelf. Among other positions, he served as special assistant to the Assistant Secretary, Land and Minerals Management, and as Acting Director of the Minerals Management Service. Before his tenure at DOI, Dr. Kitsos spent 20 years on Capitol Hill on the staff of the U.S. House of Representatives' Committee on Merchant Marine and Fisheries. His final position with the committee was Chief Counsel, advising the Chairman on national ocean and coastal issues, offshore energy development, and environmental and other marine management legislation, including amendments to the Outer Continental Shelf Lands Act and the Coastal Zone Management Act. Dr. Kitsos served as a consultant to the DOI's Outer Continental Shelf Safety Advisory Board, which submitted a report to the Secretary (September 1, 2010) on the *Deepwater Horizon* accident. He served as a member of the National Research Council Committee on the Effectiveness of Safety and Environmental Management Systems for Outer Continental Shelf Oil and Gas Operations. He holds BS degrees in education and social science from the Eastern Illinois University and an MA and a PhD in political science from the University of Illinois.

Donald Liu is retired Executive Vice President and Chief Technology Officer for the American Bureau of Shipping (ABS). His research focuses on structural dynamics, hull loading, structural stability, and probabilistic methods of structural analysis. He received the Gibbs Brothers Medal from the National Academy of Sciences for outstanding contributions in the fields of naval architecture and marine engineering. He served on the National Research Council's Committee on the Oil Pollution Act of 1990 Implementation Review and on its Committee on Naval Engineering in the 21st Century. He serves on the Marine Board and as a member of the board of directors of ABS. He received a BS from the U.S. Merchant Marine Academy; a BS and an MS in naval architecture and marine engineering from MIT; and a PhD in mechanical engineering from the University of Arizona. Dr. Liu was elected to the National Academy of Engineering in 2011.

Roger L. McCarthy is a private engineering consultant and a director of Shui on Land, Ltd., which is involved in large-scale urban redevelopment in the People's Republic of China. Dr. McCarthy has substantial experience in the analysis of failures of an engineering or scientific nature. He has investigated the grounding of the *Exxon Valdez*, the explosion and loss of the *Piper Alpha* oil platform in the North Sea, the fire and explosion on the semisubmersible *Glomar Arctic II*, and the rudder failure on the very large crude carrier *Amoco Cadiz*. Previously, Dr. McCarthy was chairman emeritus of Exponent, Inc., and chairman of Exponent Science and Technology Consulting Company, Ltd. (Hangzhou, China). In 1992, he was appointed by the first President Bush to the President's Commission on the National Medal of Science. Dr. McCarthy served as a member of the National Academy of Engineering and National Research Council Committee on the Analysis of Causes of the *Deepwater Horizon* Explosion, Fire, and Oil Spill to Identify Measures to Prevent Similar Accidents in the Future. He received a PhD in mechanical engineering from MIT. He was elected to the National Academy of Engineering in 2004.

Charles E. McQueary is a part-time consultant for the Missile Defense Agency in the Department of Defense (DoD). Most recently, Dr. McQueary served as Director, Operational Test and Evaluation (OT&E), with the Office of the Secretary of Defense at DoD from July 2006 until his retirement in May 2009. In this capacity, Dr. McQueary was charged with overseeing the development and implementation of DoD policies and procedures for the testing and evaluation of more than 300 systems valued at several hundred billion dollars. As director, he was a senior advisor to the Secretary of Defense and was tasked with annually reporting to Congress the test results for all 300 programs and systems and with providing policy recommendations. During his tenure, Dr. McQueary led efforts to reorganize OT&E and augment its staff in response to the growing challenges of complex systems and their proliferation. To this end, he also worked to establish new and strengthen existing relationships throughout DoD, the federal government, and private-sector defense industry. He served as the first Under Secretary for Science and Technology in the new Department of Homeland Security. Dr. McQueary spent 36 years in the private sector directing system design, development, and manufacturing. His professional recognitions include the 2006 National Defense Industrial Association Homeland Security Leadership Award and the 2008 International Test and Evaluation (T&E) Association T&E Professional Award (Allen R. Matthews Award). He has served as an active member on numerous public and professional boards. He is also a member of the proxy Board for Intergraph Government Solutions. Dr. McQueary earned a PhD in engineering mechanics from the University of Texas at Austin and is a National Aeronautics and Space Administration Scholar. He earned an MS and a BS in mechanical engineering from the same institution and has been named a distinguished engineering graduate.

Richard A. Sears is a consulting professor in the Department of Energy Resources Engineering, Stanford University. He is also a member of DOI's Ocean Energy Safety Advisory Committee. During 33 years with Shell Oil Company and Royal Dutch Shell, he held technical and managerial positions including Exploration Geophysicist, Technical Instructor, Economist, Strategic Planner, and General Management. The managerial positions ranged from exploration and research to fully integrated exploration and production business management. He served as chief science and technology advisor to the National Commission on the BP *Deepwater Horizon* Oil Spill and Offshore Drilling. Mr. Sears received a BS in physics from Stanford University and an MS in geophysics from Stanford University.

Gordon H. Sterling worked for Shell Oil for 35 years in the area of offshore oil and gas development systems and structures. He worked as a Project Engineer, Structural Designer, Research Supervisor, Design and Installation Manager, Production Superintendent, Project Manager, Manager of Major Deepwater Projects, and Director Year 2000 Compliance Project. He was involved with all of Shell's record-setting deepwater ventures in the Gulf of Mexico, beginning with the three-piece Cognac platform in 1974–1978 (water depth of 1,024 feet), where he served as Design and Installation Supervisor. He was the Project Manager of the Bullwinkle platform (water depth of 1,350 feet, 1985–1988) and then became Manager of Major Deepwater Projects, to whom all of the Shell Offshore, USA, and Deepwater Project Managers reported. These projects included the record-setting tension leg platform series—Mars, Ram-Powell, and Ursa—in 3,000 to 4,000 feet of water, as well as the subsea developments of Tahoe, Popeye, and Mensa (water depth of 5,400 feet). Three of the projects that he worked on, two of which he led, received the American Society of Civil Engineers (ASCE) Outstanding Civil Engineering Achievement Award. Mr. Sterling represented ASCE on the Board of Directors of the Offshore Technology Conference (OTC) and served as Chairman of the OTC; had a 4-year term on the Coasts, Oceans, Ports, and Rivers Institute (COPRI) Board of Governors; served as President of COPRI; and has been on and led other board-level ASCE committees. He has also been active in the Society of Petroleum Engineers (SPE) as Forum and Workshop Chair and as a guest and keynote speaker for the American Society of Mechanical Engineers. In spring 2007 he gave the Professor Arthur Bock memorial lecture to students and staff at the U.S. Naval Academy. In 2008 he received the Heritage Award for "distinguished service and significant contributions to the development of offshore resources" from OTC. In 2009 he was elected Distinguished Diplomate, Ocean Engineering, by the Academy of Coastal, Ocean, Ports, and Navigation Engineers. He periodically presents a commercial course on deepwater oil and gas development, consults part time, volunteers for ASCE–COPRI and SPE, and is on a review panel for the Marine Systems Engineering Program of Texas A&M University, Galveston. He is a past member of the Board of Directors of John M. Campbell Holdings Company (an oil and gas training company) and of the Board of Advisors for INTECSEA Engineering (a Worley Parsons international offshore engineering company with division headquarters in Houston, Texas). He received a bachelor of applied science degree in civil engineering from the University of Waterloo and obtained a master of science degree in civil engineering from Lehigh University.

Manuel Terranova is CEO and President of Peaxy, Inc.—a highly distributed software-based file and data management solution—designed for mid-tier and enterprise class customers as well as external cloud. Previously, he served as Senior Vice President of Regional Operations and Global Sales for the Drilling and Production Unit of General Electric (GE) Oil and Gas. From December 2007 through February 2010, he served as the head of Subsea Production Systems and Commercial Operations at GE Drilling and Production Systems. In that role, Mr. Terranova managed GE's subsea production equipment portfolio, including subsea trees and controls. From April 2006 through December 2007, Mr. Terranova served as General Manager of GE's PII Integrity Services. In that role, he served as the business leader for Integrity Engineering, Integrity Management, ThreatScan, and geographic information system software. From April 2002 through April 2006, Mr. Terranova served as the General Manager and Chief Information Officer for Information Management at GE Oil and Gas. From May 2005 onward, he worked extensively on companywide due diligence and acquisition integration activities. From 1999 through March 2002, Mr. Terranova served as Manager of E-Business Strategy for GE's Corporate Initiatives Group. During 2001 and 2002, he led GE's SupportCentral effort, a knowledge portal that he cofounded with two other GE employees. Before joining GE, Mr. Terranova served as Internet Program Manager of the Xerox Internet Channel and Marketing Group. He was responsible for designing and implementing e-business solutions for Xerox.com. He graduated from Cornell University with degrees in German literature and political science. At the Johns Hopkins School of Advanced International Studies, he obtained a master's degree in international economics and international law.