Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Resources Program Administration

FINAL REPORT

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Abstract

This document is the Research Partnership to Secure Energy for America (RPSEA) Final Report for the Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Resources Research and Development Program (Program) established pursuant to Title IX, Subtitle J, Section 999 (Section 999), of the Energy Policy Act of 2005 (EPAct). RPSEA administered three of the four program elements identified in EPAct, pursuant to Annual Plans, which included: ultra-deepwater architecture and technology, unconventional natural gas and other petroleum resources exploration and production technology, and technology challenges of small producers. The U.S. Department of Energy (DOE), through its National Energy Technology Laboratory (NETL), implemented a non-duplicative research and development (R&D) program to complement the RPSEA administered program elements. This Final Report covers the period from 2007, when research began, through 2016, when the program ended, and builds a foundation for work that can be conducted in the future.

This Final Report briefly describes each of the program elements and includes descriptions of specific projects that illustrate successful technology development efforts funded through the program. It also includes a summary of technology transfer efforts, which have reached a worldwide audience, resulting in accelerated and highly successful implementations of newly developed technologies. RPSEA members provided hundreds of subject matter experts who contributed thousands of hours in directing this program, as is evident by results described in this report; documenting a most successful public private partnership.

TABLE OF CONTENTS

LIST OF ATTACHMENTS

EXECUTIVE SUMMARY

This document is the Research Partnership to Secure Energy for America (RPSEA) Final Report for the Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Resources Research and Development Program (Program) established pursuant to Title IX, Subtitle J, Section 999 (Section 999), of the Energy Policy Act of 2005 (EPAct). RPSEA administered three of the four program elements identified in EPAct, pursuant to Annual Plans, which included: ultra-deepwater architecture and technology, unconventional natural gas and other petroleum resources exploration and production technology, and technology challenges of small producers. The U.S. Department of Energy (DOE), through its National Energy Technology Laboratory (NETL), implemented a non-duplicative research and development (R&D) program to complement the RPSEA administered program elements. This Final Report covers the period from 2007, when research began, through 2016, when the program ended, and builds a foundation for work that can be conducted in the future.

Technology developed through this program has led to safer and more efficient development of ultra-deepwater resources, more environmentally sensitive development of the tremendous shale gas resource within the U.S., and the responsible production of additional hydrocarbons from the mature fields that are operated primarily by small producers throughout the nation. The success of any research and development program is appropriately judged by the extent to which the results are applied and commercialized. This Final Report briefly describes each of the program elements and includes descriptions of specific projects that illustrate successful technology development efforts funded through the program.

It also includes a summary of technology transfer efforts, which have reached a worldwide audience, resulting in accelerated and highly successful implementations of newly developed technologies. Moreover, the results of the program are very apparent at any of the professional conferences at which research relevant to the oil and gas industry is discussed. We have documented over 5,000 reports, presentations, and publications detailing the work conducted through the program, which has significantly improved the safe and responsible development of oil and natural gas, our Nation's most prolific energy resources.

While the original intent of the Section 999 was to "maximize the value of natural gas and other petroleum resources of the United States" none of that value will be realized if the targeted resources cannot be developed in a safe and environmentally sensitive manner. The Deepwater Horizon incident caused the industry to reevaluate its approach to risk management as applied to all exploration and development operations. Issues related to onshore development, namely water usage and treatment, induced seismicity, wellbore integrity, and greenhouse gas emissions, added to the needs of this program. As a result, an important component of this program has been to ensure that risks associated with the development of ultra-deepwater and unconventional resources are fully understood, and that the means are available to fully mitigate those risks with respect to both prevention and recovery.

I. INTRODUCTION

This Final Report for contract DE-AC26-07NT42677 is provided by the Research Partnership to Secure Energy for America, RPSEA, to the National Energy Technology Laboratory (NETL) of the U.S. Department of Energy (DOE) to satisfy Section J23 of its contract which states the following:

J.23 FINAL TECHNICAL REPORT (MAR 1999)

The Final Report shall document and summarize all work performed during the contract period in a comprehensive manner. It shall also present findings and/or conclusions produced as a consequence of this work. This report shall not merely be a compilation of information contained in subsequent quarterly, or other technical reports, but shall present that information in an integrated fashion, and shall be augmented with findings and conclusions drawn from the research as a whole. The contractor shall deliver a draft copy of the final report sixty (60) days before the completion of the period of performance. The Government shall be allowed thirty (30) days to review the draft copy and to notify the contractor, in writing, of approval or recommended changes. If the Government does not approve or recommend changes within thirty (30) days of receipt of the draft copy, the report shall be deemed approved. The approved final report is due on the contract completion date.

In 2006 RPSEA was selected to administer the first three program elements of Title IX, Subtitle J, Section 999 of the Energy Policy Act of 2005 (EPAct): 1) ultra-deepwater architecture and technology, 2) unconventional natural gas and other petroleum resources exploration and production technology, and 3) technology challenges of small producers.   A contract was awarded to RPSEA in late 2006 with a start date of January 4, 2007.

II. HISTORICAL PERSPECTIVE

The Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Resources Research and Development Program (Program) was established pursuant to Title IX, Subtitle J, Section 999 (Section 999), of the Energy Policy Act of 2005 (EPAct). RPSEA was selected by the Department of Energy, Office of Fossil Energy to administer three of the four program elements identified in EPAct, which include: ultra-deepwater architecture and technology, unconventional natural gas and other petroleum resources exploration and production technology, and technology challenges of small producers.

The process to carry out this program was as follows:

- Each year, RPSEA, as the Program Consortium, was required to present its research, development and demonstration (RD&D) recommendations to DOE in the form of a Draft Annual Plan (DAP). The Secretary of Energy then prepared the Annual Plan for the cost-shared research program administered by the Program Consortium and transmitted it to Congress, which was followed by a release of the solicitation of R&D proposals based on the Plan.

- Prior to the Secretary submitting the Annual Plan to Congress each year, the legislation called for DOE to solicit advice from two Federal Advisory Committees: the Ultra-Deepwater Advisory Committee (UDAC) and the Unconventional Resources Technology Advisory Committee (URTAC). The legislation allowed for comments and recommendations from other industry experts as well. DOE's Office of Fossil Energy was responsible for organizing and managing both of these committees. The comments and recommendations received from these advisory committees related to their review of the Annual Plan were submitted to the Secretary.

- Upon approval of the Annual Plan each year, EPAct section 999B(e)(3) directed the Secretary of Energy to transmit the Annual Plan to Congress, along with the written recommendations from the Program Consortium, the two Federal Advisory Committees, and any other experts from whom comments have been received.

- Each Annual Plan included details of ongoing activities, and a list of solicitations for awards to carry out research, development, demonstration, or commercial application activities. It also was required to include topics for such work, parties eligible to apply, selection criteria, duration of awards, and a description of the activities expected of the Program Consortium to fulfill its oversight responsibility.

It was originally thought that the Act called for a 10-year R&D program; however, after review of the entire language in Section 999, inconsistencies were found as to the length of the program. Section 999F - Sunset stated that "The authority provided by this subtitle shall terminate on September 30, 2014." Section 999H (a) - Funding stated that "for each of the fiscal years 2007 through 2017, $50,000,000 shall be deposited into the Ultra-Deepwater and Unconventional Natural Gas and Other Petroleum Resources Fund." When this was brought to the attention of DOE General Counsel, RPSEA and NETL were informed that the Sunset Date trumped all other time lengths stated in the ACT. Therefore, the program would only fund eight years of research.

The mission of the Small Producer Program element was to extend the life of mature fields in an environmentally sustainable way. The term “small producer” was defined in the EPAct as an entity organized under the laws of the United States with production levels of less than 1,000 barrels per day of oil equivalent. The Small Producer Program element was established to benefit small producing companies in technology development for mature oil and gas fields (which they largely operate), with the objective of extending the life and ultimate recovery of these fields.

The mission of the Unconventional Resources Program element was to increase the supply of domestic natural gas and other petroleum resources by reducing the cost and increasing the efficiency of exploration for and production of such resources, while improving safety and minimizing environmental impact. “Unconventional natural gas and other petroleum resource” was defined in the EPAct as natural gas and other petroleum resources located onshore in economically inaccessible geological formations, including the resources of small producers.

The mission of the Ultra-Deepwater Program element was to identify and develop technologies, architectures, and methods that ensure safe and environmentally responsible exploration and production of hydrocarbons from the ultra-deepwater portion of the Outer Continental Shelf (OCS) in an economically viable (full life cycle) manner. The EPAct defined “Ultra-Deepwater” as a water depth that is equal to or greater than 1,500 meters (~5,000 feet). The program also includes technologies applicable to formations in the U.S. offshore continental shelf (OCS) deeper than 15,000 feet subsurface.

The RPSEA model for technology development involved the active engagement of stakeholders across the entire community of energy producers, researchers, technology providers, regulators, and environmental groups. It was reasoned that the best efforts of the research community would be required to develop the technology necessary to safely deliver hydrocarbons from the targeted resources; however, the knowledge residing with producing companies and service and manufacturing companies would be crucial in providing effective direction for the needed research. The rapid application of new ideas and results would be facilitated by the continuing involvement of highly skilled representatives from the operating and service - manufacturing companies to help plan and execute the research program. Furthermore, the emphasis on safety and environmental sensitivity would require direct involvement and communication with the regulatory agencies and the environmental community. Finally, the involvement of the U.S. Department of Energy and its laboratories would ensure that the needs of the U.S. Government would be addressed and that similar research efforts by the labs would be complementary and non-duplicative. The utilization of a small portion of Federal oil and natural gas royalties to partially fund the program, which would be co-funded by cost share contributions from research project recipients ,would ensure that all involved parties had “skin in the game” and would be joint contributors to a successful public – private partnership.

Over the first few months of the Program, plans were developed to implement the Program and form various committees of subject matter experts (SME's), each consisting of highly qualified representatives from RPSEA member organizations. Please refer to Appendix A for a list of RPSEA members. In addition, the DOE assembled the required advisory committees (a.k.a., FACA's) to provide insights and advice on an annual basis to the Secretary of Energy regarding the program elements.

As shown in Table 1 below, a total of $37.5 million per year was available for the three program elements RPSEA was to administer. RPSEA was to receive 10 percent ($3.75 million) for its administrative functions, and 5 percent ($1.875 million) would remain at NETL for program review and oversight. The remaining $31.875 million could be awarded annually for research projects. Under EPAct, the Small Producer, Unconventional Resources, and Ultra-Deepwater Program element annual portions of these R&D funds would be 10, 43-1/3, and 46-2/3 percent ($3.75 million, $16.25 million, and $17.5 million), less the aforementioned 15 percent administrative and oversight expenditures, of the available funds for RPSEA, respectively. Additionally, the minimum allowable cost share for any project was 20 percent of the total cost, 50 percent for field tests; and at least 2.5 percent of the project funds were required to be spent on technology transfer activities. Additional funds, not included in the table, were provided to NETL for research that was complementary to the Program.

Table 1: Annual Funds for RPSEA Consortium per EPAct

Area	Allocation	Area Funds, $	NETL Review & Oversight 5%	RPSEA Administration 10%	R&D Funds for Distribution
Small Producer	10.0%	3,750,000	187,500	375,000	3,187,500
Unconventional Resources	43.3%	16,250,000	812,500	1,625,000	13,812,500
Ultra-Deepwater	46.7%	17,500,000	875,000	1,750,000	14,875,000
Consortium Total	**100%**	**$37,500,000**	**$1,875,000**	**$3,750,000**	**$31,875,000**

By mid-2007 RPSEA recommended its initial projects to NETL. The recommendations were part of the 2007 Draft Annual Plan, submitted to DOE in July 2007. Once approvals were received, RPSEA went out for bids via Requests for Proposals (RFP's), in response to which any U.S. based entity could submit a proposal. RPSEA assembled its SME's to evaluate and prioritize the proposals, and to recommend selections to NETL. Following NETL approval of selections, RPSEA negotiated subcontracts with the selected proposing entities and forwarded each subcontract and supporting documentation to NETL for individual project approval. Project Statements of Work (SOW) were scrutinized by SME's, as well as by RPSEA and NETL project managers prior to approval, so that each project would have a definitive set of deliverable items that would measure its success, as well as stage gates to alter or halt projects that might be in need of modification to improve their chances of success. Once approved, RPSEA signed the individual contracts and each project commenced. RPSEA utilized its network of SME's and other interested member organizations to oversee the technical aspects of the projects and guide project principal investigators, while RPSEA also provided project management and invoice payment functions.

The program continued to expand, with additional projects awarded for the 2008 and 2009 program years. In late 2010, following the Deepwater Horizon disaster, DOE reevaluated the direction of the program and made the decision that all future RPSEA projects were to be directed primarily toward safety and environmental sustainability. Furthermore, DOE determined that individual RFP and project selection recommendations made by RPSEA to NETL would require additional review and approval by DOE headquarters in the case of all future projects. To that end, additional review criteria were recommended for several projects. Some of these were approved based on the following additional criteria, beginning in 2011 and carrying through the 2012 program.

- Small Producer Program element:
    - Reduced cost and improved efficacy of well interventions and drilling
    - Extending economic life of mature fields through environmentally safe efficiency improvements
    - Mitigation of environmental impacts in mature fields
    - Reducing operating costs through more effective and efficient compliance with operating regulations

- Unconventional Resources Program element:
    - Minimized surface disruption associated with shale gas development, including well site construction, air emissions, noise, visual impact, and impact on surface water resources
    - Isolation of producing formations and wellbores from shallower formations, particularly near-surface aquifers
    - Maximizing the efficiency of hydraulic fracturing operations to ensure that the minimum amount of fluid is used to completely stimulate the reservoir zone and that the need for re-fracture treatments is minimized
    - Prediction and mitigation of induced seismicity associated with unconventional gas development, including hydraulic fracturing and injection well disposal
    - Developing means for managing the fluid use associated with shale gas development, including understanding and minimizing the impact on regional water resources, the development of "green" drilling and fracturing fluids that minimize contamination concerns, the development of improved treatment and re-use options, and minimization of fluid waste streams.
    - Demonstrating and integrating promising technologies to facilitate early utilization and commercialization

- Ultra-deepwater Program element:
    - Improved well control technologies and techniques
    - Improved well design and construction
    - Improved subsea ultra-deepwater measurement and monitoring instrumentation

- Improvements in flow assurance predictions
- Increased understanding of complex fluid phase behaviors that occur under conditions of extreme pressure and temperature
- Assessments and quantification of risks of environmental impacts from deepwater oil and gas exploration, drilling, and production activity on newly developed technologies
- Research on sensors, instrumentation, command electronics, and advanced data interpretation technologies
- Improved reservoir characterization and recovery methods
- Continued research and technology development and demonstration of certain previously identified concepts and needs

In late 2012 RPSEA was notified that the R&D budget would be reduced by 6 percent in 2013 as part of the Federal government's efforts to reduce spending. However, the spending reduction did not affect RPSEA's administrative budget.

In late 2013 the U.S. Congress repealed Section 999 of EPAct 2005 as part of its budget compromise, eliminating additional funds to continue the program's operation and new R&D efforts. At the time, about seven years of funding ($221,212,500) had either been authorized or obligated for the Program. Prior to the President's signing of the budget in early 2014, DOE agreed to provide the 2014 administrative funds to RPSEA to continue administration of the program and to develop a plan for transferring that function to NETL for management of ongoing research through early 2017. RPSEA and NETL worked closely together to develop a plan which would allow ongoing projects time to complete their research as efficiently as possible. The plan included the transfer of project management and contract administration responsibilities to NETL. RPSEA would continue to provide project and program coordination functions, as well as pay the invoices of the subcontractors. This cooperation and coordination provided the best possible outcome for a program that was terminated earlier than planned.

RPSEA member organizations felt that a chief strength of the Program and a reason for its many successful project outcomes was its ability to provide a neutral, collaborative, and highly integrated environment in which researchers and potential end users could jointly solve problems. Because of its unique capability to pull in SMEs from a wide variety of sources, as well as its effectiveness in information dissemination and objective, science-based evaluation, RPSEA's members urged the organization to remain involved in the technical outcome development and dissemination portions of the Program beyond the termination of funding. Thus, RPSEA continued to act as a technical information coordinator and utilize its network of experts throughout the remainder of the Program. These functions worked hand in hand with NETL project managers after project management responsibilities were transferred to NETL in 2014, to ensure that all remaining project deliverable items were high quality, relevant to industry needs, and properly transmitted and disseminated for further development or use.

III. PROGRAM ELEMENTS

There are three Program Elements to this contract: Small Producer Element, Unconventional Resources Element, and Ultra-Deepwater Element. Each element is described below and is followed by a summary of many, but not all, of the related projects, noting their successes and learnings, as well as their commercial application. All project summaries are posted on the RPSEA website www.rpsea.org. The Small Producer and Unconventional Resources Elements are combined into one –Onshore Programs – for simplification.

Also, the Projects sub-section under the Conclusions section of this report contain a prioritized list of Onshore and Ultra-Deepwater projects that RPSEA believes merit additional funding in order to become commercial successes. Priorities are based on RPSEA's assessment of potential positive safety and environmental impacts and those projects' inability thus far to secure added private funding to continue required R&D.

A. Small Producer Element

1. Mission

The mission of the Small Producer Program Element of the consortium-administered R&D program was to increase the supply from mature domestic natural gas and other petroleum resources through reducing the cost and increasing the efficiency of production of such resources, while improving safety and minimizing environmental impact, with a specific focus on the technology challenges of small producers.

"Small producer" is defined in EPAct as an entity organized under the laws of the United States with production levels of less than 1,000 barrels per day of oil equivalent.

2. Goal

The goal of the Small Producer Program Element was to address the needs of small producers by focusing on areas including: complex geology involving rapid changes in the type and quality of the oil and gas reservoirs across the reservoir; low reservoir pressure; unconventional natural gas reservoirs in coalbeds, deep reservoirs, tight sands or shales; and unconventional oil reservoirs in tar sands and oil shales.

3. Objectives

The small producer community is quick to adopt new technology that has been shown to have an economic benefit in their operating environment, but does not generally have the time or resources to provide a test bed for technology development efforts or the demonstration of new applications of existing technology. The Small Producer Program Element had a crucial role in ensuring that leading edge exploration and production technology is made available to small producers, allowing them to maximize their important contribution to the nation's secure energy supply.

The approach to enhancing the impact of small producers on energy production involves two related but distinct activities. First, individual small producers facing representative challenges were engaged to work with technology providers to help identify, and then develop and apply technology solutions to enhance economic and environmentally responsible production and resource recovery. The support provided through the program was designed to mitigate the economic risk normally associated with the application of new technologies. Second, the information acquired as a result of projects served as the basis for technology transfer efforts, promoting appropriate novel technology applications throughout the small producer community. These objectives were met, as documented in the project descriptions. It should be noted that some of the demonstration projects included larger independent producers that face challenges similar to those of small producers.

B. Unconventional Resources Element

1. Mission

The mission of the Unconventional Resources Element of the consortium-administered R&D program was to identify and develop economically viable technologies to locate, characterize and produce unconventional natural gas and other petroleum resources, in an environmentally acceptable manner.

2. Goal

The overall goal of the Unconventional Resources Program Element was to increase the supply of domestic natural gas and other petroleum resources through the development, demonstration, and commercialization of technologies that reduce the cost and increase the efficiency of exploration for and production of such resources, while improving safety and minimizing environmental impact.

The contribution of natural gas to the Nation's gas supply from three specific unconventional resources—gas shales, coal seams, and tight sands—has grown significantly during the past 20 years. These resources have been highlighted by the Energy Information Administration (EIA) and others as important supply sources during the next 20 years

For the program to be successful by maximizing the value of natural gas and other petroleum resources of the United States through new technology, the transfer of that technology to companies operating in the targeted resources needed to be an integral part of the program planning and execution. Additionally, any development of new resources must be accomplished in an environmentally acceptable manner, so it was important that technologies developed under the program be applied in ways that minimize the impact of resource development on natural and cultural resources.

3. Objectives

Objectives for the Unconventional Resources Program Element were initially developed with input from the Consortium's unconventional onshore Program Advisory Committee (PAC), along with the results of a series of workshops and forums held from 2003 through early 2007. As the program progressed, the objectives were updated as additional information was gathered through efforts to identify and prioritize the technology challenges to the efficient and safe development of unconventional resources. These efforts included: (1) a series of Forums on topics relevant to unconventional resources held in various producing basins by RPSEA; (2) participation by RPSEA staff in industry meetings addressing unconventional resources organized by professional societies such as the Society of Petroleum Engineers and American Association of Petroleum Geologists, as well as publishing organizations such as Hart's Energy Publishing, Platts, and Pennwell; (3) input provided to the Annual Plans by the Unconventional Resources Technical Advisory Committee (TAC); and (4) input provided by PAC and TAC members associated with projects selected for the program.

4. RPSEA Onshore Program Technology Accomplishments & Impact

Onshore Resources for Energy Independence

Not long ago the door to U.S. ***Energy Independence*** *was solidly shut. Today, with the development of low permeability resources, led by small producing companies, U.S. energy independence may be achievable.*

The RPSEA Onshore Program, which includes projects from both the Small Producers Element and the Unconventional Resources Element, yielded a broad span of benefits in terms of the impacts on environmentally sustainable domestic oil and natural gas production and its positive impact on the economy, jobs, taxes and wealth creation.

The benefits accrue from: (1) providing a foundation for environmentally safe development of shale gas, (2) catalyzing the development of technologies that will increase the volume of economic reserves of domestic oil and natural gas, (3) helping to directly or indirectly reduce our carbon footprint, and (4) quantifying and characterizing the safety and environmental risks of various oil and natural gas exploration and production processes.

Some of the accomplishments are described below.

a. Provide a foundation for environmentally safe development of shale gas

The inception of the Ultra-Deepwater and Unconventional Natural Gas and Other Resources Research Program in 2007 corresponded perfectly with the dramatic takeoff of the shale gas industry in the U.S. The Unconventional Resources Program Element (UCR), whose initial objectives were spread over the resources of shale gas, coalbed methane, and tight gas, subsequently modified its research focus to concentrate on shale gas, which is now projected by the EIA to makeup almost half of our natural gas supply by the year 2040. Not only was the focus moved to shale gas, there was also subsequently a shift to more heavily focus on the environmental concerns of shale gas development. Beneficial technologies developed under this program were not limited to natural gas producers, as evident of the US “Shale Revolution” that included oil and natural gas.

As an example of this focus, the onshore program element has been a major sponsor of the Environmentally Friendly Drilling Systems Program (EFD), a consortium of industry, government and academic partners. The EFD program integrates low-impact technologies designed to reduce the footprint of drilling activities tailored to the specific requirements of the areas under development.

Another family of onshore projects dealt with the environmentally friendly treatment and re-use of fracturing flowback water. Another project developed technology for improving zonal isolation in wellbores that were hydraulically fractured. These selections were aligned with the increase in water volumes needed to hydraulically fracture gas shales and addressed public concerns surrounding the potential effects of hydraulic fracturing on surface and subsurface water sources.

b. *Environmental technology and environmental impact mitigation*

The RPSEA program had a strong environmental component and reached out to both regulators and industry, often serving to broker the middle ground in the interest of environmentally safe development of the resource. The Program impacts include the following:

- RPSEA informed the U.S. Environmental Protection Agency (US EPA) regarding hydraulic fracturing issues, including leading and facilitating the US EPA workshop on hydraulic fracturing water requirements.
- RPSEA supporters, Board members and advisors participated on the Secretary of Energy Advisory Board (SEAB) and provided technology program input. The SEAB recommended RPSEA support.
- US EPA has utilized the RPSEA/Colorado School of Mines produced water program for understanding produced water needs.
- Hydraulic fracturing water usage and flow back chemistry data has been documented and reported to industry and the public through multiple venues.
- Working closely with industry consortiums in the Barnett and Marcellus shale areas and sponsoring several forums to inform both industry and public regarding water issues related to hydraulic fracturing.
- Reaching out to thousands of constituents through the Environmentally Friendly Drilling (EFD) program to provide environmental best practices and techniques.
- Technologies and knowledge products that have been developed include the following:
    - Electro-dialysis for efficient produced water and fracture flowback water treatment.
    - Technology for removal of salt and management of naturally occurring radioactive material (NORM) to enable beneficial reuse of flowback water.
    - A coal bed methane produced water technology management center that is being utilized worldwide.
    - Best practices guidance and technology for minimization of hydraulic fracturing water footprint (Figure 1).
    - The Marcellus flow back study, prepared through working with the US EPA, the Pennsylvania EPA, and others, which concluded (after analyzing samples for more than 250 contaminants) that flow back water is similar to produced water, a waste product which has been managed successfully by industry for many years. The perception that hydraulic fracturing flow back water was a “witch’s brew of toxins” was mitigated, supporting practical and effective regulation.

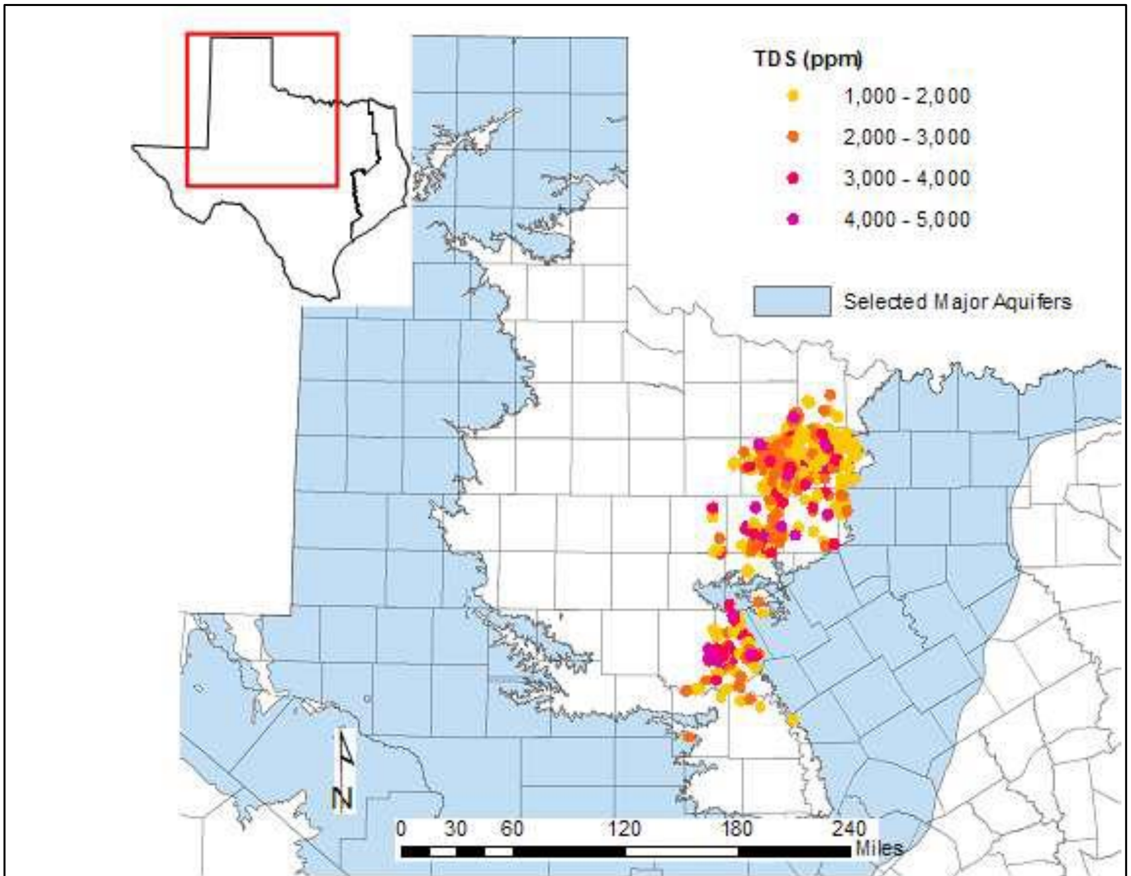


Figure 8-18. Map and Piper plot of Pennsylvanian group

Figure 1: Map of non-potable water in Texas Barnett area. Technology development will allow usage of non-potable water for HF treatments, preserving potable water for other usage.

c. Development of technologies that increase the volume of economic reserves of domestic oil and natural gas

Another benefit of the Onshore Research Program was an increase in the size of our nation's oil and natural gas reserves. RPSEA research has contributed to innovations that have enabled the oil and gas industry to grow significantly both onshore and offshore, helping make the U.S. the world's largest producer of both oil and natural gas. Any increase in our domestic reserves decreases the amount of energy that must be imported, and consequently improves the U.S. balance of trade with other nations and increases our energy security. Significant increases in natural gas supply reduce the price of natural gas (in fact, such a price decrease has already been seen as shale gas production has increased). Increased domestic production also generates economic growth which translates into jobs as well as federal, state, and local tax revenue from a combination of production taxes, corporate income taxes, and personal income taxes. When production is on federal land, the federal and state governments also collect revenue from royalties.

Some of the research projects were conducted to identify and quantify reserves through "basin study" resource assessments. Several such studies have been funded in the onshore program. Examples of some of the regions that have been analyzed, where increased reserves were noted are the Marcellus, the Mancos shale, the New Albany shale, Alabama shales in the Black Warrior Basin and the Appalachian Thrust Belt, and Paleozoic shale gas resources residing in the Colorado Plateau and the Eastern Great Basin in Utah. By focusing on these frontier regions, the program has increased public knowledge of this resource and spurred industry interest, leading to accelerated exploration and development, thereby helping to increase reserves.

Another way to increase reserves is by increasing the portion of the resources considered to be economically recoverable. This involves reducing costs or increasing efficiency: production optimization. Multiple Program projects focused primarily on the optimization of production for gas shales. These projects analyzed current production and completion techniques being used in shale plays and sought to optimize well performance, improving production economics and increasing the volume of gas resource that can be converted to reserves at a given price. Projects in the Small Producer part of the Program focused on technologies to either reduce the operating costs in mature producing fields or to apply enhanced oil recovery techniques. Both objectives work to extend the life of a mature field, thereby increasing reserves.

d. New gas resources.

The current (technically recoverable) gas resource base of the U.S. is over 2000 trillion cubic feet (TCF). Unconventional gas, including gas shales, represents a significant percentage of this volume and this share has grown dramatically, enabled by past research targeting low permeability formations (Figure 2).

This fundamental research, begun in the 1970s, was often criticized by some groups within industry and government as being wasteful. History has shown otherwise.

RPSEA research built on this legacy when it addressed the “characterization and understanding of our U.S. unconventional gas endowment.”

One project has identified over 800 TCF of gas-in-place in Alabama shales, with approximately 70 – 100 TCF technically recoverable. This technically recoverable gas is not included in the current U.S. resource base inventory, but as the cost of technology needed to produce it drops, it will provide a share of the shale gas production needed to meet the Nation’s needs in the year 2040.

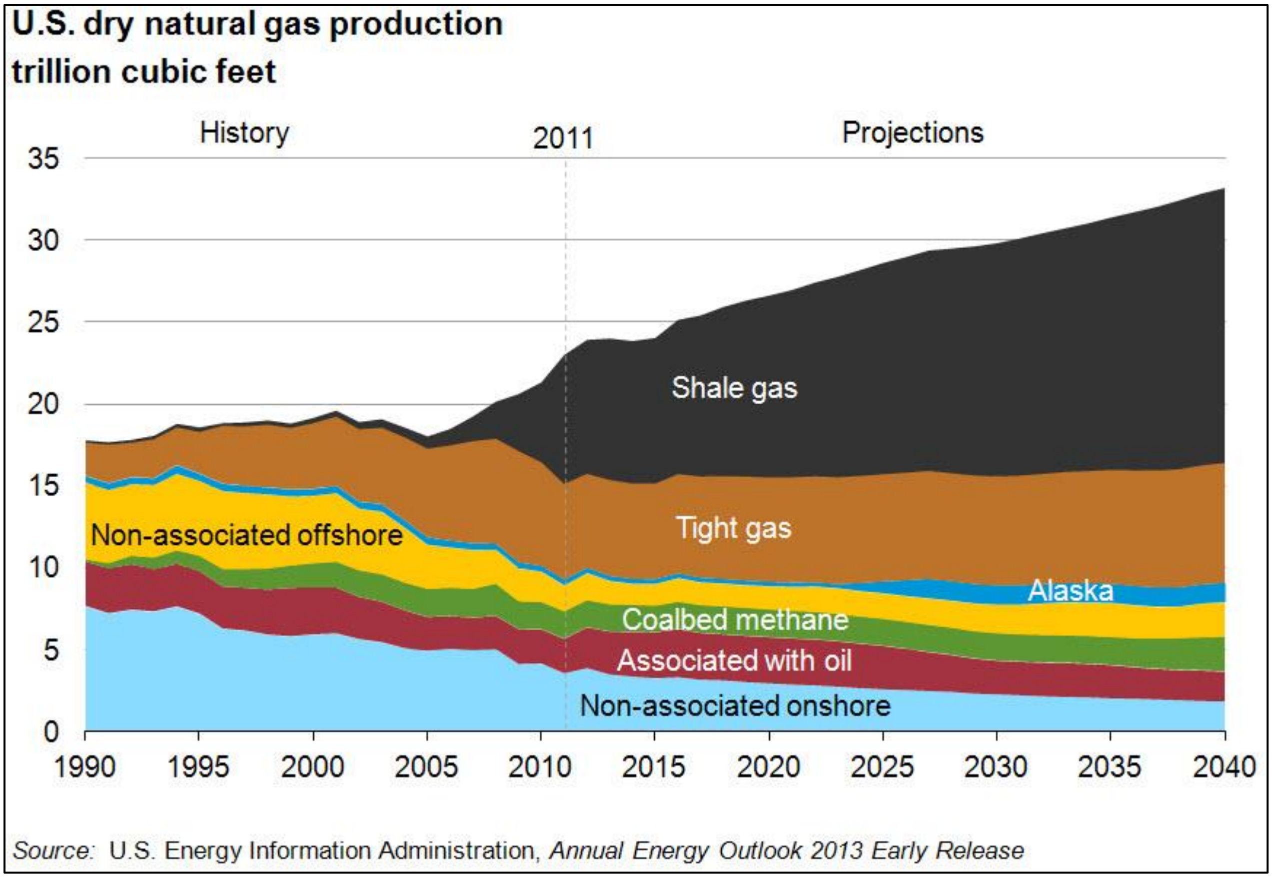


Figure 2: U.S. Gas Production – Historical and Projected - Research from the 1980's is providing for today's gas supply. Research today is adding to our current resource base providing for tomorrows gas production.

e. ***Characterizing the safety and environmental risks of various oil and natural gas exploration and production processes – hydraulic fracturing***

Growing public concern over the safety and potential environmental impacts of hydraulic fracturing during development of shale gas reservoirs has generated interest on safety and environment relative to shale gas.

While safety and environmental impact have been key elements of the Onshore Program since its inception, after 2010 RPSEA moved to more fully define the risks associated with unconventional gas development and ensure that appropriate technologies are available to mitigate those risks.

Given the environmental challenge to onshore unconventional resources, the Onshore Program supported research with particular emphasis on protection of groundwater and was accomplished by conducting research in the following areas:

- Documenting the impacts of development and production of shale gas on regional air and water quality (including major projects on environmental baseline monitoring, fugitive methane emissions, and fracturing flow back water characterization).

- Quantifying the potential for hydraulic fracturing activities to induce seismic activity and/or affect underground sources of drinking water (including projects that modeled fracture propagation and induced seismicity).
- Ensuring public confidence in regulatory decision-making through science-based assessments and risk prediction.

f. Hydraulic fracturing research – providing assurance of safety and environmental acceptance and efficiency – enabling pad drilling and new resource access

Hydraulic fracturing technology has advanced tremendously over the past few decades. Introduction of pad drilling to mitigate environmental footprints requires long horizontal wellbores be drilled and the individual well laterals treated with multiple hydraulic fracturing treatments. The efficiency of the process however is very low; less than 50%.

A RPSEA project addressed this issue through a field based assessment of where over 100 HF treatments were performed. Extensive research using the RPSEA model of a "best in class" team of researchers identified new insights into the hydraulic fracturing process (Figure 3).

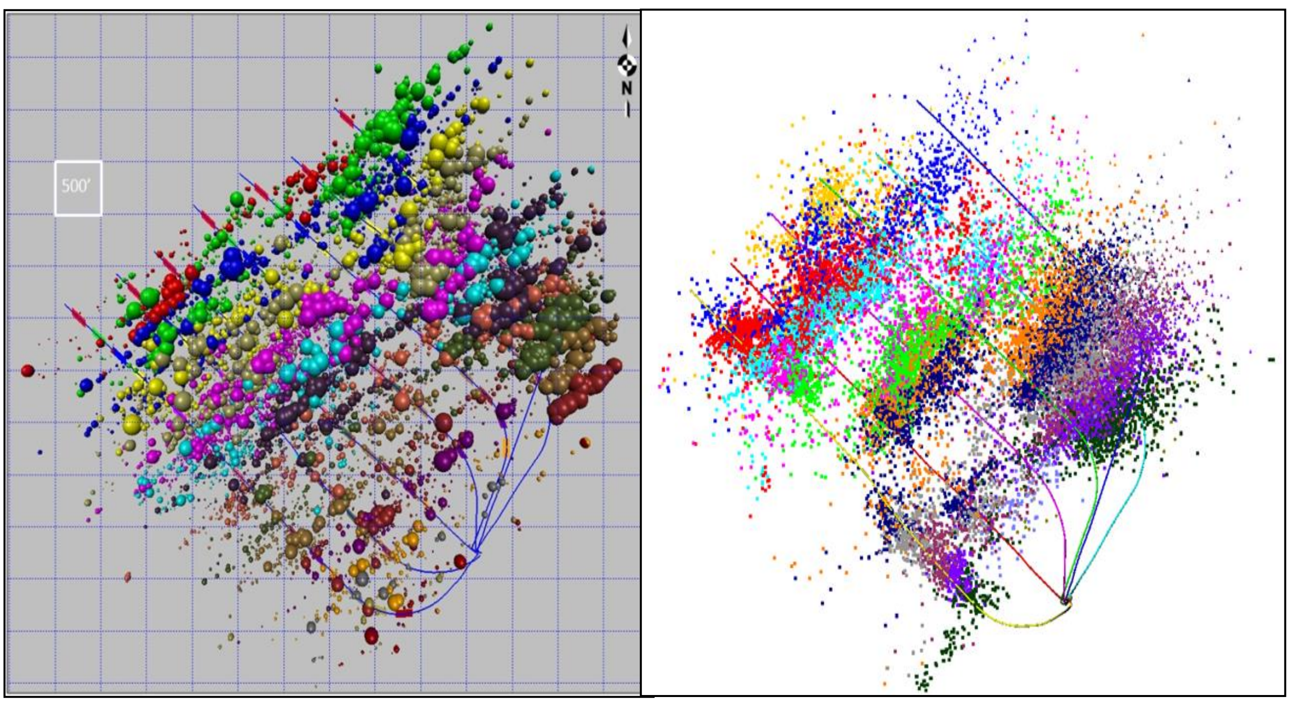


Figure 3: Downhole and surface seismic obtained on a 7 wellbore pad in the Marcellus formation. New insights into HF growth in the horizontal configurations were determined and fracture dimensions carefully measured.

The research conducted reached across "boundary lines of interest" with respect to stakeholder. Regulators, industry, the public, and other stakeholders all have interest in achieving an in-depth understanding of hydraulic fracturing impacts.

An early research result was the identification of more efficient pumping protocols for hydraulic fracturing treatments. The research led to improved assurance of hydraulic fracturing safety, environmental acceptance, and greater efficiency.

g. *Fundamentals of gas shale rock properties*

As technology has been developed to produce gas shales, an almost equal number of new technology challenges have been identified. Some of these challenges are associated with our fundamental understanding of hydrocarbon and water storage and flow in unconventional reservoir rocks. For example: How does a methane molecule the same size as the rock pores through which it flows manage to flow into the wellbore, or does it?

Technology to address and understand these fundamental questions was another dimension of the RPSEA program (Figure 4). What is at stake? Current recovery of gas from gas shale formations is much less than 40 to 50%. This is a tremendous volume of hydrocarbon resource that is currently being left behind. If this technology code can be deciphered, significant new volumes of gas will be recovered. An added and significant benefit is that the entire infrastructure – roads, pads, wells, meters, production facilities, and pipelines – is already in place to deliver this gas.

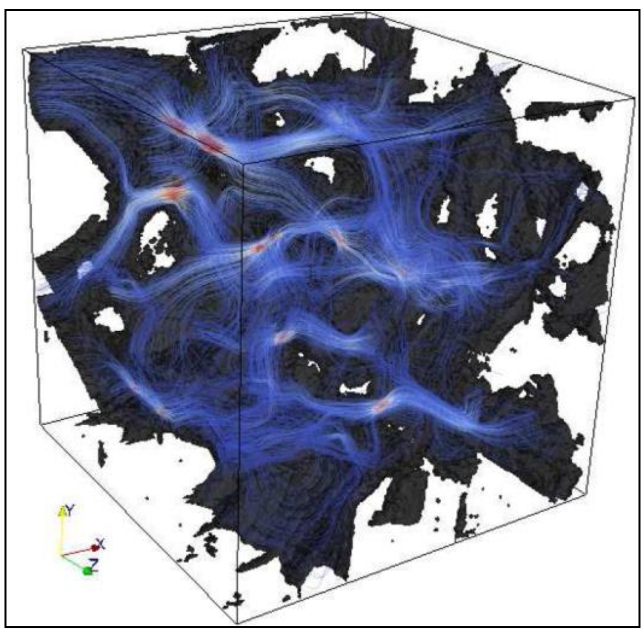


Figure 4: Flow through nano-darcy (very low k) rock as imaged by high resolution imaging technology as exists within our current National Lab capability (Lawrence Berkeley Lab). Guided by industry input and data from shale formations RPSEA is reaching out to significant past investments in technology capability across the country to solve difficult but important challenges.

h. *Technology Readiness Levels – Onshore Program Element*

Technology Readiness Level (TRL) definitions can be found in Attachment 1. They are taken from DNV's definitions, which use a 0 to 7 determination of maturity. There are other TRL scales used, including one by DOE, however the scale used for this assessment is one the oil and gas industry primarily uses and the one most applicable to these projects.

Attachment 2 is a table of each onshore project depicting its TRL as of this writing. Technologies from the following 12 projects are either already deployed (i.e., commercialized, TRL 6) or considered fully proven (I.e., market penetrated, TRL 7).

1. 07123-01: Low Impact Testing of Oil Field Access Roads: Reducing the Environmental Footprint in Desert Ecosystems (TRL 6)
2. 07123-05: Cost-Effective Treatment Of Produced Water Using Co-Produced Energy Sources For Small Producers (TRL 6)
3. 07123-07: Reducing Impacts of New PIT Rules on Small Producers (TRL 7)
4. 08122-35: The Environmentally Friendly Drilling Systems Program (TRL 7)
5. 08123-10: Electrical Power Generation from Produced Water: Field Demonstration of Ways to Reduce Operating Costs of Small Producers (TRL 7)
6. 08123-19: Commercial Exploitation and the Origin of Residual Oil Zones: Developing a Case History in the Permian Basin of New Mexico and West Texas (TRL 6)
7. 09123-03: Field Testing and Diagnostics of Radial-Jet Well-Stimulation for Enhanced Oil Recovery from Marginal Reserves (TRL 7)
8. 10122-06: The Technology Integration Program: An Extension of the Environmentally Friendly Drilling Systems (TRL 6)
9. 10123-17: Identifying and Developing Technology for Enabling Small Producers to Pursue the Residual Oil Zone (ROZ) Fairways of the Permian Basin, San Andres (TRL 6)
10. 11122-55: Development of Geographic Information System (GIS) - Based Tool for Optimized Fluid Management in Shale Gas Operations (TRL 6)
11. 11122-73: Development of Subsurface Brine Disposal Framework in the Northern Appalachian Basin (TRL 6)
12. 11123-03: Cost-Effective Treatment of Produced Water Using Co-Produced Energy Sources Phase II: Field Scale Demonstration and Commercialization (TRL 7)

Details about these projects and their results can be found in the individual project reports.

The following report section reviews a selection of projects from the onshore portfolio which review environmental issues, better describe resource characterization and provide techniques to enabling small producers and unconventional resource developers to better develop the low k onshore resource. Each selected project summary is preceded by a statement of the challenge being addressed by the research (in italics).

> *Exploration and production (E&P) of oil and gas requires the construction of access roads. Access roads can have immediate and long-term effects on the surrounding environment and the life it supports. The effects can be both beneficial and detrimental. For example, roadside ditches can benefit wildlife by providing water, food, and shelter; but at the same time, removal of vegetation, erosion, vehicle traffic, and pollution from runoff containing minerals, heavy metals, and sediments, can have a dramatic negative impact. The construction of low impact roads*

would help reduce the environmental footprint of E&P activities, and help demonstrate to the general public that sensitive lands and waters will not be spoiled in the process.

The project goal of the "Low Impact Testing of Oil Field Access Roads: Reducing the Environmental Footprint in Desert Ecosystems project," 07123-01, was to design, test, and evaluate novel temporary and permanent road materials for low environmental impact road construction in two desert-like ecosystems in west and south Texas (Figure 5). For this research, three different road materials (Recycled Well site Waste, Newpark Mats, and Wyoming Mats) were tested at two sites southeast of Pecos, TX, and southeast of Cotulla, TX. The following results were obtained:

- For the Newpark and Wyoming mats sections, plant life and weeds returned within one year after abandonment. The mat segment connection method used on the Newpark mats caused buckling on their outer edges. Keylocks installed on the outer edges will be required to keep mats at the same elevation and prevent buckling. Trucks driving off the sides of the mat caused them to crack. Adding a trim piece prevented failure, but will add significant cost to the product. The mats were required to be moved during the test, which demonstrated that they are reusable. Newpark mat segments each cost $2,400, or $6 per day if rented. Totals for the lengths needed were estimated to be $2.2 million dollars for purchase, or $5,900 per day rental. The use of removable mats offers an alternative to the commonly accepted practice of using caliche (hardened calcium carbonate cementacious material) gravel for well site access road construction. Removable mats, however, are more expensive. The cost difference between Newpark mats and standard caliche construction, at present, is significant. New products under development that are reusable and less expensive will reduce costs.
- The Wyoming board mats cracked under vehicular weight. It was found that they would require a road base, which would retard plant growth, thus negating the environmental benefit of a temporary road.
- The cost for using recycled well cuttings and drilling mud for construction was found to be equivalent to or less than current caliche construction costs when transportation and disposal costs were considered. However, maintenance estimates over the road's life cycle would be 25% greater than caliche road maintenance. This could be justified if access is critical and cuttings disposal options are limited.
- Well pad costs using caliche were estimated to be in the $7 - $27 range, with totals estimated to be from $35,000 to $135,000.

A TRL of 6 has now been achieved for this project.

Figure 5: Installation of rollout panels.

In 2009 the New Mexico Oil Conservation Division adopted the New Mexico Oil and Gas Division (NMOGD) "Pit Rule," or NMOGD Rule 17 (which was subsequently revised in 2013). The Pit Rule is a regulatory system that addresses drilling mud pit permitting, location siting, closure methods, operation, design and construction, reclamation, re-vegetation, and constituent level standards. It is designed to provide reasonable protection of fresh water and protection of public health and the environment. The rule requires operators to present a wide variety of data in the permitting and drilling for oil and gas development, and the completion of a C-144 form. The new form requires the inclusion of geo-referenced data and associated map attachments, which increases the preparation time for the applicant and the review and verification time for the regulatory agency. Producers, especially small producers, may not have the specialized staff and may find compliance burdensome and expensive.

The objective of the "Reducing Impacts of New Pit Rules on Small Producers" project, 07123-07, was to address the concerns expressed by producers and regulatory agencies about the required increase in expertise, time, and cost in the preparation/verification of documents for compliance. The solution was to develop software and maps, utilizing open source GIS software that allows quick generation of C-144 forms and associated mapped data for any proposed well/pit location in New Mexico.

This project provides producers with the ability to generate stronger, more complete applications in relatively short periods of time. At the same time, it gives regulators an online tool that can utilize all the required data sources to more quickly verify applicant data and process applications. In order to minimize the administrative impact of the 'pit rule', the research team made available all of the data needed for compliance. They developed an automated online format that does not require a specialist, and facilitates rapid completion of documents. Both producers and regulators have access to all required data, resulting in faster application processing and reductions in delays. The software and database can examine specific, user-defined locations and provide the user with specific requirements for a particular location, and/or can generate maps showing optimal, allowed, or prohibited locations of pits/tanks. Necessary forms, including the C-114 and reporting/permitting requirements, can be catalogued and then filled out, in part or in whole by the software, and then uploaded by operators as part of their online permit applications. In areas that are demonstrably non-sensitive, sufficient data can be obtained to negate the need for an onsite survey. Locations clearly in need of onsite surveys or needing additional input can also be readily identified. Early identification of site requirements saves operators the cost of unnecessary site surveys, and allows operators to better estimate expenses for production, end-of-well-life, and protocols necessary for that particular location.

The preliminary release of the database and software was immediately put to use in reducing compliance time and costs. Also, during the course of the project, it became apparent that users were finding ways to effectively utilize the database and GIS software for non-Pit Rule purposes, such as pipeline routing and supplemental data for the completion of forms required by other regulatory agencies. The project was extended, at no-cost, for an additional year to allow the generation of a second generic national regulatory data portal extending some of the utility of the Pit Rule portal nationwide and to implement additional drawing and query tools. The National Mapping Portal was developed to include data for surrounding states. Mapped natural resources include, but are not limited to: depth to water and ground water elevation from USGS gauging stations; topography; aerial photos, digital elevation models; surface geology; 27 karsts; and surface water (Figure 6). In addition, the mapping portal includes spatial search capabilities that allow querying data to determine proximity of natural resources to a subject site. A TRL of 7 has been achieved for this project.

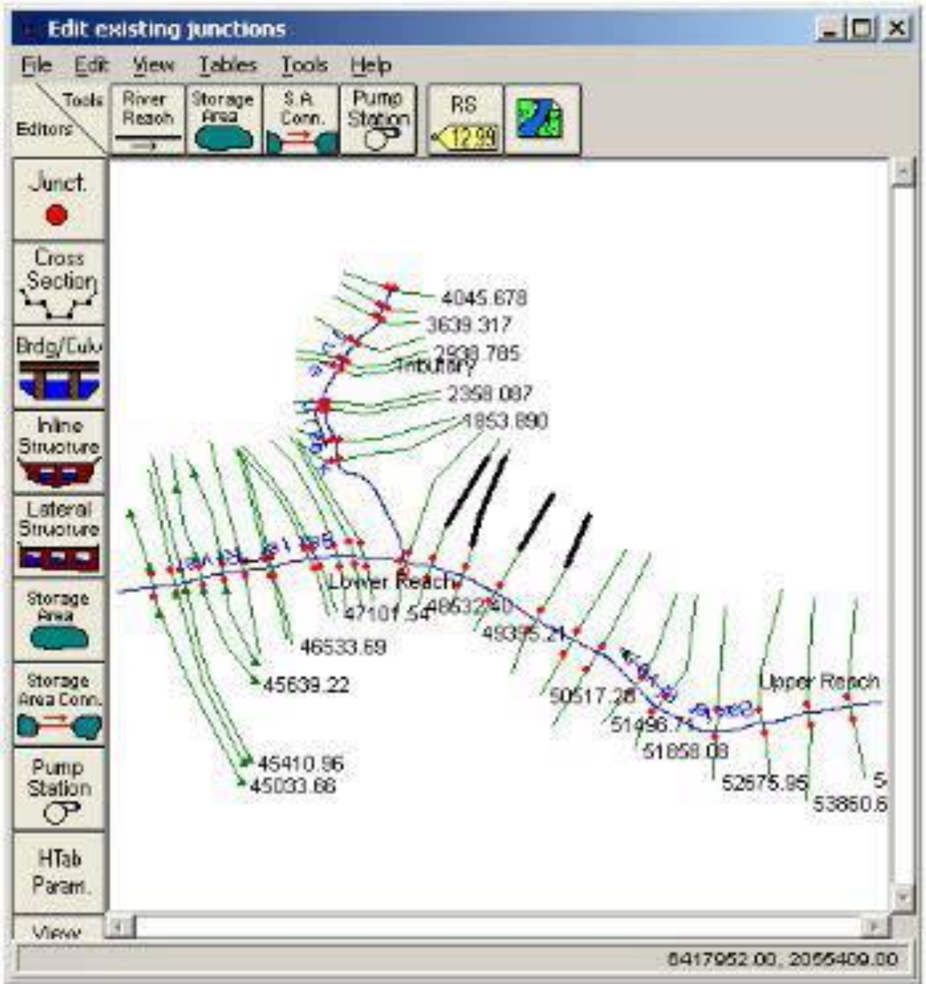


Figure 6: Geometric data for a single stream section. Lines represent possible flood extent and the red dots normal stream flow.

> *There are over 823,000 oil and gas wells in the U.S. that co-produce hot water during oil and gas production. This equates to approximately 25 billion barrels annually of water that could be used as fuel to produce up to 3 GW of clean power. Not only will generating power from the produced water from these wells add much needed electrical generation, the life of many of these wells will be extended allowing for additional oil and gas production.*

The research goal of the "Electrical Power Generation from Produced Water: Field Demonstration of Ways to Reduce Operating Costs of Small Producers" project, 08123-10, was to identify and demonstrate technology that will reduce the field operating cost of electricity and minimize the environmental impact by creating "green" electricity using produced water with no additional fossil fuel requirement. The electrical generation technology demonstrated in this project used waste heat from oil wells' produced water as the heat source for the waste heat-to-power (H2P) generator. The technology is based on an Organic Rankine Cycle (ORC) generator. ORC generators create pressure by boiling various refrigerants/chemical working fluids into a high-pressure gas. The gas then expands in a one-way system and turns an expander or high speed turbine, which then drives a generator that produces electricity.

Historically, ORCs incorporating turbo-expanders or turbines have not been commercially viable in sizes less than 1MW. ORC systems in the 250 kWh - 1 MW range require large hot water flow rates. Typically, wells with high water volumes are shut in because of the high cost of water disposal. The shut-in occurs long before they reach the water rates required to operate such ORC systems. However, one novel technology uses a patented, robust, low-cost twin screw expander that requires a much lower water volume than the larger ORCs. The ElectraTherm Green Machine® is capable of generating between 30 and 65 kWh with hot water flows of 200 gallons per minute (GPM) and less. And, because most oil and gas wells produce less than 200 GPM of hot water, the ElectraTherm Green Machine waste H2P generator was selected for the project.

The research focused on demonstrating the ability of the ElectraTherm Green Machine waste heat generator to produce electricity from the waste heat in produced water, proving that producing electricity from produced water does not interfere with the normal operations of an oil/gas well, and addressing the needs of small oil and gas producers to increase the profitability of producing oil and gas wells by adding additional income (or reducing electric power costs) during production. The research included two phases. Phase I involved well selection, and Phase II included installation, startup, and operation of the waste heat generator.

An oilfield in Laurel, Mississippi was the site of the field demonstration. At the site a produced water flow line was bypassed through the ORC heat exchanger in a simple three-valve configuration to prevent any interference or disruption in production. The machine was operated in the field for six months to investigate both the economics of the approach and potential problems and pitfalls with the following results:

- Over 1,000 hours of operation allowed revisions to be made to the on-board hardware and software. During this time investigators were able to determine optimal operating parameters for ambient temperature and gained valuable information for design improvements.
- Remote control commands were used to optimize operation during a summer heat wave.
- Findings led to a redesigned air-cooled condenser that is much more efficient, particularly for those areas with high annual ambient temperatures.
- The equipment is relatively easy to use in a “plug and play” type setup. It can be mounted on a trailer and can be installed and brought to operation within 24 hours.

The study found that this kind of co-generation can be particularly effective in reducing the energy costs for pumping hard-to-reach oil wells, an increasing issue in remote fields in the U.S. Depending on criteria, there is an attractive return on investment in locations where cost of power is $0.10/kWh or higher. In locations where cost of power is less than $0.10/kWh, additional incentives or corporate objectives would be necessary to make the opportunities attractive. The product is now commercial (TRL 7).

Subsequent to completion of RPSEA Contract 08123-10, based on the demonstrated the ability of the ElectraTherm Green Machine waste heat generator to produce electricity from the waste heat in the produced water, the EFD TIP Field Trial Project employed this technology in a new application to fire a low emission hot water boiler at a HESS site in the Bakken Shale play in North Dakota.

This combination of ElectraTherm's Organic Rankine Cycle heat-to-power system with a low emission hot water boiler accomplished the goal of reducing NO_x and VOC emissions at existing long term flares. It concurrently used the thermal energy contained in the natural gas flare to create distributed, operator-free electricity within an economically viable repeatable package. The combined benefit provided compelling economics for the owner of the flare and this system, while providing definitive local environmental benefits associated with the reduced emissions.

The real benefit of this work is reflected in the useful power generated by natural gas that would otherwise be wasted by open flaring. Furthermore, this new technology helps to meet the goals of the US EPA and North Dakota Department of Health – Air Quality by reducing emissions and providing energy by reuse of produced raw gas or fuel gas.

Water produced from oil and gas reservoirs can contain a myriad of organic and inorganic substances that can be reused providing their concentration and other constituents are reduced to levels that meet the requirements of the intended reuse. In order for small energy producers to continue the development of our nation's energy resources, the development and evaluation of technologies to manage and treat these produced waters in an environmentally sound and sustainable manner is essential.

The research goal of "Treatment and Beneficial Reuse of Produced Waters Using a Novel Pervaporation-Based Irrigation Technology," Project Number 09123-11, was to provide small producers with a critical engineering assessment of a pervaporation-based technology for treating produced water in geographically diverse locations for beneficial use in agricultural irrigation. Pervaporation is a separation process that involves the separation of mixtures based on differing rates of diffusion and solubility using a non-porous membrane, followed by an evaporative phase change. This work was conducted to determine the effects of environmental conditions on the performance of the pervaporation system in generating water for irrigating alfalfa plants (Figure 7).

Project researchers evaluated two types of hydrophilic pervaporation membranes: 1) a polyether ester (PEE) membrane and 2) a flat-sheet composite hydrophilic cellulose triacetate membrane (CTA). Contact angle measurements were taken to establish the relative hydrophobicity of the membranes. Swelling analyses on the PEE samples determined the amount of water that the material can absorb. Scanning electron microscopy (SEM) and imaging allowed documentation of changes in surface morphology between dry and wet pervaporation sheets. SEM image evaluation and elemental analysis was also used after experiments to determine if contaminants were passing through the membranes.

Field trials were conducted at the University of Wyoming's Agricultural Research Station in Sheridan, WY. Researchers constructed four test plots using only tubular PEE membranes: two control plots on which no plants were grown and two active plots on which alfalfa plants were grown. The source water for the field trials was produced water that was collected from gas wells in Sheridan.

The membrane performance (flux rate and rejection) was found to be highly dependent on the following parameters: membrane thickness, vapor pressure gradient (ΔVP, manipulated by changing the feed water temperature), affinity of water to the hydrophilic membranes, and feed water salinity. The tubular pervaporation membranes were found to show consistent water fluxes regardless of feed water salinity. Soils that are capable of wicking away moisture from the irrigation tubing, such as clays or clay loams, are ideal for use of the pervaporation irrigation system. However, fluxes were found to generally increase as the relative humidity and surrounding soil moisture decreased.

The CTA membrane displayed superior water flux characteristics to the PEE membrane. Both membranes demonstrated that water fluxes were maintained even at high salt concentrations. The pervaporation membranes were capable of desalinating produced water samples from active well sites without any pretreatment for organic removal. Overall, the nonporous hydrophilic pervaporation membranes showed potential to be used as a produced water treatment and irrigation system for small producers to manage produced water. The technology is best suited for managing low volumes of produced water and in locations already suited for agricultural activities. Of note is that use of the technology does not require that crops be grown; the technology may be employed for irrigating green spaces (natural grasses) or other areas requiring watering. The resultant TRL was 4. Further development and optimization of the membrane materials is needed to increase the characteristic water flux and durability of the irrigation membranes. These advancements will increase the diversity of produced water management applications for this technology.

Figure 7: Pervaporation field studies on alfalfa plants.

A major challenge to drilling in the Marcellus Shale is maintaining adequate zonal isolation from the time cement is placed through well completion, especially in horizontal well systems. At times, zonal issues, including gas migration, cannot be predicted until such time as a well has been drilled and logged at the earliest. If the issue is not addressed, problems may include *sustained casing pressure on intermediate casing strings, poor completions, and potentially up-hole communication.*

The research goal of "Lowering Drilling Cost, Improving Operational Safety, and Reducing Environmental Impact through Zonal Isolation Improvements for Horizontal Wells Drilled in the Marcellus and Haynesville Shales," Project Number 10122-19, was to comprehensively study the cementing processes used in drilling horizontal wells in the Marcellus Shale play and to examine the effects of zonal isolation problems on safety and the environment. It focused on analyzing existing zonal isolation technology to help develop best practices for cementing in the Marcellus Shale play. The project analyzed all aspects of wells drilled and cemented in the Marcellus Shale play between January 2012 and December 2012—from drilling through well performance post-cementing.

After these analyses were completed, a field representative observed 60 cement jobs over a five-month period. Researchers tested a cement blend and water samples from the locations, initially conducting typical oilfield cement testing, but expanding the analyses once baseline parameters were established. Data collected were used to determine if there were operational causes for potential zonal isolation problems and to develop a method of quantifying the potential for zonal isolation failure on any particular well. Through analysis of each well, the team determined, within a certain confidence level, those wells that would continue to experience successful zonal isolation. They then created a decision matrix for cementing and drilling operations designed to reduce the likelihood of occurrence of poor zonal isolation. Potential issues with the cement systems being used and some cementing protocols were discovered as part of this work. Also, it was found that intermediate (near surface) casing annuli had the highest occurrence of sustained casing pressure, one of the two major cement systems being used for that annulus was experiencing more leakage than the other. Zones with the higher percentage of leakage had poorer mechanical properties as compared to zones with better field results. It was determined that an improvement in the system's mechanical properties should reduce the observed gas migration. A TRL of 7 was achieved. Further, a model developed by the University of Houston based on this research may help to predict failure in an annulus using several dimensionless variables. By targeting and improving specific best practices, the project team predicts fewer wells will experience gas migration in the future.

Accurate and consistent practices for characterizing potential impacts and/or waste streams associated with shale gas development assist in the evaluation of environmental aspects associated with shale gas extraction. Understanding the key drivers for variability in dissolved methane concentrations is an important step to improving baseline sampling programs and stray gas identification. Producers will benefit from real-time data collection, improved delineation of air emissions, and quantification of emission rates.

The objective of the "Reducing the Environmental Impact of Gas Shale Development: Advanced Analytical Methods for Air and Stray Gas Emissions and Produced Brine Characterization" project, 11122-45, was to evaluate current sampling and testing technologies and develop practical guidance for baseline sampling and stray gas investigation as well as to develop a practical protocol for baseline water quality testing programs based on an improved understanding of the variability associated with sampling methodology and temporal factors. Produced water characterization included evaluation of tools and techniques for on-site analysis of key chemical and microbial constituents in flowback/produced water to facilitate cost-effective reuse, treatment, and/or disposal. Documentation of new "field ready" products will enable rapid analysis of produced water and improved decision making for water treatment. Key findings and recommendations from the Phase I program included the following:

- Baseline regulations and guidance vary considerably between state agencies, national/ regional organizations, and international agencies, making compliance with baseline sampling requirements challenging for operators in multiple locations.
- Sampling method can impact observed dissolved methane concentrations, particularly at wells with methane concentrations approaching or exceeding solubility. A closed-system sampling device that minimizes loss of gases to the atmosphere is better suited for collection of effervescing or near-saturation water samples from residential water wells (Figure 8).
- Preliminary trials were successfully performed to select optimal geometric and equipment positioning configurations for the OP-FTIR and to optimize collection of chemical concentration and meteorological data. The OP-FTIR and integrated weather sensors successfully delineated the source of methane at preliminary field trials.
- Preliminary trials of treatment and analytical technologies yielded promising results. Approximately 16,000 gallons of brine were passed through coated and uncoated membranes without any change in the throughput rate and pressure. No significant fouling was noted with either of the filters. Turbidity was reduced from 140 NTU to values between 2 and 11 NTU. Real-time measurement of organic components in produced water was successfully achieved using a portable GC/MS.

The TRL resulting from this project is a 5.

Figure 8: Pennsylvania farm site where testing was performed.

The "Relationships between Induced Seismicity and Fluid Injection: Development of Strategies to Manage Fluid Disposal in Shale Hydrocarbon Plays" project, 11122-27, included two primary goals: (1) to determine the relationships between fluid injection practices, regional geology and stress regime, and the occurrence of earthquakes and (2) to identify waste disposal strategies for injection that reduce and minimize the triggering of seismic activity, or that ensure that seismic activity is confined to low-magnitude, harmless events (Figure 9). Two-year surveys of earthquake activity were conducted in the Fort Worth Basin of Texas, the Eagle Ford play of Texas, the Bakken /Williston Basin of North Dakota and Montana, and the Haynesville play of Texas and Louisiana.

- The project identified 67 earthquakes occurring during the 2009 - 2011 survey period in the Fort Worth Basin of which only 8 had been reported by the U.S. Geological Survey. All of the reliably-located events of these 67 earthquakes occurred in eight clusters, each cluster situated within 3.2 km of one or more high-volume injection disposal wells, i.e., wells having maximum monthly injection rates exceeding 150,000 barrels/month. This finding suggests that higher-volume injection wells in the Fort Worth Basin triggered earthquakes. However, there were numerous other such high-volume wells that did not have earthquakes nearby. It remains unclear why earthquakes occurred near some high-volume wells and not others.
- In the Eagle Ford play area, the project identified 62 earthquakes occurring during the 2009 - 2011 survey period, of which only 4 had been reported by the U.S. Geological Survey. The majority (47) of these 62 earthquakes occurred following increases of fluid extraction (Note: not injection) from nearby wells. The most reasonable conclusion is that most earthquakes identified in the Eagle Ford were triggered by petroleum operations—mostly by

production/extraction of petroleum and water. The triggering mechanism looked to be clearly different than in the Fort Worth Basin, where earthquakes were associated with injection wells.

- The project identified only nine earthquakes occurring during the 2008 - 2011 study period in the Bakken/Williston Basin. Of these nine, only three were near injection disposal wells. Thus, earthquakes, and possibly triggered earthquakes, were far rarer in the Bakken/Williston Basin region than in the Fort Worth Basin or the Eagle Ford play regions of Texas.
- The project identified 50 earthquakes in the Haynesville play area of Texas and Louisiana during the February 2010 through 2012 study period. The project identified a cluster of activity near Bienville Parish, LA that had not been previously reported, including 16 earthquakes of magnitudes ranging from 1.2 to 2.7 that occurred over just a few months (August - October 2011). These smaller magnitude earthquakes without a preceding larger event for the Bienville Parish activity are most consistent with the classification as a "seismic swarm."

The project results indicate that the relationship between seismicity and injection is not consistent among the four geographic regions studied. Injection disposal triggered nearby earthquakes in the Fort Worth Basin; fluid extraction triggered earthquakes in the Eagle Ford; earthquakes were virtually non-existent in the Bakken; and two earthquake sequences occurred within the Haynesville, including a magnitude 4.8 triggered event, but otherwise there was little apparent triggered activity. The observation that the injection/seismicity relationship may be significantly different in different geographic regions is important and has implications for managing injection waste disposal operations. It implies that surveys should be undertaken to assess the relationship between injection and seismicity within a particular locale before crafting regulations or implementing hazard-reduction actions. The project also highlighted the continued need for investments in monitoring seismicity in areas of active oil and gas activities. The TRL resulting from this project is a 4.

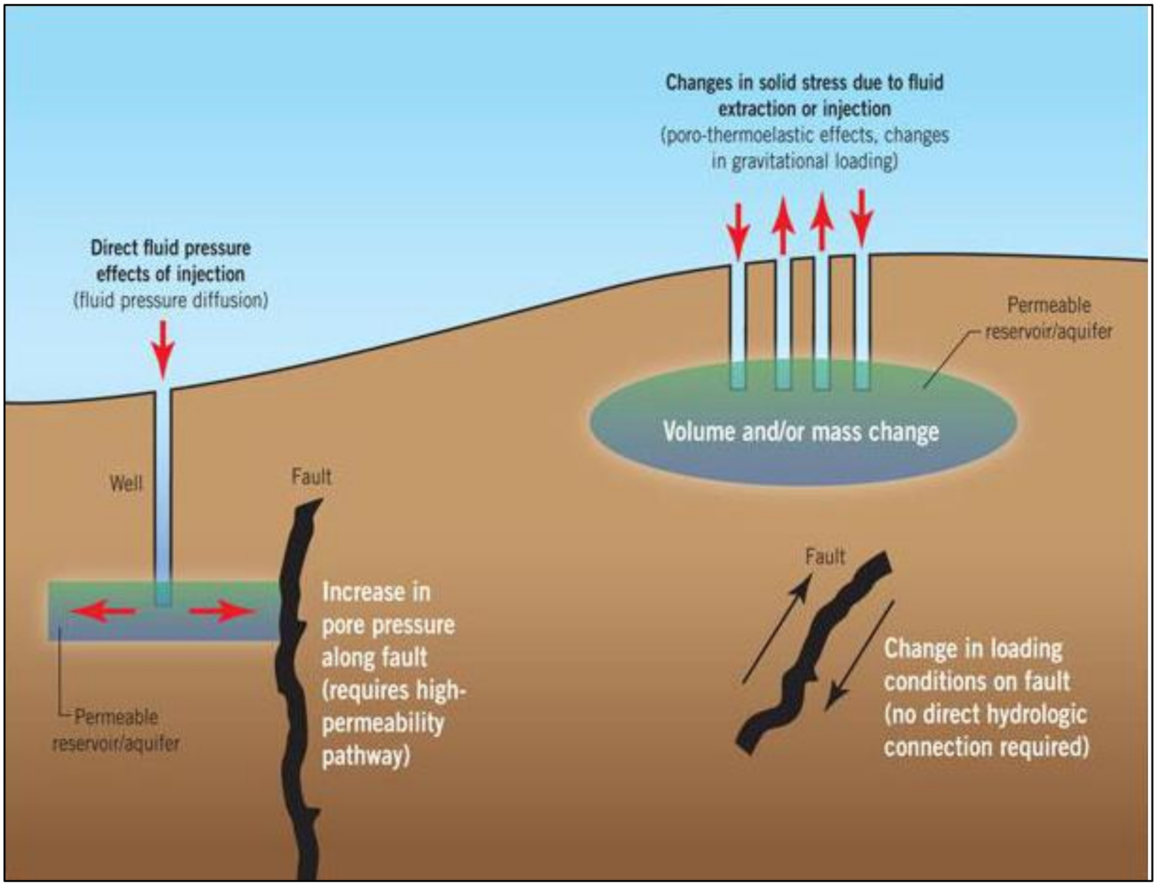


Figure 9: Mechanisms for Inducing Seismic Events

> *The mechanisms that block gas flow in tight rock formations are not fully understood. By determining the physical mechanisms that limit gas recovery in tight rock formations, new ways can be found to increase the volume of gas that might be recovered.*

The purpose of "Petrophysical Studies of Unconventional Gas Reservoirs Using High-Resolution Rock Imaging," Project Number 07122-22, was to gain a better understanding of the key factors that influence the rate of flow and ultimate level of gas recovery and subsequently investigate methods of volumetrically changing the formation properties to optimize production in space and time. Researchers used the Advanced Light Source facility and Focused Ion Beam technology at Lawrence Berkeley National Laboratory to analyze the high-resolution images of gas-bearing shale rocks in order to estimate gas shale and tight sands flow capabilities under different conditions (including *in situ* conditions). The research team investigated the effect of pore-space geometry in different rock formations on flow properties, including absolute and relative permeabilities, capillary pressure, and Klinkenberg coefficients and used computer modeling to determine the optimal pressure needed to yield the highest volume of gas recoveries. The 3-D images made during this project can be used to develop depositional models and link the petrophysical properties of rock to its geology and the geological history of the reservoir. A thorough and comprehensive study of existing unconventional gas-bearing formations will create a knowledge base for the development of emerging tools for increasing the productivity of gas wells by optimizing gas recovery techniques. The project resulted in the following:

- 3D images were generated using a scanning electron microscope coupled with a focused ion beam in order to gain a better understanding of the pore space in shale and tight sands. Shales imaged included Collingwood, H2, Barnett, Utica, Eagle Ford, Marcellus, Montney, New Albany, and Kern.
- The imaging revealed a rich variety of gas shale structures; however, it also showed very low permeability. Images of Barnett shale showed pores in organic and mineral phases. Images of New Albany shale showed almost no porosity even at very high resolution. Techniques used to image tight sands included optical microscopy, X-ray, computed tomography (CT), and scanning electron microscope (SEM) methods. Tight sands were typically densely-packed small grains with little porosity. The pores were frequently filled with much smaller clay particles, which left almost no porosity. Other pores were only a few microns wide and had a slit-like opening.
- A model of gas flow to a fractured well best fit the low porosity of rock.
- Achieving the required sample size needed for shale nanotomography was found to be a challenge due to sample preparation and mounting issues.
- The resolution of current imaging tools is not yet high enough to adequately capture grain size. Due to these constraints, pore-scale simulations were done on computer-generated data.

Although this work proved that the combined techniques could be useful, it indicated that much additional research is required in order to better understand the relationships between the properties of various shales and recovery mechanisms at the nano-scale. The TRL resulting from this project is a 4.

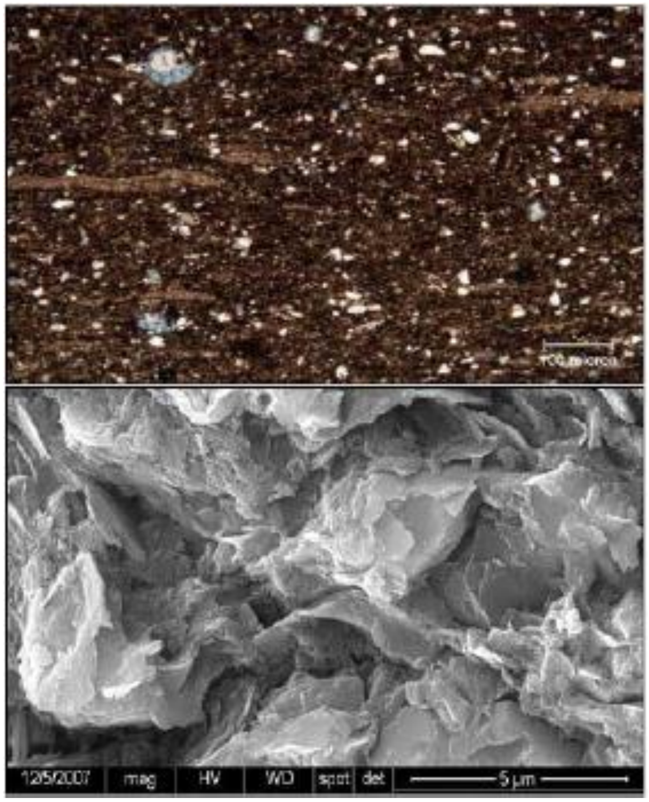


Figure 10: Representative thin section (top) and SEM (bottom) of the best reservoir quality rock in the Marcellus shale.

Methane is a naturally-occurring gas that is both a danger to coal miners and a viable source of energy. Releasing methane from coal seams is a slow process; a quicker, more efficient method is needed to remove this gas.

The research focus of "Enhancing Appalachian Coal Bed Methane Extraction by Microwave-Induced Fractures," Project Number 07122-27, was to determine the ability of microwave energy to create micro-fractures in coal samples under simulated downhole conditions of pressure and temperature. Short bursts of microwave energy from an industrial X-ray CT scanner were applied to bituminous coal core samples taken from the Pittsburgh seam to determine if methane could be removed from coal beds by using microwaves to create new fractures and expand existing cleats (fractures naturally found in coal). In this process microwave energy heats the water within coal and forms steam that fractures it.

The team examined both hydrostatically stressed and unstressed North American bituminous coal cores. They used a microwave transparent Argon gas pressurized (1000 psig) polycarbonate vessel to simulate hydrostatic stress at a depth of 1875 feet. They then examined cleat frequency and distribution for two cores via micro-infused X-ray computed tomography, before and after microwave exposure, and with and without the application of hydrostatic stress. Optical microscopy was performed to examine the role of litho-types in microwave fracturing.

Since microwave energy has been used successfully by the coal industry to fracture mined coal before pulverizing for burning, the question of microwave energy accomplishing this under *in-situ* conditions of pressure and temperature were investigated. Results demonstrated that the application of microwave energy succeeded both in creating fractures and expanding cleats (Figure 11). Although the fractures were expected to occur vertically due to overburden stresses, most fractures created in this manner were horizontal. Cleat expansion ranged from 100 to 400 percent. Samples subjected to pressure reacted similarly to those that were not, but fewer new fractures were created and the cleats expanded less. Results of this work (TRL 3) indicate feasibility to improve recoveries via this technology, opening the way to future downhole tools that use microwave energy.

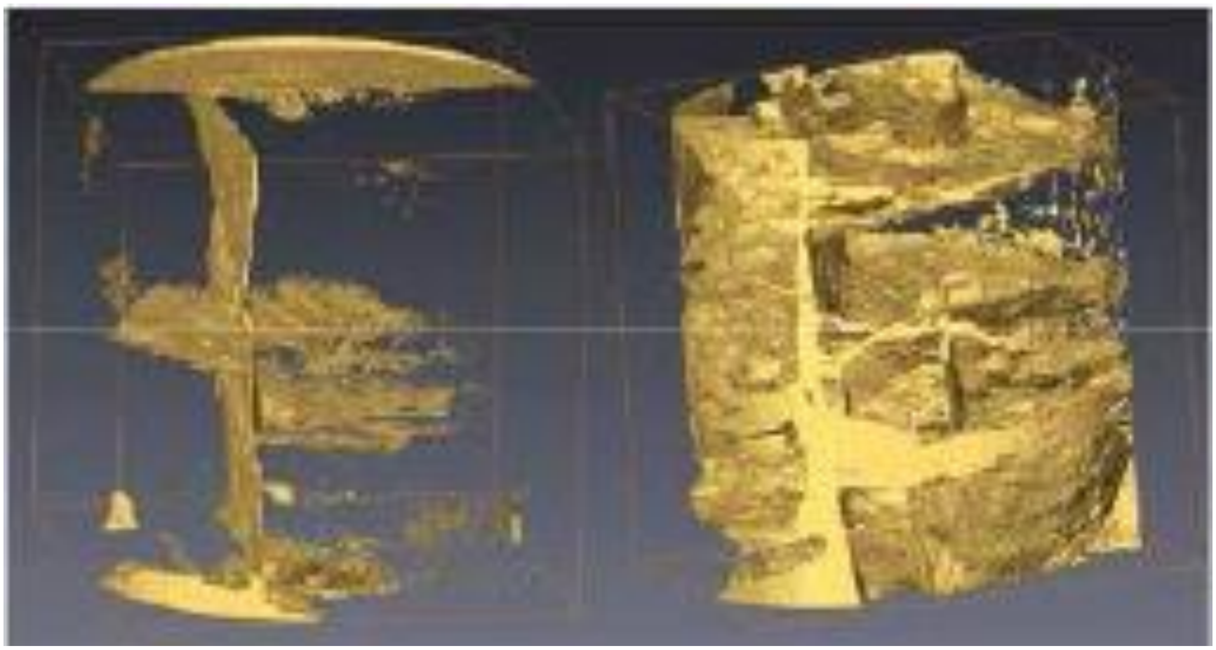


Figure 11: Fracture map of the unconfined coal core before (left) and after (right) microwave exposure.

The Houston Advanced Research Center (HARC) Environmentally Friendly Drilling (EFD) Technology Integration Program (TIP) (RPSEA project #10122-06) was a program designed to assess all RPSEA projects for technology readiness. In particular, field testing of multiple technologies was performed across many of the producing regions on the US, documenting testing results and moving the technologies toward or into commercialization. This project assembled an unprecedented broad based team of experienced project managers, universities, national laboratories, service providers, operators, regulators, and environmental organizations all committed to working together in order to meet the program's objectives.
The following technology is one example of many that were moved into commercialization.

The Land Use Site Selection Information Tool (LUSSIT) project was a multi-year project and a collaborative effort between the Houston Advanced Research Center (HARC), the University of Arkansas'

Center for Advanced Spatial Technologies (CAST), and Latitude Geographics (Latitude). The specific program within HARC which lead the development was the Environmentally Friendly Drilling Technology Integration Program (EFD-TIP).

Geocortex Decision Support for Oil & Gas is a map-based decision support system that operators can use to optimize oil and gas infrastructure placement. Shipped with powerful analytical tools and an intuitive collaborative design, the Esri ArcGIS Platform based tool helps to address environmental aspects, facilitate more effective communication, and reach the permit stage of oil and gas development more quickly. HARC and CAST collaborated earlier on a web-based application, the Infrastructure Placement Analysis System (IPAS), which was designed to allow oil & gas companies operating in the Fayetteville Shale to make environmentally-sound infrastructure location decisions.

The objective of the work was to build and host a GIS-based analytical tool that aggregates a large number of attributes and considerations that are spatially distributed in the region of interest. The resulting aggregation of information can be used to find optimal well sites and placement of pipelines, production facilities and lease roads, and/or to determine impact of actions on land values and environmental quality. Each topic of consideration is represented as a 'spatial layer' that can be then joined with other layers. Aggregate values can be displayed on a map. Any number of layers or topics can be assembled and simple to complex relationships between layers can be implemented. Topics for layers include: lease boundaries, road systems, wildlife migration patterns, waterways, aquifer recharge areas, archeological assets, etc. The map layers can also be processed to include proximity values, such as distance from noise sources or distance from schools or hospitals. The technology is web-based and can be used as a planning tool as well as a monitoring tool. Real time or near real time data feeds can be integrated to provide an up to the minute showing of operational impact. Sensor utilization systems that measure and report real time air quality, water quality (disposal, reclamation), habitat impact and wildlife migration impact can provide valuable perspectives for decision-making.

Version 1.0 of Geocortex Decision Support for Oil & Gas has been developed and released and features:

- An application centered on a collaborative, familiar interface that allows team members to interact with GIS data without needing to be GIS experts. Share maps with other users in the organization, provide input on siting decisions via comments and view/respond to tasks assigned by others.
- Targeted, easy to use workflows help oil and gas operators, regulators and other stakeholders make informed decisions. Perform spill and view-shed analyses, assess the immediate environment for risks and be aware of the distance and bearing from a proposed well to the nearest map features.
- The application can be set up in a cloud environment, or on-premises, with an operator or a third party consultant. It can Import your standard business processes and turn your traditional approach into a project networking tool that streamlines the permit approval process.

Geocortex Decision Support for Oil & Gas has become an important component of Latitude Geographics Energy suite of products and with operators already adopting this package they are on track for achieving the goal of broader use in the oil & gas community.

C. Ultra-Deepwater Element

1. Mission

The mission of the Ultra-Deepwater (UDW) program was to identify and develop technologies, architectures, and methods that ensure safe and environmentally responsible exploration and production of hydrocarbons from the ultra-deepwater portion of the Outer Continental Shelf (OCS) in an economically viable (full life cycle) manner.

This mission of technology development encompassed:

- Extending basic scientific understanding of the various processes and phenomena directly impacting the design and reliable operation of an ultra-deepwater production system
- Developing "enabling" technologies
- Enhancing existing technologies to help lower overall cost and risks
- Pursuing new technologies which, if successfully developed, are capable of "leapfrogging" over conventional pathways
- Accomplishing these tasks in a safe and environmentally friendly manner.

Relevant 2005 Energy Policy Act definitions include:

- Ultra-Deepwater - a water depth that is equal to or greater than 1,500 meters (~5,000 feet). The program also includes technologies applicable to formations in the OCS deeper than 15,000 subsurface.
- Ultra-Deepwater architecture - the integration of technologies for the exploration for, or production of, natural gas or other petroleum resources located at ultra-deepwater depths.
- Ultra-Deepwater technology - a discrete technology that is especially suited to address one or more challenges associated with the exploration for, or production of, natural gas or other petroleum resources located at ultra-deepwater depths

2. Goal

The goal of Ultra-Deepwater Program Element was originally to develop environmentally sensitive, cost-effective technologies to identify and develop resources in increasingly challenging conditions and ensure that the understanding of the risks associated with ultra-deepwater operations keeps pace with the technologies that industry has developed. The UDW Program Element assessed and mitigated the risk in offshore production activities related to controls, safeguards, and environmental impact mitigation procedures in place during drilling, completion, and production operations.

This goal was altered following the 2010 Deepwater Horizon blowout and oil spill in the GOM. While the mission remained the same, the UDW Program Element, at the direction of DOE, redoubled its efforts to ensure that hydrocarbons can be safely extracted in an environmentally sound manner. The Program therefore focused on the identification, analysis, and mitigation of risks associated with development of UDW techniques and tools to responsibly drill for and produce oil and gas in this environment. In short, the original mission to develop the tools to reduce dependence on foreign sources via the GOM ultra-deepwater were subsequently intertwined with the safety and environmental sustainability requirements to ensure that future work can be performed soundly with positive results. By doing so, the research and development performed under the UDW Program Element will lead to greater public understanding and acceptance of future industry endeavors to unlock and tap these precious reserves.

3. Objectives

The UDW Program Element solicited input and volunteer efforts to develop its objectives through several avenues. A chief strength of the Program lies in its unique use and engagement of over 950 subject matter experts and other interested parties. These volunteers met with RPSEA periodically to review project progression, develop ideas for additional project work, and share their knowledge with one another. In addition to providing high-level input from oil and gas operating companies that are ultimately responsible for the production of deepwater energy resources, this highly developed process of idea generation, vetting, and project selection formally facilitated the direct input of universities, regulatory bodies, service companies, manufacturers, national laboratories, and other key stakeholder groups. The broad engagement through expansive and inclusive advisory committees provided the UDW Program with significant *pro bono* expertise, as well as potentially significant cost share funds, to further accelerate the development of ultra-deepwater technologies.

The UDW Program Element utilized a Program Advisory Committee (PAC) and several Technical Advisory Committees (TACs) in advisory roles. The PAC consisted of upper level technical managers within operating companies, service and manufacturing industry, and safety and environmental firms, as well as experienced academic researchers. The PAC provided high-level input on program priorities, field areas of interest and technology dissemination, as well as a link to the producer and research communities; but its primary role was project selection. PAC engagement in the process was critical because:

- The operators would be the organizations called upon to actually deploy and operate the new technologies developed under the program
- The service, supply, and manufacturing industry representatives provided a unique perspective concerning development issues related to novel technologies
- The safety and environmental enterprises were fully aware of new developments and specific technological gaps and needs within their areas of expertise
- Academic researchers provided an additional link between fundamental and applied research that could shed light on newer, promising, beyond the horizon technologies.

Supporting the PAC were six TACs, each of which was focused on a particular ultra-deepwater technology area (see Table below). The number of TACs was reduced from nine to six to account for the restructuring and refocus of the UDW Program Element toward more of an environmental and safety area of interest, as well as to increase collaboration and cross-pollination of certain functional knowledge areas. The role of the TACs, with representation from subject matter experts (SME) who study and apply ultra-deepwater technologies in real field situations, was to identify current technology gaps and define the specific R&D efforts needed to address these gaps. As such, the TACs provided a bottom-up, end-user-driven program.

Table 2: UDW Technical Advisory Committees

Drilling & Completion and In-well Interventions	Environmental, Safety & Regulatory and Met-ocean	Floating Facilities & Risers and Systems Engineering
Flow Assurance	Geosciences and Reservoir Engineering	Subsea Facilities

The focus areas for the initial (2007 and 2008) solicitations were developed using a DeepStar Systems Engineering study that was based on industry UDW experience and needs. Four base case field development scenarios were identified as representative of future Gulf of Mexico (GOM) ultra-deepwater developments with technical barriers which challenged development. These scenarios were drawn from four key areas of activity in the deepwater GOM. The 2009 and 2010 selections continued to address challenges associated with specific field types, which were described in prior year Annual Plans. The Program expanded the R&D efforts to carry projects addressing the most important gaps closer to implementation and commerciality stages. It was during the 2010 UDW Program project selection stage that the Deepwater Horizon blowout and spill occurred. Consequently, in the months that followed, a renewed emphasis was placed on safety and environmental sustainability (S&ES). As a result, the 2010 UDW solicitation process was altered to ensure that S&ES and risk mitigation were addressed wherever possible. The 2010 UDW Program solicitations were therefore highly focused on S&ES issues.

After 2011, research topics were influenced by the work of the Ultra-Deepwater Advisory Committee (UDAC) Subcommittee on Risk Assessment, which dictated that project selection should focus on one or more of the following: development of improved well control and wild well intervention techniques; evaluation of appropriate safeguards to include standards for BOPs, cementing and casing; evaluation of instrumentation and monitoring; improvement of flow assurance; expediting the completion of relief wells, and other topics associated with deepwater operations. In 2012 and beyond, initiatives were solely based on direction from the UDAC Subcommittee on Risk Assessment and The Department of the Interior Ocean Energy Safety Advisory Committee (OESC). Projects focused on quantification and assessment of risk.

4. RPSEA Ultra-Deepwater Program Technology Accomplishments & Impact

The Ultra-Deepwater Program (UDW) element consisted of 73 R&D projects. The following discussion will focus on 46 of these projects from the perspective of functional groups, which are subgroups of the UDW Technical Advisory Committees (TAC's).

TAC's were defined as generalized functional areas and consisted of SME's from all sectors of the industry (operators, service and manufacturing companies, national labs, safety and environmental organizations, and academia). Members of the TAC's had several roles within RPSEA: identification of key technical challenges and opportunities, stimulating ideas and developing solutions, leveraging technical expertise to support project development and operational guidance, and technology transfer within their respective organizations. TAC member responsibilities included: providing technical expertise in support of Annual Plan development and project management, UDW project idea identification and generation, UDW project idea prioritization, and proposal ranking.

Each project included a Working Project Group (WPG) of volunteer SME's, led by a designated Project Champion. The purpose of each WPG was to: assist the Project Champion during RFP preparation (Scope of Work, deliverables, evaluation criteria, etc.), participate in bid reviews and selection recommendation process, provide guidance during execution of the project; act as an advisory committee to the Project Champion, attend periodic technology reviews and milestone meetings, and participate in reviewing interim and final reports. Often the WPG members worked as expert peer reviewers for professional papers and presentations of RPSEA project results.

a. *Drilling, Completions, & Interventions*

Producing offshore in ultra-deepwater requires large vessels to provide buoyancy to hold the weight of subsurface drilling and production pipes called risers and topsides processing equipment. Lighter weight risers could lessen the need for gigantic vessels to hold those risers, reducing cost and shortening the time to access reserves. If this could be done safely, what would be the approach? RPSEA volunteer subject matter experts from industry recommended research in composite pipe technology. Composite drilling risers represent a great challenge since motion inside the pipe could destroy the riser. Drilling into geologic conditions of unknown pressure and possible corrosive fluids found in ultra-deepwater could adversely affect the composite riser.

The objectives of the "Composite Riser for Ultra-Deepwater High Pressure Wells" project ,07121-1401-01, included a complete Basis of Design study and analysis to determine appropriate criteria for design and analysis as well as fabrication and proof of concept testing of full-diameter, length-scaled drilling riser joints. The primary objective during this stage of the program was to create a riser system that satisfies regulatory concerns, industry performance standards, and sufficient margins of safety to eliminate apprehension at the operator level. The project designed and tested a carbon fiber overwrapped 1" steel thick drilling riser pipe to produce a 20" ID x 15,000 psi working pressure for 10,000 water depths (Figure 12). During technical planning meetings, it was determined that the maximum expected temperature will be no greater than 180^{o}F, an O.D. (with buoyancy) based on a 60-inch rotary will be used, and that a 19.5" drift diameter riser design will be used for the project. This work confirmed preceding studies suggesting a potential weight savings of 40 to 50 percent in comparison to all steel construction. Full-diameter prototypes demonstrated manufacturability and sufficient margins of safety with respect to burst strength, fatigue, and tolerance to impact damage. Thus, a TRL 3 was achieved. Although additional work was recommended, no operator has stepped up to fund it.

Figure 12: Winding the composite riser prototype

A very real concern is how fast and safely an operator could re-access its equipment on the sea floor when needed for stopping a leak, performing a workover, starting a repair, or logging an inspection. Usually the process takes months, a subsea vessel for early determination, and then a large, expensive vessel to perform an intervention. Such combinations of vessels are not readily available, rarely ready to go "NOW!" and cost in the millions of dollars. RPSEA TAC members recommended a study to find a fast, safe, environmentally friendly, and cost friendly solution. That resulted in two studies to combine all intervention media onto one vessel, incorporate onshore Coil Tubing methods tried on some offshore MODUs, and reduce the size of a ship conventionally thought necessary.

The primary objective of the "Coil Tubing Drilling and Intervention System Using Cost Effective Vessel" project, 08121-1502-01, was to provide the basis for detailed design of a cost-effective deepwater coil tubing (CT) system for downhole work in deepwater Gulf of Mexico (GOM) satellite wells without need for a mobile offshore drilling unit (MODU). This work showed the feasibility to facilitate improved resource recovery from existing satellite wells and make it practical to develop reservoirs that would otherwise not meet economic hurdles. Tasks and deliverables included specification of equipment, identification and assessment of hazards and failure modes, and a comprehensive report including a plan and design basis for detailed design in Phase 2 (Figure 13). This project retained the largest Working Project Group of all UDW investigations.

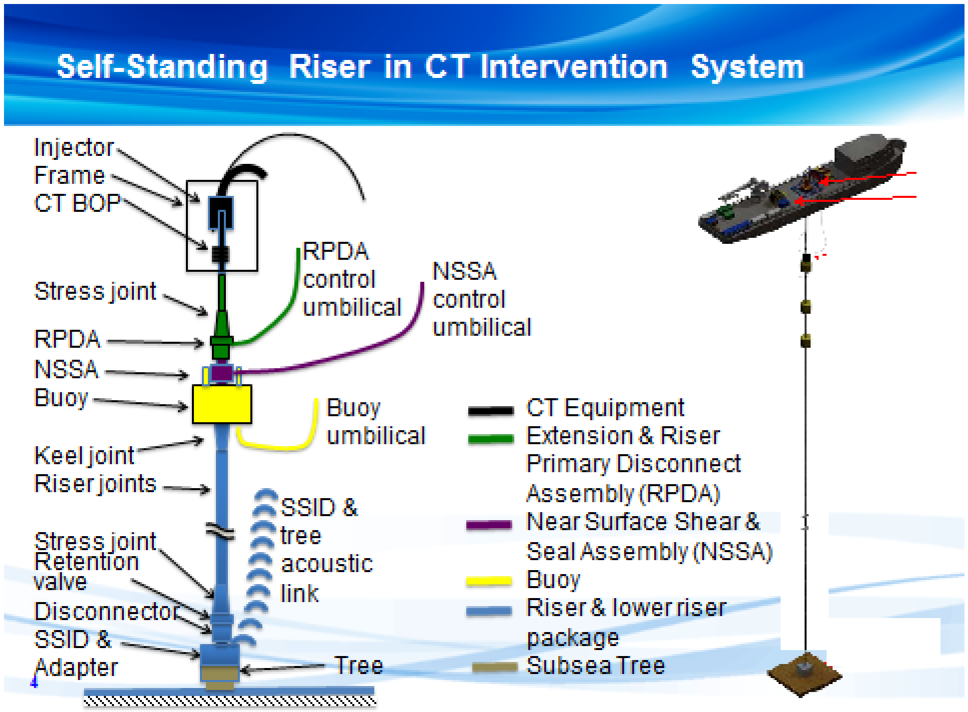


Figure 13: Self-Standing Riser concept for a coil tubing intervention

In Phase 2, which was awarded under a 2010 RFP, the "Coil Tubing Drilling and Intervention Systems Using Cost Effective Vessel" Project, 10121-4505-01, the concept was verified via the issuance of a Certificate of Feasibility for the use of the self-standing riser (SSR) for CT intervention. An extensive set of input data (met-ocean dynamics, vessel responses, CT loads, and weights) necessary for quantitative dynamic systems analysis was generated. The system properties and numerous performance cases were defined for dynamic analysis. The SSR was simulated and analyzed as a dynamic system for select cases. There are no remaining significant technologies or conceptual gaps. Development still requires due diligence in industry standard recommended practices for intervention riser systems. The riser (TRL 6) enables a full performance envelope of coiled tubing abilities (TRL 2). A successful field test on a deepwater satellite well (not yet performed) could prove that a small vessel can operate coiled tubing through an SSR in deepwater, demonstrate improved safety and environmental protection, and incur a cost less than half that of a MODU. Market forces and regulatory concerns have kept operators from prototype testing this strategy. However, CT has been used from MODU's.

Offshore drilling can be very difficult, especially in deeper wells when the mud weight margins between pore pressure and fracture gradient converge towards one another. Managed pressure drilling is one technique that has recently come into operational existence, yet, no matter if it or more conventional drilling is employed, simulators often fail to properly account for certain aspects such as drillpipe rotational energy and torque, frictional issues along the drillpipe – hole wall, and other physical characteristics. As a result, our TAC recommended a physics based pre-drill simulation tool that would help all drillers and rig staff better understand and control pressure risk.

“Advanced Steady-State and Transient, Three-Dimensional, Single and Multiphase, Non-Newtonian Simulation System for Managed Pressure Drilling,” Project 08121-2502-01, resulted in the development of a simulation tool that used fully predictive accurate pressure profiling methods along general well paths by solving mathematical models that do not bear the limitations of *ad hoc* assumptions implicit in mean hydraulic radius, slot flow, multiphase empirical correlations and like approaches. Highly eccentric borehole annuli (with possible washouts, cuttings beds, and fractures) are estimated using custom boundary-conforming curvilinear grids, and the general steady and transient, non-Newtonian flow equations are written to and solved in these special coordinates. Numerical methods are hosted by user-friendly, “plain English,” graphical interfaces (with integrated 3D color capabilities) that support job planning efforts and particularly on-site field use. The work was the subject of four papers presented at the 2011 AADE Conference and one at the 2011 Offshore Technology Conference. In addition, Elsevier Scientific Publishing published this research, plus practical applications, as a new book, “Managed Pressure Drilling: Modeling, Strategy and Planning” (TRL 6). The use of fast computer modeling is available to the entire industry and not only will save millions of dollars in prevented downtime of offshore rigs, but is designed to save lives, and reduce or prevent oil spills (Figure 14).

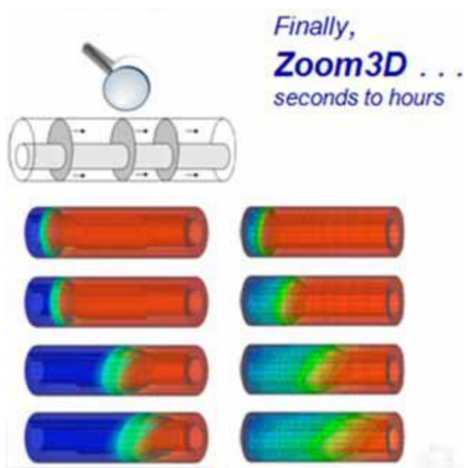


Figure 14: Eccentricity effects on drilling fluids and cuttings simulation

One of the most important aspects of wellbore safety incorporated in every newly drilled well is the assurance of wellbore integrity. A proper cement job, which includes placement, setting (drying and hardening), and sealing, is paramount to integrity. The TAC recommended more projects on cement, and RPSEA responded by focusing more resources on cement issues and strategies than on any other topic. A bad cement job can be a recipe for disaster in well control, and it can significantly diminish reservoir performance as well. A poll of operators and well service companies showed that, while most admitted to having good cement installations under their watch, no one could recall a “perfect” cement job. Results of the RPSEA research work have shown that even more concern is merited regarding proper cementing practices, composition of materials, and use of borehole drilling fluids.

In the "Smart Cementing Materials and Drilling Muds for Real Time Monitoring of Deepwater Wellbore Enhancement" project, 10121-4501-01, various technologies were used to develop "smart" drilling mud and cement slurries with enhanced sensing properties that can be deployed for real time monitoring during well construction. Smart cement has been designed to monitor the well casing-to-cement bonding over the entire service life of a well. New technologies were developed and integrated to make chemo-thermopiezoresistive cement and drilling muds. Electrical resistivity of smart cement and smart drilling muds was selected as the sensing property for the two materials. In this study, small, large and field models were designed, built and used to demonstrate the concept of real time monitoring of the flow of smart drilling mud, space fluid and smart cement and hardening of the cement in place (Figure 15). The effects of various additives, water-to-cement ratios, curing conditions, curing time and temperatures on the piezoresistive behavior of the smart cement and various contaminations on the smart drilling fluids were quantified. Also, curing and piezo-resistive constitutive models were developed to characterize the smart cement behavior. Importantly, change in the resistance of hardened cement in the field well was continuously monitored for more than one year. It was found that pressure in the casing can be predicted from changes in resistivity of smart cement. It was found that smart cement can be used to not only determine contamination and stresses in the cement sheath, but also pressure and temperature in the well at different depths. The field test demonstrated a potentially alarming and game changing observation: the smart cement required over six months to cure. While this was the result of a single test, the field practice of completing wells, along with perforating casing within hours of primary cementing could be a hazardous practice, and could also lead to poor reservoir isolation with a resultant reduced reservoir performance. While this project accomplished a TRL of 3, much more work is needed on smart materials and fast, stable, and predictable cement curing.

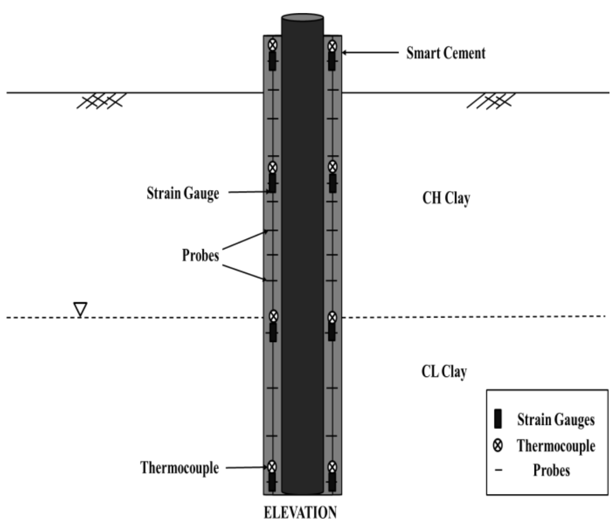


Figure 15: Depiction of wellbore apparatus to test Smart cement

Concerns about cement placement led to a project that took onshore reverse circulation practices and evaluated their feasibilities offshore. Thus, the "Deepwater Reverse-Circulation Primary Cementing" project, 10121-4502-01, evaluated the process, modified existing software, and conceptualized modified gravel pack and sting-in float technologies. However, technology needed for future development includes the modification of float equipment and a switchable crossover that will divert fluids on demand. The overall concept remains at a TRL 0. The idea was well received, but some reluctance from operating companies' management has slowed adaption because the cost offshore due to a failure can be staggering. *Since the industry still did not understand problems with various drilling fluids that could be used in that method, or for that matter, more conventional approaches, one TAC recommendation was to first improve the understanding of the capabilities and limitations of available drilling fluids that are actively being used in thousands of wells worldwide before seeking to alter the cementing process.* Nevertheless, one operating company and one service company continue to work on reverse circulation cementing as an alternative method.

The objectives of the "Analysis of Best Practices for Deepwater Cementing in Oil Based Mud (OBM) and Synthetic Based Mud (SBM)" project, 12121-6503-01, were to develop a fundamental knowledge of oil and synthetic based drilling fluids-cement compatibility issues related specifically to deepwater cementing, quantify risks associated with cementing in OBM/SBM, and develop best practices and recommendations in order to reduce the recognized risks. This study analyzed the relationships between temperature, pressure, cement bond, and the degree of mud removal and its effect on zonal isolation in complex well architectures. Fluids under laboratory investigation included typical commercially available designs of cement slurries, SBM, OBM, and spacers, with a focus on micro-particulate fluids and other new technologies. Environmental benefits of a successful project should include a decrease in contamination, and improved bonding of cement. Long-term wellbore integrity will be improved and environmental and safety issues such as leaks from the formation and Sustained Casing Pressure (SCP) will be mitigated reducing safety risks. OBMs and SBMs allow for much more stable drilling in high pressure - high temperature (HPHT) and ultra-deepwater environments. However, mud properties that were beneficial for drilling become detrimental to cementing, completions, and well productivity. Fluid incompatibilities resulting from contamination, residue, fluid swapping and other fluid interactions can result in reduced cement compressive strength, channeling, downhole gelation, and/or a poor cement bond. Incompatibility and incomplete borehole cleaning can result in safety and environmental risks including job failure, future operational issues and loss of zonal isolation. The work resulted in a guideline manual that operators have begun incorporating into their best practices is being promoted as tech transfer by the Association of American Drilling Engineers, and has been introduced to the American Petroleum Institute for incorporation into its cementing recommended practices (TRL 6).

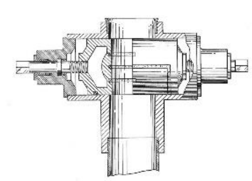


Figure 16: Blow-out Preventer, patented 1922.

The Blow-Out Preventer [BOP] actually does not prevent a blow-out but is designed to close a well opening at the top of the well casing, thus confining an existing blow-out. The technology was first patented in 1922 (Figure 16). Little has changed since that time. Tens of thousands of *wells have been drilled without incident. Hundreds have been shut in by a BOP and the BOP accomplished its purpose. However, the tragedy of April 2010 at Macondo offshore GOM changed our understanding of the purpose and deployment of BOP's, and forever changed the measurement of failure in terms of human life and environmental consequences. The industry represented by RPSEA TAC's took initiative from public concerns by recommending several safety improvements long before regulatory authorities collected any of the published billions of dollars in compensation. One successful project deals with how to close a BOP when a drill string itself might be in the way of stopping a calamity such as what happened on the Deepwater Horizon drilling rig.*

The "Intelligent BOP RAM Actuation Sensor Systems" Project, 11121-5503-01, designed, developed, and laboratory tested an instrumented BOP ram prototype. A system feasibility determination, a gaps analysis, and a risk assessment were conducted, followed by technology selection. Instrumentation was conceptualized and reviewed, and then designed. A prototype was constructed and bench scale tested, and was followed by a review with BSEE and API. Also, a commercialization plan was developed. In Phase 1 various sensing systems were evaluated, integration approaches were developed and integration risks were identified and evaluated. A combined electromagnetic (EM) and ultrasonic (UT) multi-sensor system was selected based on its ability to perform pipe diameter measurements. Since both sensing modalities exhibit different sensitivity to the error and noise source, the combined system offers a high degree of robustness in the presence of confounding noise sources.

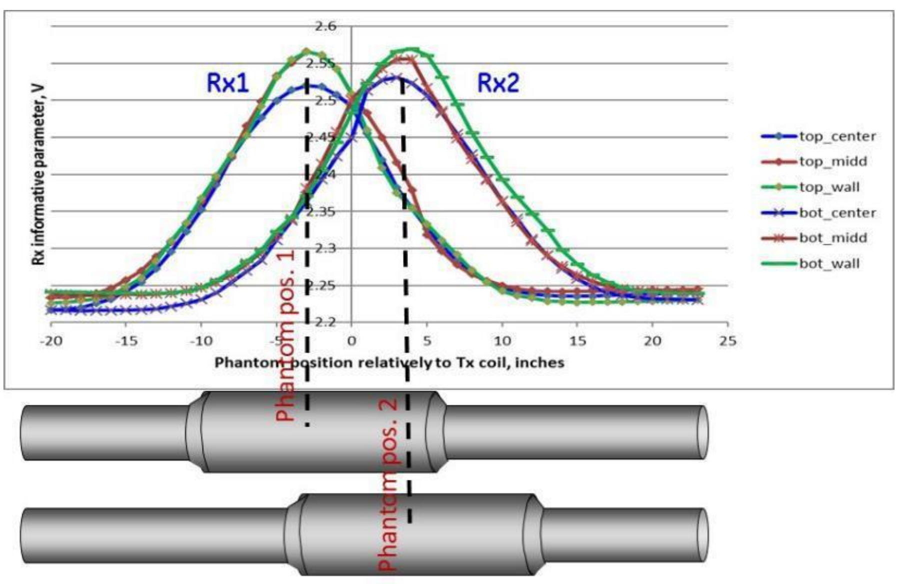


Figure 17: Response from the receiving coils Rx1 and Rx2 while a joint phantom is passing through the coils for three different pipe axial shifts.

In Phase 2 a detailed sensing system design was specified for a prototype test system; laboratory test prototypes incorporating the EM and UT sensors and associated electronics, data acquisition and signal processing were built; tests were then conducted, including pipe position, drilling mud and cuttings attenuation, electromagnetic losses in ferromagnetic metal components, and statistical signal variation due to measurement, estimation, and electronics noise. The functional testing for both EM and UT sensors showed that the devised error and noise mitigation approaches are capable of providing robust detection to the presence of tool joints in the vicinity of the sensing system (Figures 17 and 18). Limited environmental testing with prototype sensors indicated that survivability across the temperature range of operation, as well as robustness across multiple temperature cycles, was achievable (TRL 3). The TAC deemed this technology ready to proceed to early environmental testing leading to commercialization. The technology in the prototype is designed for new BOP construction, but thus far it appears readily adaptable to existing equipment.

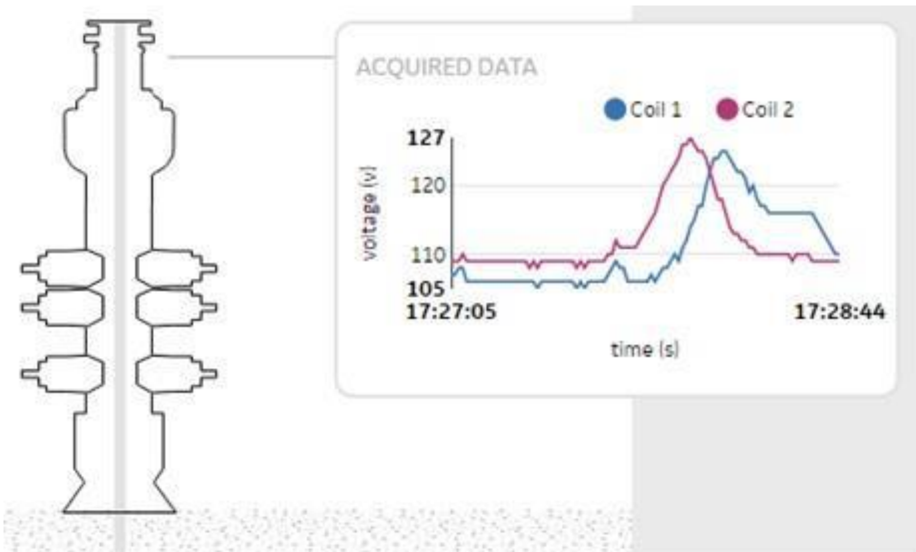


Figure 18: Web application displaying EM coil data in real time over the network.

The objective of the “Intelligent Production System for Ultra-Deepwater with Short Hop Wireless Power and Wireless Data Transfer for Lateral Production Control and Optimization” project, 09121-3500-01, was to develop a safe, single system to optimize production for deployment in multilateral wells, which will increase the life of the wells while decreasing production costs. The system would provide remote flow control capabilities inside laterals using an electric, ultra-low power choke system, and would have the capability to collect production data in real time. The system was developed and lab tested, and is composed of the following new technologies: (1.) wireless power transfer, (2.) wireless communications transfer, (3.) low power - high stability sensors, (4.) low power flow control system, (5.) sensor integration into completion tools, and (6.) an integrated surface command & controls and communication module system (Figure 19). As a result of this work, Shell installed the Intelligent System on a fracture stimulation job where four flow control systems with built-in gauges were deployed using a single electrical cable connecting the surface system to the downhole tools. BP Alaska requested a system for a through- tubing wireless application in which gauges are built separate from the flow control tool. These prototypes were further developed and are now fully commercialized products, although they have yet to be mass produced (TRL 6).

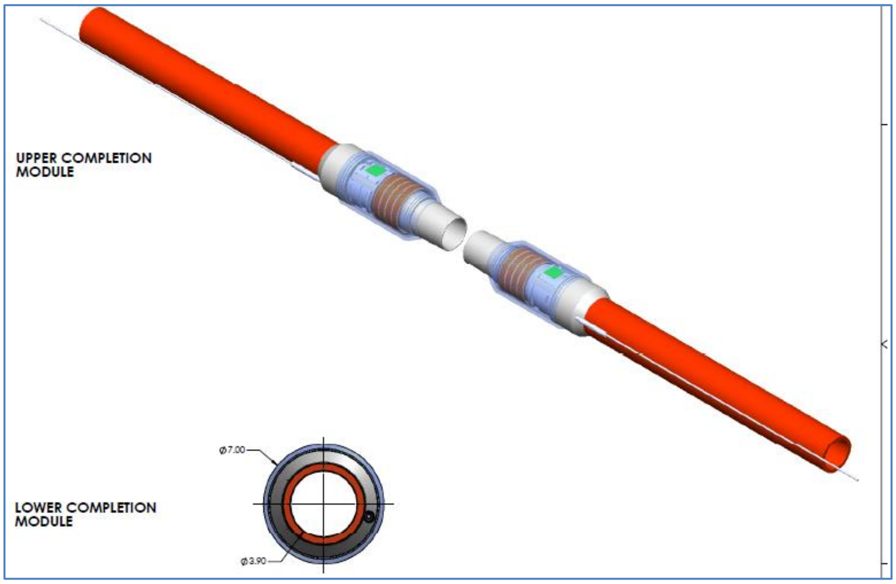


Figure 19: Configuration of the wireless power and communications for upper and lower completion integration.

Annular pressure buildup (APB) occurs in all wells with high bottomhole temperature, multiple casing strings, and annuli that cannot be vented, which includes most deepwater Gulf of Mexico wells. Unless a well is properly designed and constructed, APB can result in casing string and premature well failure sometimes with catastrophic results.

"Reliability of Annular Pressure Buildup (APB) Mitigation Technologies" project, 12121-6502-01, was designed to assess APB risks for numerous typical load cases, evaluate various APB mitigation methods including novel strategies and analyze them for effectiveness, and develop recommendations (Figures 20, 21). This project successfully cataloged and analyzed 17 APB mitigation technologies. It also provided industry with a stochastic tool for analysis, comparison, and possible choices (i.e., ranking) of APB mitigation techniques applicable to specific well and field situations. This newly developed tool was successfully post-tested against several known and reported ABP failures and underwent intense scrutiny and review by a panel of over 35 SME's. An APB Mitigation Techniques Summary Report was prepared as a Society of Petroleum Engineers publication and was forwarded to the American Petroleum Institute for review. The tool is now being employed by several deepwater operating companies and is expected to gain wider support as others become aware of it (TRL 6).

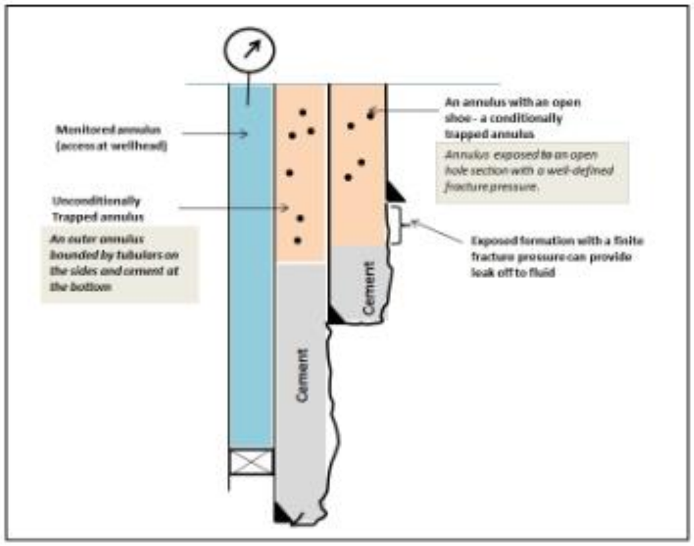


Figure 20: Types of subsea annuli

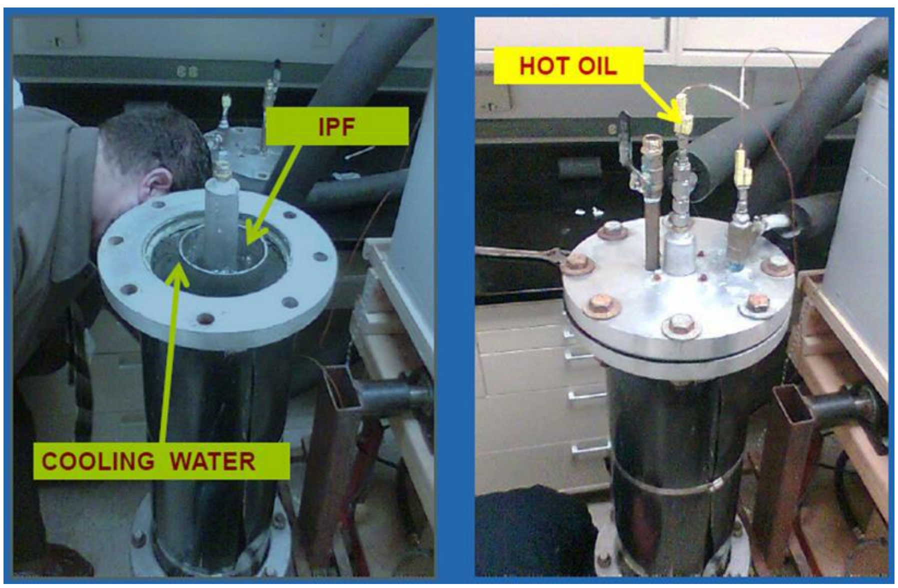


Figure 21: Test rig to determine insulation performance of an IPF (N-Solate™)

b. Environmental, Safety, & Regulatory

Several projects were performed strictly under the Environmental, Safety, and Regulatory (ESR) subgroup, although over 80 percent of all UDW projects had an ESR component.

<u>"Human Factors Evaluation of Deepwater Drilling, including Literature Review," Project 11121-5101-01</u>, began by providing a comprehensive summary of all offshore oil and gas related human factors documents, which heretofore had never been compiled. The project also developed a software tool that identifies and traces barriers to unsafe drilling practices and can be used for competence based training or post-near miss or post-incident evaluation (Figure 22). As a result of this project the newly developed tool prototype has been used by several industry operating companies and one safety company, and it

has a TRL of 5. Additional testing and product development is expected to be necessary prior to the tool becoming fully commercial.

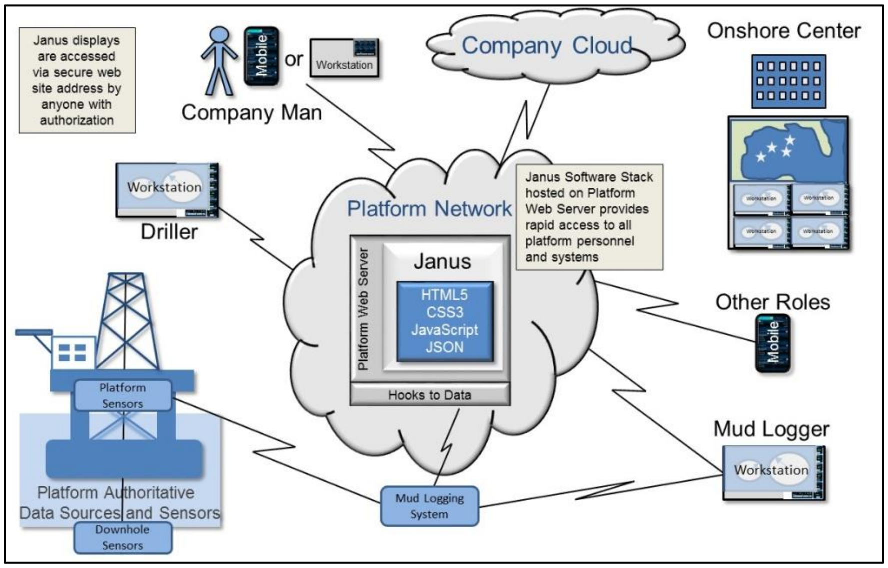


Figure 22: Operational view of Janus for well control.

<u>“New Safety Barrier Testing Methods,” Project 08121-2101-02</u>, found that current state-of-the-art for testing of safety valves is largely blind to the dynamics of the fluid column and that simply using pressure decay curves without accounting for temperature and other effects of long tubing depths can adversely impact the confidence level. In stratified columns, the temperature effects on the gas portion are difficult to discern from leakage effects, but modeling can be used to generate trending curves for valve integrity determination and normalization of some of the parameters allows for the same model to be used on the same well family over the course of its life with little modification (Figure 23). One of the goals of this project was to use model simulations to determine safety valve leaks, so that additional instrumentation will not be necessary. This project was unable to definitively provide such a result, but the modeling work suggested that downhole distributed temperature sensing (DTS) might improve fidelity for the models. It is believed that several manufacturers of safety valves are privately and confidentially studying the application of DTS, as well as other technologies, in an effort to gain a competitive advantage by providing industry with more definitive information regarding leak and failure probabilities throughout the valve lives.

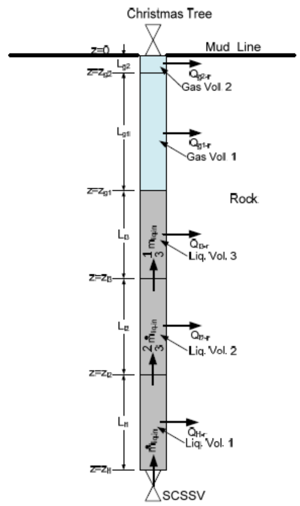


Figure 23: Safety barrier analysis; gas cap and liquid sub-model for SCSSV leak detection computational fluid dynamics.

<u>"Replacing Chemical Biocides with Targeted Bacteriophages in Deepwater Pipelines and Reservoirs," Project 08121-2902-04</u>, and its companion "Enumerating Bacteria in Deepwater Pipelines in Real-Time at a Negligible Marginal Cost Per Analysis: A Proof of Concept Study," Project 08121-2902-06, looked at a "green" method to counter the bacterial agents responsible for microbially influenced corrosion (MIC) and reservoir souring. The first project found that phages have similar inhibitory effects on active sulfate reducing bacteria cultures as do currently used chemical biocides, but phages have a longer lasting inhibitory effect, implying that phage-based biocontrol can provide a better treatment option for the petroleum industry to counter MIC and possibly reservoir souring. The project achieved a TRL of 5. After further testing and field trials (Figure 24) after the completion of this project, it was determined that phages could be made to attack specific targeted bacteria. Phages are now being piloted by several companies and have been expanded into the wastewater and soil remediation industries.

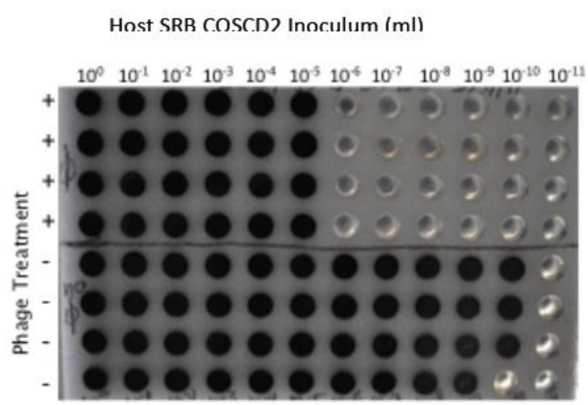


Figure 24: Results of one of the phage trials showing the effect of phage on bacteria on multiple phage–host ratios.

The second project developed a method for the real-time detection of microorganisms in bacterially contaminated environments that can quantitatively identify organisms at the species level in samples, in real-time. The Single Particle Aerosol Mass Spectrometry (SPAMS) 3.0 was developed in the

"Enumerating Bacteria in Deepwater Pipelines in Real-Time at a Negligible Marginal Cost per Analysis" project, 08121-2902-06, was a project focused on remote detection and was successfully tested in the field for a TRL of 7. As a result, Livermore Instruments streamlined the prototype, increased its ruggedness, has commercialized the product and is actively marketing it (Figure 25).

Figure 25: Photo of Livermore Instruments SPAMS 3 portable sensing and analysis technology *(courtesy of Livermore Instruments)*.

"Corrosion and Scale at Extreme Temperature and Pressure," Project 10121-4204, was aimed at developing the necessary data, models and experimental tools to assess corrosion and scale formation, as well as their inhibition, under extreme conditions of temperature and pressure (xHTHP). This was needed because existing models relied on extrapolation of lower pressure and temperature data, mechanisms were increasingly found to be incorrect, and because test apparatus was incapable of handling the extreme environments. The methodology and equipment/apparatus to test corrosion and scale at xHTHP was developed for conditions of up to 24,000 psig, 250°C, and 300,000 mg/L TDS. A methodology was developed to rapidly and accurately analyze general and pitting corrosion (Figure 26). Also, a method to produce strictly anoxic solutions (<<1 ppb O2) was developed to study mineral scale kinetics and inhibition (TRL 7). Mineral scale solubility was determined at xHTHP for several oilfield scale species, and several inhibitors were evaluated for their thermal stability and performance. A new method for evaluation of the pitting potential of corrosion resistant alloys (CRA's) at HPHT was developed. As a result of this work, a commercial tool now exists that is capable of testing for scale and both general and localized corrosion at xHTHP (TRL 7). Plans include expanding the database for solubility, corrosion, and materials selection at xHTHP conditions with realistic brine composition and at strictly anoxic conditions (<< 1 ppb O_2).

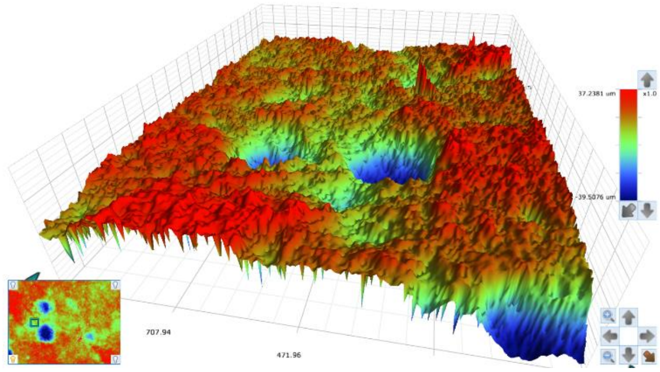


Figure 26: VSI image showing two corrosion pits on test coupon surface after exposure to 250°C field brine with CO_2.

c. ***Floating Facilities & Risers and Systems Engineering***

As operations move further offshore and into deeper water, the surface area of a vessel must become larger so that it can support ever longer and heavier risers and float the growing topsides facilities needed for processing, drilling, and a larger crew that stays offshore for longer periods of time. Now common are production vessels larger in tonnage than modern aircraft carriers used by the U.S. Navy (93 to 119 thousand tonnes). As vessels are built larger, and have deeper drafts to safely operate under extreme met-ocean conditions, problems occur in some areas for which industry does not have answers, chiefly related to motion, integrity, vibration, mooring, and storm survivability. A number of innovative designs exist to address some of these problems and more are on the drawing board. The RPSEA TAC was very active in studying and recommending designs and solutions. RPSEA projects on dry tree ultra-deepwater solutions that originated with the RPSEA TAC were the longest-lived and most integrated set of independent projects in industry history.

Many vessels have mooring "anchoring" lines while others use dynamic positioning to maintain position. A typical mooring line, and there are dozens of varieties, costs about $1,000,000 per 1,000 feet of "rope." Four mooring lines are commonly deployed per side for a conventional rectangular shaped mobile offshore drilling unit (MODU).

Risers have problems with weight, material, motions and vibration. Maintaing the integrity of these links between surface and subsurface is perhaps the most important aspect of deepwater operations. As water depths increase, riser designs must adapt.

The topsides on floating vessels are similar to refineries - stacked over several levels. But unlike onshore refineries, crews live in and work on these vessels. The helipad is a most obvious feature, but dangers abound below deck. The most serious ones could result from possible deflagration, fire, or explosion.

The "Ultra-Deepwater Riser Concepts for High Motion Vessels" project, 10121-4401-02, was created to investigate riser concept(s) in water depths approaching 10,000 feet supported by high-motion vessels.

Its primary objective was to establish and bring to maturity at least one safe riser system that will reduce risk and increase safety to people, infrastructure, and the environment, as well as help maintain uninterrupted production. It is known that vessel-imposed motions, which are forces, affect the long-term integrity of riser systems on offshore floating facilities. These forces are amplified for vessels tagged as “high-motion” such as conventional semi-submersibles and ship-shaped FPSOs, both of which can have significant heave motion, roll and pitch; all angular motions. The riser configurations that showed promise as viable alternatives for high-motion vessels and were evaluated are: (1.) Distributed Buoyancy (a.) Lazy Wave Riser and (b.) Steep Wave Riser; (2.) Discrete Buoy (a.) Hybrid Riser Tower and (b.) Tension Leg Riser. Two of these four configurations, the Lazy Wave Riser and the Hybrid Riser Tower are already technically mature, as shown per recent installations by Shell and by Petrobras, respectively. The Tension Leg Riser concept was thoroughly studied by Mobil in the late 1990’s and established steps on how to install a submerged buoy. The other components of the Tension Leg Riser to install (which are the catenary risers hung-off the buoy and the catenary jumpers) are common items. A detailed dynamic analysis (considering both extreme sea-states and fatigue sea-states) and risk assessment were performed to confirm the selected candidate system(s) of design coupled with conventional riser materials (Figure 27). Testing was conducted via simulation to confirm the steel catenary riser (SCR) as the single chosen concept valid for most field applications. This project ended early on recommendation of the subcontractor and agreement by the SME’s in the Working Project Group, since results clearly favored SCR’s in the Lazy Wave configuration. The conclusions of this work have since been used to design lazy wave risers in planned conventional production projects scheduled in the GOM (TRL 7).

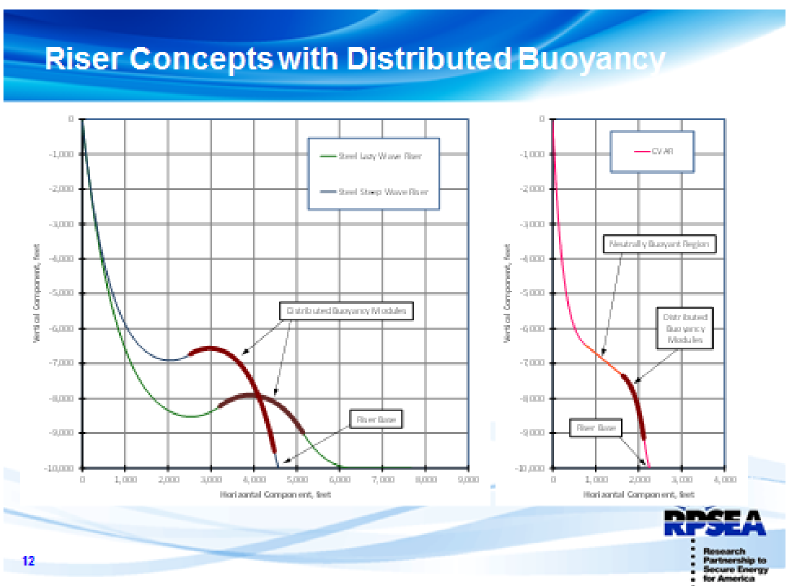


Figure 27: 2D Depiction of model for GOM UDW steep and lazy wave risers (Left) and compliant vertical access riser (Right).

<u>The objective of the “Integrity Management of Risers to Support Deepwater Drilling and Production Operations”</u> project, 11121-5402-01, was to develop a reliable, cost-effective, real-time riser integrity management system that would close technology gaps that included: availability and use of historical riser data for assessment of long-term integrity management of deepwater riser systems; utilization of

on-board subsea equipment controls to detect anomalous behavioral modes from risers and communicate to the surface; and implementation of mitigation strategies from analysis of long term data. There were already existing safety management systems and software for riser system integrity, but they were not standardized, and many of them had compatibility issues. Data storage, riser performance and a user interface for on-ship and onshore issues had been addressed by others. Solutions encompassing hardware, software, processes, and people were integrated in this project and installed on an active deepwater production vessel to study riser integrity management. This new concept, known as the Riser Life-cycle Management System (RLMS), was designed and developed with the assistance of and input from key end-users, who helped develop global requirements for any system design. The selected design then was built and tested as a scaled subsystem - a preliminary prototype design. Five sensors were deployed on a deepwater drilling riser down to about 6000 feet subsea (Figures 28, 29). Software and business process system integration was accepted and for now is (TRL 2). The Phase 1 work yielded several proposed benefits for the RLMS system (TRL 4):

- Extending life of a riser - $10 million plus/riser
- Riser inventory optimization
- Long term asset management
- Real time data analysis of failure and fatigue not currently available
- Post failure analysis for design and mitigation methodology

Additional software integration work will be required to ensure a production plan for a commercially viable deepwater riser integrity management system that can be used for retrofit or new unit installation. At that point, additional testing will need to be conducted to carry the system to commercialization.

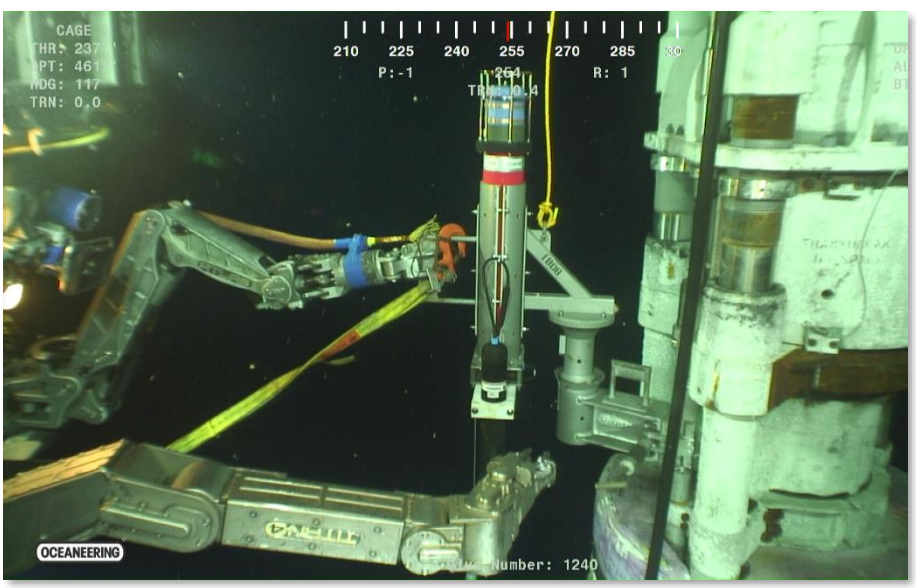


Figure 28: Subsea sensing and acoustic telemetry module attached to a riser.

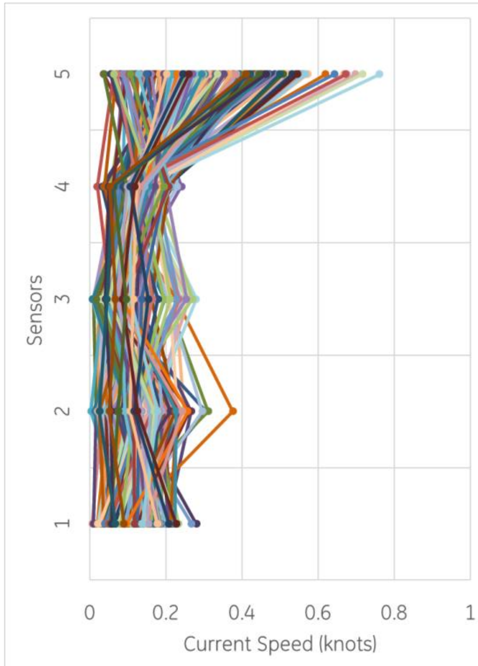


Figure 29: Current speed with depth.

Mooring ropes are expensive, and can be compromised by merely dropping them onto the seafloor, causing absorption of ultra-fine sand particles into the rope fibers. However, on some occasions ropes have been dropped and recovered, and have shown no signs of damage. Because of the possibility of damage or weakening of mooring lines if dropped onto the seabed, regulators have forbidden their subsequent use should they come into contact with the seafloor. This is expensive.

The objective of the "Effects of Fiber-Rope/Seabed Contact on Subsequent Rope Integrity" project, 10121-4406.01, was to test new technology in mooring line sand protection and enable qualifying mooring rope designs for pre-installation. Establishing pre-installation approval from BSEE would greatly reduce sanction risk, reduce time required to hook up mooring lines to a floating facility, and reduce time to reach a safely moored condition when needed before arrival of severe weather or in response to vessel movement due to weather or accident. It is possible for soil particles to bypass particle filters, become embedded in the rope core, and intensify normal fretting wear damage as the installed ropes respond to vessel cyclic wave loads resulting from extreme weather forces (such as hurricanes). This situation will increase the risk of mooring-line failure. Therefore, specific objectives were included in this effort to develop a fundamental technical understanding of the effects of fiber rope contacting the seabed, whether accidental or planned, analyze the primary cyclic-wear process that reduces the strength of fiber ropes, define mitigating risks to avoid unsafe conditions, and develop and conduct a test plan with input from project industry participants and U.S. regulatory agencies to qualify polyester mooring ropes for incidental seabed contact and seabed pre-installation.

The project acquired two 15-meter rope inserts from each of five major polyester rope manufacturers, representing the products that are being used most in the Gulf of Mexico and other offshore mooring systems. Test methods and equipment were developed to determine the presence or absence of soil in five different mooring inserts recovered after being deployed to the seafloor and dragged, lifted, and lowered again before removal after a five-day deployment for days on the seafloor, as well as to determine the effects of such soils on the long-term integrity of the mooring ropes. Based on advice from RPSEA's Industry Workshop, a new rope sample water-ingression test chamber was developed to determine the physics of water entering a ½-meter sample of rope as the rope is dropped from the surface to the seafloor. A new Four Sub-rope Test Machine was designed and constructed to test four sub-ropes with individually measured loads — a major improvement on the previous DeepStar-developed method (Figures 30, 31). Soiled and unsoiled sub-ropes were cycled at 15 to 45 percent of the Average Break Load for 20,000 cycles on the new test machine, and then subjected to a break test. No significant differences were found between the break-test loads of soiled and unsoiled sub-ropes, except with one design that was being deployed and failed at the connection loop. All testing conducted during this program demonstrated that mooring rope designs with multiple layers of filtering material (as well as one alternative filtering system evaluated) can completely protect mooring ropes from soil ingression. Based on these results, it was concluded that these types of ropes can be dropped to the seafloor without damage or loss of long-term integrity. This project resulted in BSEE approval to allow these new ropes with protection to be used, even if they were accidentally dropped to the seabed. As a result, a major operator avoided redeployment of 16 mooring ropes that failed in RPSEA tests, saving between 16 and 18 ropes that were used for a vessel in more than 4300 foot water depth, at a cost savings of approximately $77,400,000 in materials plus deployment costs (TRL 7).

View From Dead End

View From Live End

Fork-Liftable Top Covers

Figure 30: RPSEA/Stress Rope Testing Machine

Figure 31: Deployment/Recovery Operations

> *Producing and temporarily storing oil offshore for offloading can be easier than transportation of that oil to an onshore facility, especially in the far offshore and ultra-deepwater environments. Further complicating production are weather, availability of offloading vessels, and Jones Act restrictions (in the U.S.). The need exists for a vessel-based storm strategy retaining some oil storage in order to produce reserves in the far out GOM.*

The objective of the "Low Cost Flexible Production System for Remote Ultra-Deepwater Gulf of Mexico (GOM) Field Development", Project 10121-4404-03, was to study the feasibility of a circular shaped floating platform unit as compared to two current FPU concepts, semisubmersibles and spars. The circular design was found to be favorable to a storm survival application (Figure 32). For this study, the floater host is assumed to be located in 2000 to 3000 meters of water. Production will be gathered via four production risers from two separate drill centers. Gas will be exported through an export gas riser/pipeline. The drill centers will sustain up to 10 well risers. Each well will be connected to a wet tree that is controlled via umbilicals and power cables. Artificial lift is supplied by either subsea pumps or downhole electric submersible pumps. Processed oil will be directly offloaded from a single offloading station. It is anticipated that capacity for three additional risers for future improved oil recovery via water injection and/or future tie-ins will be required. Testing included computer analysis based on known safety and weight factors, riser limitations, and was followed by tank testing a scale model. The results showed that the circular design meets all criteria. However, the design is not yet certified for this purpose through a HAZID study, although circular designs have been built for other purposes. Once the vessel is certified, this approach can store up to 1 million barrels of oil in normal operations and appears to be capable of storing 600 thousand barrels of oil in tropical storm conditions or 300 thousand barrels in hurricane conditions. The cost savings should be significant per barrel and will protect from catastrophic oil spills. Another design, which was originally intended to be tested in this project but backed out, has improved their patented circular design and is advancing their capability (TRL 3).

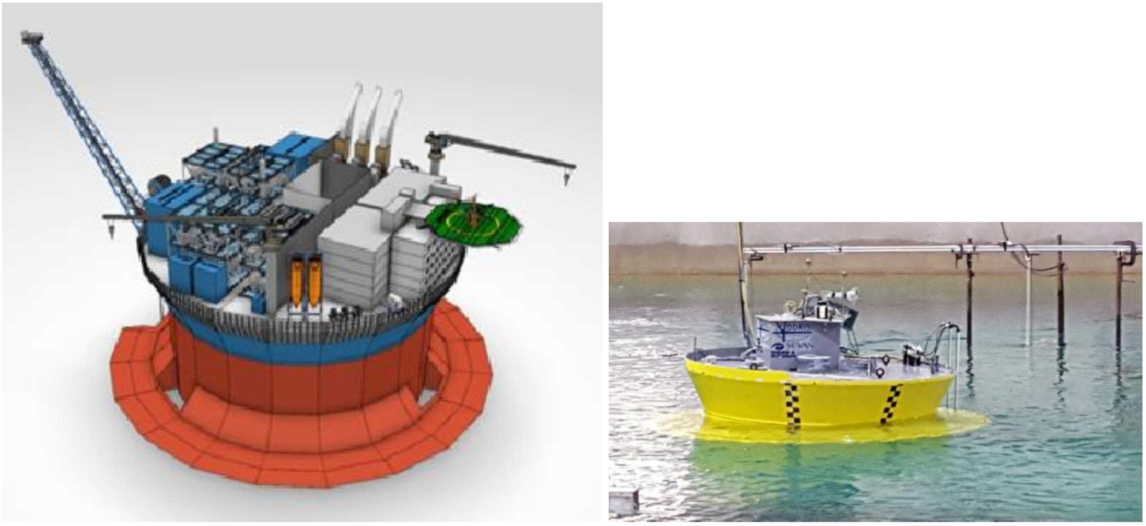


Figure 32: Concept (Left) and model (Right) of circular shaped floating production and storage platform.

Thunderhorse is an ultra-large production vessel in deepwater of the GOM. It displaces about 129 million tonnes, cost over $5 billion, and has over 750 dedicated employees, with a BP unit vice president overseeing operations. The RPSEA TAC questioned if this level of investment would be economically justifiable for future reserves or should be attempted again. They openly asked if the same functions could be performed safely with a smaller vessel. That might be accomplished with a dry tree drilling and production facility design and lighter risers.

Several projects were performed to address this question. The figure below summarizes their evolution (Figure 33).

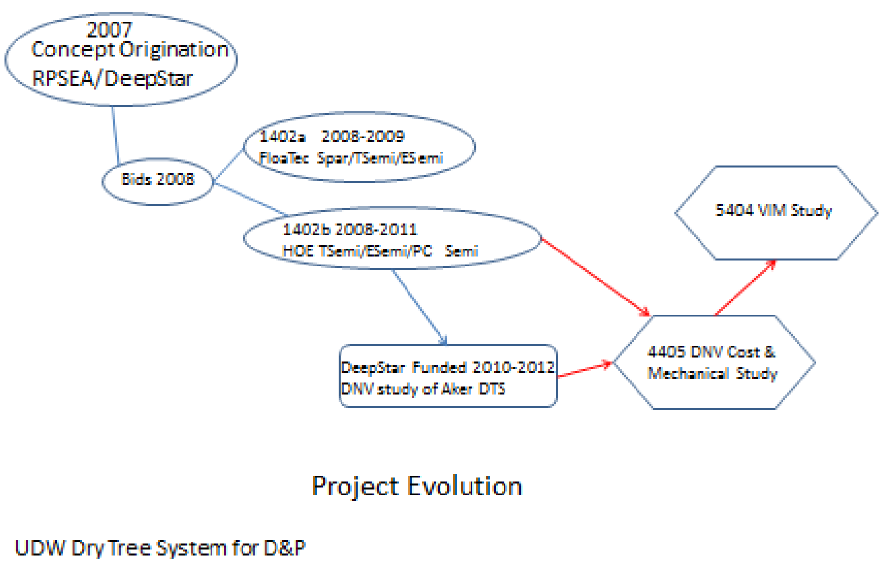


Figure 33: Ultra-Deepwater dry tree drilling and production facility project evolution.

Project 07121-1402a "Ultra Deepwater Dry Tree System for Drilling and Production (a)," was a RPSEA contract to examine three generic specifications of popular designs. The concepts were of existing large Spars, large Truss Semi-submersibles, and large Extended Draft Semi-submersibles. A base case and a sensitivity case that would meet an ultra-deepwater dry tree drilling and production mission were evaluated. The conclusion, reported in May 2009, stated that either semi design is significantly superior in both space and safety to enlarging a Spar. A second, simultaneous and competing study, Project 1402b, "Ultra Deepwater Dry Tree System for Drilling and Production (b)," examined different Truss and Extended semi designs and a novel, yet to be built, paired column semi-submersible design. The investigators, with review by the TAC, selected the Paired Column (PC) design as superior based on marine-industry standard computer simulations, and scale model wind tunnel and water tank tests. DeepStar (a private organization that represents about 12 industry leaders and is led by Chevron) elected to test an up-design of an existing, conventional, very large dry tree semi-submersible (DTS) as proposed by a third contractor. Results of RPSEA's 1402b and the DeepStar report both stated that more work was critical before any capital investment in either technology would be attempted. The remaining critical steps as of 2012 were to complete the technology in the following areas:

1. System maturity of the floater concept, especially the riser attachment to the floater;
2. Constructability, not just in U.S. ports, but in dimensionality of construction, water depths to tow, and time-frame to physical build out;
3. Performance on the drilling/production site, especially of the risers relative to fatigue, safety in normal weather and under extreme conditions;
4. Well bay designs to allow drilling while producing, and keeping the area safe for workers;
5. The effects of either design, with or without attached risers, to vortex induced motions (VIM);
6. Cost efficiency short of $200 oil and $20 gas, after adding safety to address ESH issues.

Project 10121-4405-02, "Ultra-Deepwater Dry Tree System for Drilling and Production in the Gulf of Mexico, Phase 2," was awarded to finish design testing criteria of the PC semi and the DTS. An attempt to answer all the above six concerns would be excessive in scope for one project. Therefore, this project was designed to further develop two dry tree semi-submersible concepts for 8000 foot water depths in the GOM: (1.) a Paired Column semi-submersible developed by Houston Offshore Engineering (HOE), and (2.) a Deepwater Dry Tree Semi-submersible (DWDTS) developed by Kvaerner Field Development (KFD). The contractor evaluated the design documents from each designer and ensured that both concepts were developed in accordance with the same design basis and each had addressed its unique design challenges to be project ready. All critical elements identified previously for the two concepts had been addressed, e.g., VIM and quayside integration for HOE PC semi concept and riser tensioner qualification for the Kvaerner DWDTS concept. Both concepts performed a VIM model test and extensive engineering work. DNVGL conducted Approval in Principal evaluations for both concepts and Technology Qualification for the riser tensioning system. This project not only involved large number of senior specialists in DNVGL, but also engaged many subject matter specialists from the industry in key steps, including design basis, progress review, model tests, and final Conceptual HAZID workshops. The objective was to seek advice and feedback from the subject matter specialists and end users to ensure that the concept development was in line with industry practice and meets the requirements for a safe operation in the GOM. It was concluded that all critical elements had been addressed, and both concepts were considered feasible and project ready, assuming that all comments raised and actions suggested in project's final report would be properly addressed in project phase.

The follow-on project, "Vortex Induced Vibration Study for Deep Draft Column Stabilized Floaters," 11121-5404-03, was designed to use state-of-the art technology to address VIM on the vessels, since VIM can produce unwanted and dangerous vortex induced vibrations (VIV) that can destroy a riser or the vessel itself. Previous RPSEA projects, as well as this project, resulted in substantial changes to VIM/VIV suppression strake designs, column geometry modifications, and/or active flow control systems. For this project a systematic computational fluid dynamics (CFD) analysis was conducted to improve the VIM/VIV performance of sixteen (16) semisubmersible designs, based on the two hull types (paired column and conventional), with eight variations in column and node configuration (shape, spacing, and orientation) (Figure 34). The computer model tested VIM suppression devices or hull geometric optimization recommendations with due consideration to the platform global performance and constructability. The experimental measurements were added and compared to CFD based analysis. Once validated or verified, the CFD tools were used for further parametric analysis aimed at optimizing the design of a DDSCF.

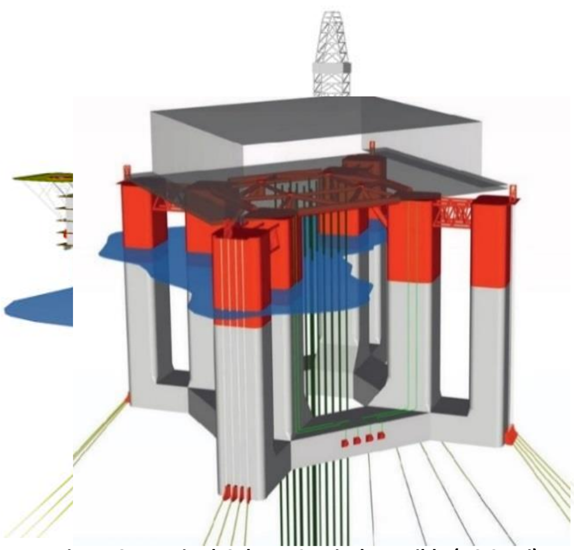


Figure 34a: Paired-Column Semisubmersible (PC-Semi).

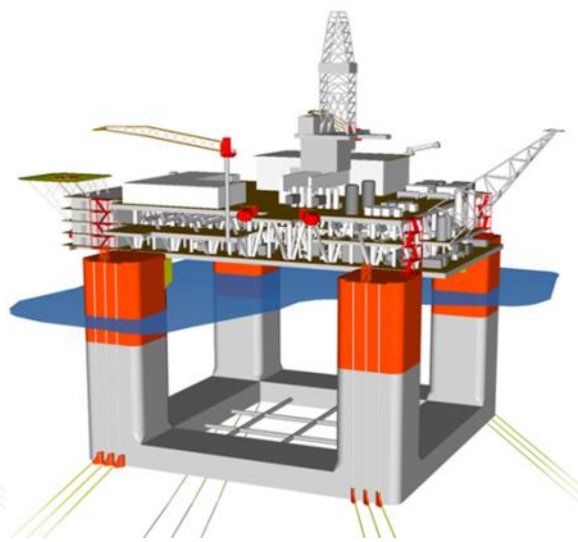


Figure 34b: Conventional Semisubmersible (C-Semi).

Phase 1 of RPSEA 5404 included an extensive evaluation from among world-recognized experts of CFD capability to predict VIM of semisubmersibles, development of a methodology for performing CFD analysis and an investigation into the effect of external damping on the semisubmersibles due to mooring and risers (Figure 35). Methods were compared to industry studies, privately conducted, and found to be leading edge. Phase 2 of the of the RPSEA 5404 project included repeated model tank tests in a campaign at MARIN [Maritime Research Institute Netherlands], the world standard test facility in Wageningen, Netherlands. Testing there was to set the objective standard of credible data for a multi-billion dollar argument within the industry of just what is the "Best" dry tree design for ultra-deepwater. RPSEA's TAC, along with the project's working project group (WPG), chose to study the VIM phenomena and the effect of external damping on the units due to moorings and risers on the two hull configurations. CFD analyses of the VIM phenomena on the two hull configurations were also performed to validate the results from the RPSEA 4405 and RPSEA 5404 model test campaigns. The WPG consisted of representatives from Chevron, Statoil, ABS, DNV, Technip, NETL, and RPSEA. A TRL 3 was achieved for both designs.

The final objective of the RPSEA 5404 project was to disseminate the lessons from the project to the oil and gas industry, including the experience gained from the analysis using commercially available CFD software (Fluent™, AcuSolve™, StarCCM+™) and the model test campaign carried out at MARIN. In line with the API RP 2SK recommendation to use the 'latest research in this area', an industry guidance document, "VIM Design Practices Report," which summarizes the lessons from 5404, was prepared. The document serves both as guidance for the initial design of the DDCSF and also aims to be the "go to" reference whenever there is a significant design parameter (geometry, environment, etc.) change during the design cycle of the DDCSF. The report achieved a TRL 6.

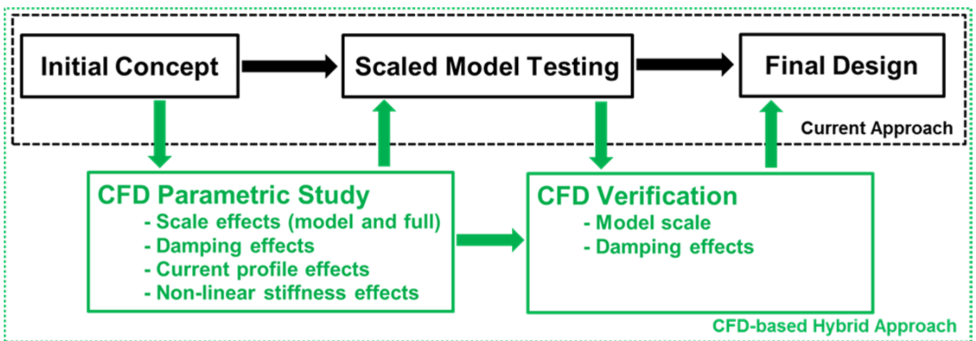


Figure 35: Floating vessel CFD-based hybrid approach.

On a related note, the PC design is being considered for further study to help mitigate safety concerns over the danger of deflagration to detonation on highly congested vessels. Simply, "Deflagration to detonation transition (DDT) refers to a phenomenon in ignitable mixtures of a flammable gas and air (or oxygen) when a sudden transition takes place from a deflagration type of combustion to a detonation type of combustion. The effects of a detonation are usually devastating." (See https://en.wikipedia.org/wiki/Deflagration_to_detonation_transition.) DDT studies are required before commissioning a vessel for work in the North Sea. No such regulation currently exists for the GOM. Operators believed that open air rigs posed less danger than closed environments. However, the loss of several GOM open air offshore rigs proves that assumption incorrect. RPSEA and one of its members initiated a study to upgrade North Sea DDT software for GOM conditions. Public reaction over the Deepwater Horizon caused some reluctance of the TAC to move forward on this proposal. After open, but frank discussion, the TAC voted to test generic designs and make all test results of the generic designs public. As will be noted below, everyone involved with the project was surprised, if not shocked, by early results in December 2015, which indicated a major flaw in the software predictability. Everyone agreed that the predictive software needed improvement to help save lives. At that point, one week after the RPSEA January 2016 TAC public meeting, NETL added funding, operators added cost share funding, and *importantly, operators contributed specific vessel designs to test.* ***Project 6403 may ultimately be the most important safety research RPSEA conducted in this Program, impacting everyone who works offshore and protecting thousands of miles of shoreline environment surrounding the offshore oil and gas industry. Continuing effort providing publicly available results on this topic would have significant benefits.***

The primary objective of the "Development of Advanced CFD Tools for the Enhanced Prediction of Explosion Pressure Development and Deflagration Risk on Drilling and Production Facilities" project, 12121-6403-01, was to provide oil and gas companies operating in the GOM with the tools necessary to design "inherently safer" offshore facilities that can survive gas explosion incidents and prevent escalation. The project was designed to improve and adapt the capabilities of FLACS software to predict a maximum credible event (MCE) early in the design phase of GOM UDW drilling and production facilities, and provide the information necessary to design facilities to minimize the consequences of explosion incidents. The FLACS DDT onset prediction capability was tested for scales and geometries relevant to GOM UDW structures in Phase 1 through a series of large-scale (near full-scale) experiments to provide data for model validation. Large scale testing began in December 2015 and continued for several months. Preliminary results indicated that DDTs at large scales may be quicker to occur than previously thought, predicted from FLACS, or assumed from previous experiments that had been performed in smaller test rigs (Figure 36). This work provided critical validation and resulted in improvements to the predictive tools, so that they can guide owners and operators to plan inherently safer layouts and create platforms that mitigate the risk of high consequence events. Work was also performed to study the effects of congestion, using an as-built library of designs of platforms provided by the project cost share partners. This project has resulted in software improvements leading to a TRL 4. In Phase 2 (beyond the scope of this project) an anticipated congestion methodology (ACM) will be developed for safer design of GOM offshore drilling and production facilities, or finding mitigation measures to existing vessels. The contractor is seeking participation for Phase 2 from operating companies, drilling companies, and from onshore refiners that face the similar issues of DDT.

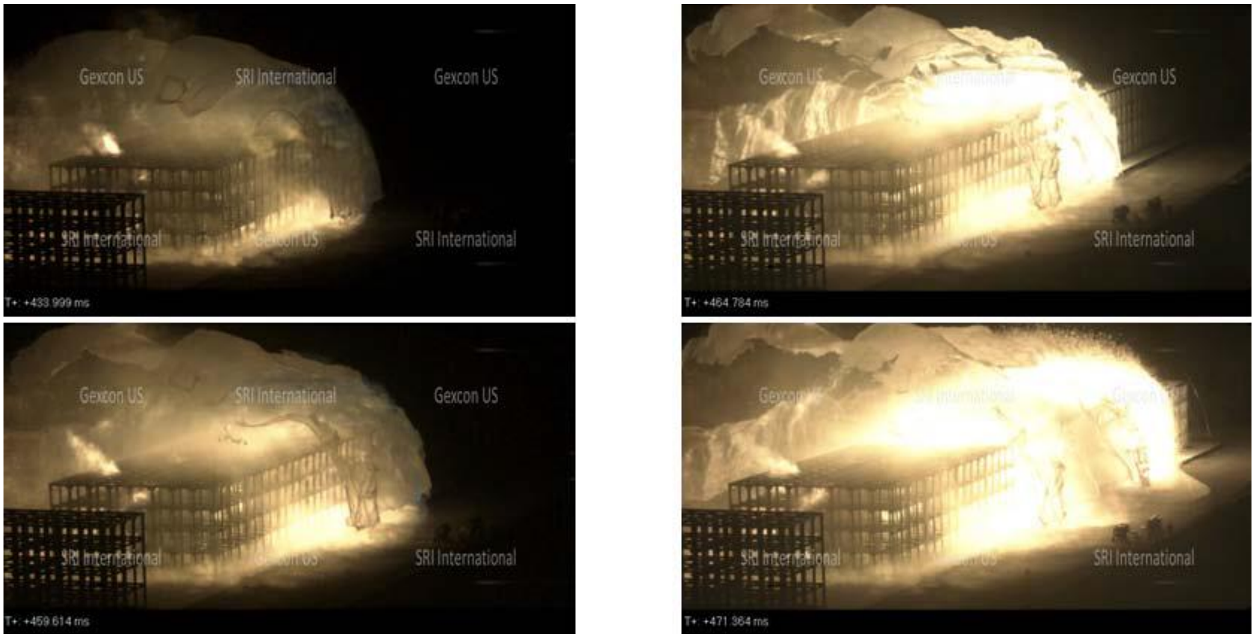


Figure 36: Phase 1, Test #5 high-speed video screen time lapse capture of the DDT (back view)

d. Flow Assurance

The flow assurance arena included four projects, two of which were closely related to one another.

“Heavy Viscous Oil Pressure – Volume – Temperature,” Project 08121-2201, arose from the need to properly evaluate heavy crude oil physical PVT characteristics, as traditional methods and models provided false results. As a result of this work, several guidelines and recommended practices are now being adopted by the oil and gas industry. First, dewatering procedures for heavy oil were developed. Second, the applicability and limitations of three type of viscometers typically used in heavy oil viscosity measurements were validated, and recommendations regarding viscometer selection and practical procedures to be used in viscosity measurements for both dead and live heavy viscous oils were provided (Figures 37, 38). Third, procedures of live heavy oil reconstitution and validation were provided and validated.

Fourth, a reliable heavy oil-solvent viscosity data set that will support viscosity model validation and development was generated. The project achieved a TRL of 7.

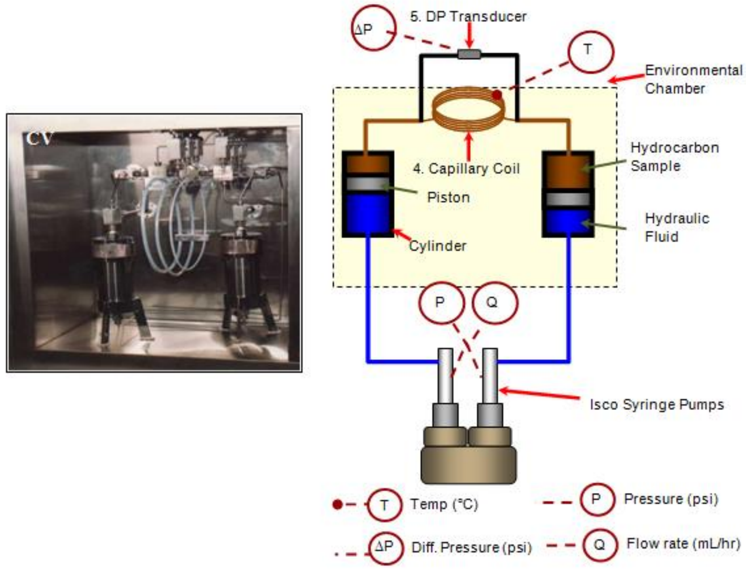


Figure 37: Photo and schematic depiction of capillary viscometer.

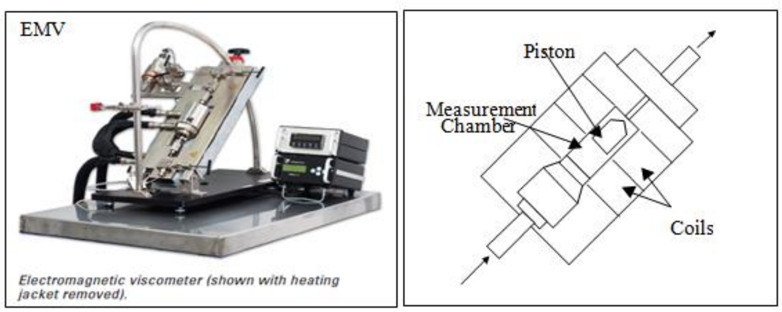


Figure 38: Photo and schematic of a Cambridge Electromagnetic Viscometer.

"Hydrate Characterization & Dissociation Strategies," Project 07121-1603b, developed hydrate plugs in a lab setting (Figure 39) and evaluated their dissociation under typical heating and depressurization scenarios, the latter of which was discovered to not occur uniformly as was commonly believed. The project resulted in a first-generation new software model that can be used to predict hydrate dissociation under different conditions and continues to be refined through additional testing outside of this program. It achieved a TRL of 3.

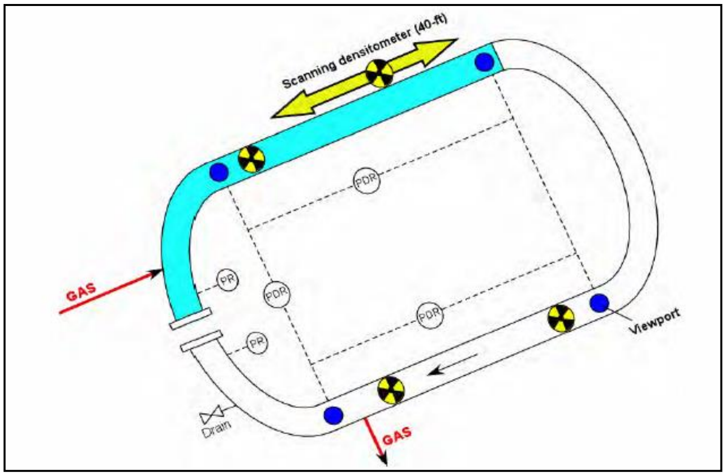


Figure 39: Schematic of flow loop configuration for hydrate plug generation in low spot for characterization and dissociation analysis.

<u>"Flow Phenomena in Jumpers-Relation to Hydrate Plugging Risk," Project 07121-1603a, and "Displacement & Mixing in Subsea Jumpers – Experimental Data and CFD Simulations, Project 09121-3300-02</u>, involved flow loop tests of two-phase (water and natural gas) fluids in simulated subsea jumpers (Figure 40). The initial tests found that commercial predictive software incorrectly predicts final liquid content, which could result in re-plugging in live scenarios. Corrective software was developed and has been shared with industry via an added subroutine in OLGA, a leading commercial predictive software product, as well as in Tulsa University's software (TRL 7). The follow-on project studied flow characteristics when adding hydrate inhibitors and found large discrepancies between OLGA simulation results and experimental data for low injection rate cases. Computational fluid dynamic (CFD) simulations helped optimize the chemical additive amounts and flow rates required, as well as to optimize the locations of the injection ports. Both 2-D and 3-D CFD simulations provided reasonable prediction for thermodynamic hydrate inhibitor distribution along the jumper after displacement tests; however, neither model was able to reproduce methanol overriding the water phase at either low spot (TRL 2). As a result of this work additional experiments are being carried outside of the program to improve the predictive capabilities when inhibiting with methanol. In addition, this project led to a third project, as noted immediately below.

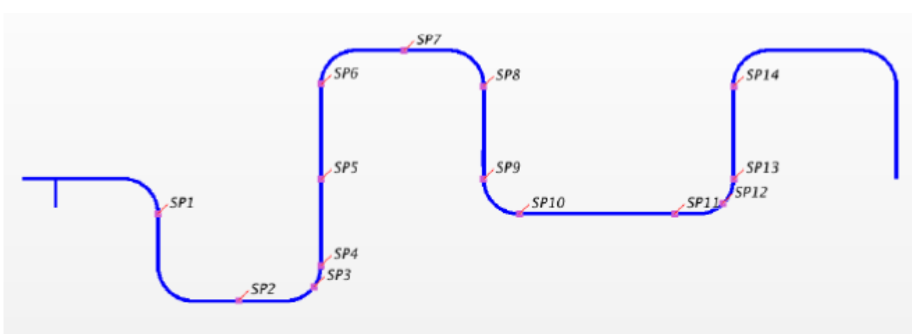


Figure 40: Side-view schematic of flow loop jumper system depicting 14 studied sample points for hydrate analysis (Project 09121-3300-02).

"Hydrate Modeling & Flow Loop Experiments for Water Continuous & Dispersed Systems," Project 10121-4202-01, looked at hydrate behavior for continuous, as well as dispersed three-phase (oil-water-natural gas) fluid systems (Figure 41). It was found that partially dispersed fluid systems exhibit a bedding/plugging onset at lower hydrate volume fraction than either water continuous or oil continuous systems. A conceptual model was developed and validated for hydrate formation in water continuous and partially dispersed systems to correct the hydrate growth models and improve the hydrate predictions. The application of a low dosage hydrate inhibitor – anti-agglomerant chemical for the mitigation of hydrate bedding/accumulation in partially dispersed systems was also studied and the results were applied to the model. This model will be shared with industry to reduce safety risks associated with hydrate plug formation, allowing for significant extension of subsea tieback distances (TRL 4). Additional testing will be performed over a wider range of field conditions to verify the model on a universal scale.

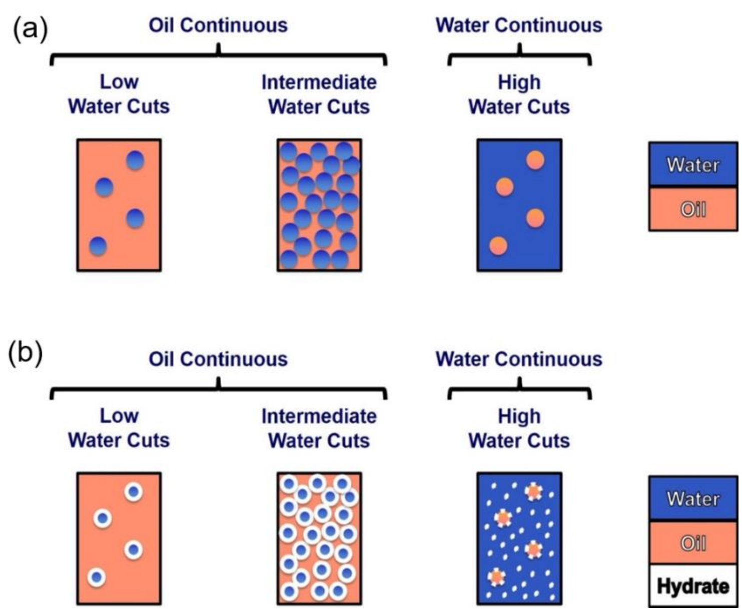


Figure 41: Conceptual picture for hydrate particles' dispersion in oil and water continuous systems with a model oil with inversion point close to the intermediate water cuts using anti-agglomerants.

a.) Oil/water dispersions before hydrate nucleation at low, intermediate and high water cuts.

b.) Oil/water/hydrate dispersions after hydrate nucleation at low, intermediate and high water cuts.

In addition, Oceanit Laboratories developed and provided superhydrophobic and icephobic internal pipeline coatings, which were evaluated in the lab to their effects on reducing hydrate deposition/adhesion. The favorable results (TRL 3) will be followed up post-project large-scale testing of coatings over a range of water contents and pipeline conditions.

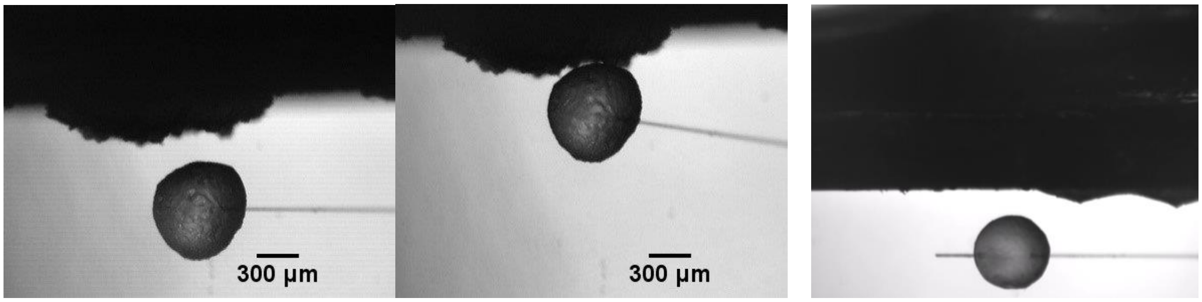


Figure 42: Time-lapse adhesion effect of surface coated free water on hydrate particle (Left and Center); Effect of Everpel coated surface on hydrate adhesion (Right).

Thirdly, Paulsson, Inc. developed a fiber optic-based external pipeline sensing system to detect and monitor hydrate deposition (Figure 43). The system worked well in the lab, as verified with video imaging and pressure measurements (TRL 3). Additional lab testing will be necessary to further determine its capabilities.

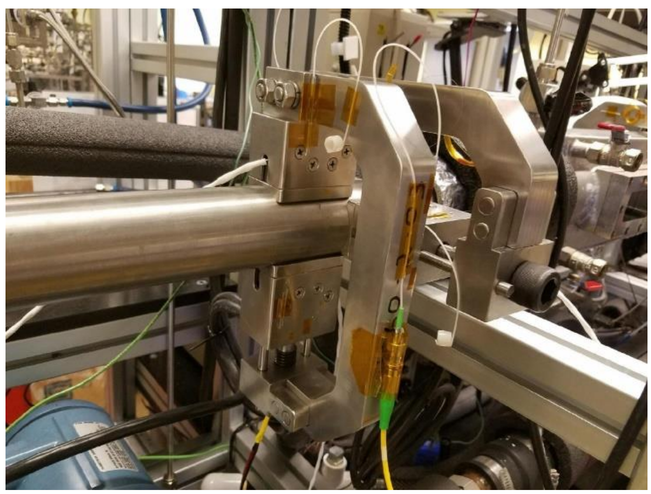


Figure 43: Photo of fiber-optic sensing system sensors mounted vertically and horizontally on the 2" pipe section downstream of the testing section of the flow loop.

e. Geosciences & Reservoir Engineering

RPSEA began research in 2007 with one of its primary assignments focused on improved understanding of offshore hydrocarbon reservoirs and improved recovery of US deepwater reserves, the "SE" part of RPSEA. Finding and exploiting resource technologies were mentored under a Geoscience TAC. Reserves determination extraction strategies and technologies were under a Reservoir Engineering TAC. Such projects were the backbone of the Energy Policy Act of 2005. Due to public concerns arising from the Deepwater Horizon accident, DOE directed NETL and RPSEA to eliminate funding of "resource only" focused projects and focus on research in environmental impact reduction, and secondarily in improved safety of hydrocarbon extraction. The two RPSEA TAC's were combined; new projects on the schedule were deleted or canceled. As projects matured in reservoir engineering, the participation of valued volunteers waned or ended. A few new projects were proposed and some were funded incorporating geoscience technology to predict pore pressure *before drilling, or to detect fine detail issues in reservoirs after some well penetrations existed in early field development. Both have strong ties to safety and environmental impact technologies.*

The most quoted RPSEA UDW project report across the offshore industry is "Development of a Research Report and Characterization Database of Deepwater and Ultra-Deepwater Assets in the Gulf of Mexico, including Technical Focus Direction, Incentives, Needs Assessment Analysis and Concepts Identification for Improved Recovery Technology," Project 07121-1701-01. That project was later extended by DeepStar, a private operator/service company JIP. Input for the project was supplied by the accumulation of government data and a generous supply of millions of dollars' worth of operator data from RPSEA members. The results dramatically show that seafloor footprint could be significantly reduced if further geoscience technology would be brought to bear on accurate prediction of subsurface reserves before and during active field development. Fewer trips to the seafloor would result in less safety and environmental risk. Furthermore, this project documents the results of an 18-month study on identifying concepts for improving oil recovery (IOR) in deepwater fields of the Gulf of Mexico. A comprehensive database was provided as a deliverable with detailed information for over 80 fields and 400 reservoirs with original oil-in-place (OOIP), rock and fluid properties, cumulative produced oil volumes, and forecasts of expected ultimate oil recovery. A detailed evaluation of oil trapping mechanisms was demonstrated to be a precursor to the selection of relevant IOR processes.

The forecasted average oil recovery factor is 31.6 percent for Neogene age reservoirs, with a range from 16 (P90) to 48 percent (P10). A total of 19 IOR processes were identified and evaluated. The 19 IOR processes were included under the broad categories or themes of water injection, water-based enhanced oil recovery, gas injection and gas-based enhanced oil recovery, pumping and artificial lift, and well technology. The evaluation includes an estimation of the low and high range of "technical" incremental recovery, number of target fields, target OOIP, unrisked IOR potential barrels, risking by use of the "technical readiness factor," and ranking of the processes (Figure 44). Key findings include analysis of water injection and particularly low cost alternatives, such as aquifer dump flooding and seafloor injection, which have highest near-term benefits. Pumping and artificial lift solutions are required technologies for successful IOR. Other IOR processes which show potential and are recommended for further study include low salinity water injection, microbial enhanced oil recovery, nitrogen injection, riserless light well intervention, and improved fracturing technology.

Recommendations were made for future research to help "bridge" the identified technical gaps. The report achieved a TRL 7, but recommended IOR and EOR methods vary from a TRL 1 to a TRL 3 in offshore deepwater environments. Additional work to bridge the gaps was recommended for future projects but rejected by DOE headquarters at that time because it appeared more related to recovery efficiency than safety and environmental sustainability. **These recommendations provide a significant opportunity for R&D to increase projection from these known reservoirs.**

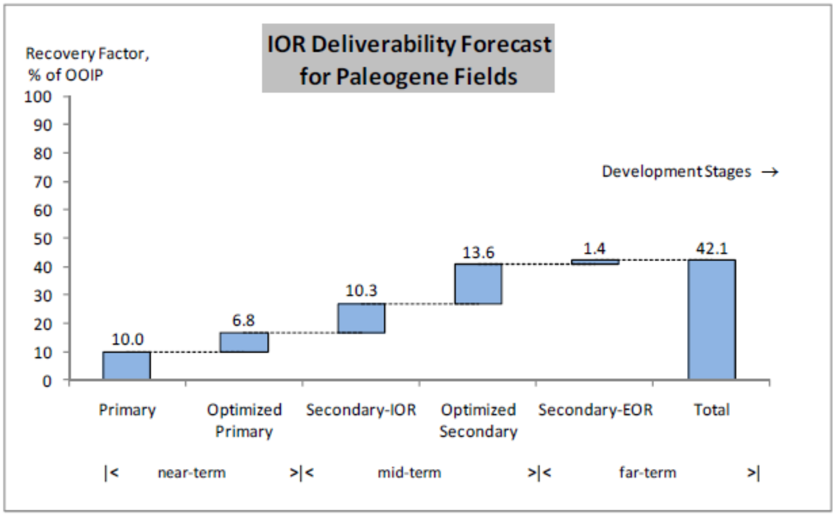


Figure 44: Improved oil recovery forecast for Tertiary Paleogene fields

> *Sometimes a novel technology catches the interest of the research community who try to help advance that idea from the idea maker's brain into the field. The effort spawns new potential uses for the novel technology. The inventor then responds with changes to upgrade to the new expectations. The viewers then respond with more applications, the inventor upgrades, and the cycle continues. One such DOE funded project ("A 400 level fiber optic seismic receiver," 2004) was advanced via RPSEA. The project intended to record high resolution shear wave seismic data for oil and gas exploration, but also has applications in the geothermal community. Both have need for tools that can operate in high temperature environments that can exceed 350 degrees F. The project extended through RPSEA funding opened another window to vector seismic, which is capable of resolution less than one foot, amplitudes detected below -4 Richter, and "listening" ability to "hear" fractures or earthquakes in progress, whether micro-seismically induced, via hydraulic fracturing, or from water injection into wells.*

"A 1,000-Level Drill Pipe Deployed Fiber Optic 3C Receiver Array for Deep Boreholes", Project 09121-3700-02, was selected to design a drillpipe deployed borehole seismic array versus a wireline array that is capable of deploying up to 1000, 3C sensors, i.e., 3,000 channels. The array used a novel broadband fiber optic sensor adapted from the U.S. Navy but utilized as a conventional set of vertical seismic profile "geophones." The sensors were designed to be deployable to at least 300ºC (570ºF) and up to 30,000 psig, and to a drilled depth of 30,000 feet, vertical or horizontal. A tubing deployable system instead of wireline deployable makes the application conducive to use in horizontal wells (Figures 45, 46). Initial sensor development gave frequencies above 800 HZ (Typical sensors elsewhere, wire coil or digital, are commonly 300 HZ, and state of the art in research is 600 HZ.). Removing the electronics from the hostile well environment by using all fiber optic downhole will allow the system to be permanently deployed into wells, since fragile components are installed topsides in a controlled environment where they can be monitored, repaired and/or replaced. The Fiber Optic Seismic Sensor (FOSS)™ design had the following attributes: (1.) Flat frequency response over the largest frequency range of same purpose tools, (a.) High Frequency performance: Tested [2016] to new industry level of 6,000 Hz, (b.) Low frequency performance: Tested to less than 0.03 Hz; (2.) Very high sensitivity – capable of recording [circa 2014] an earthquake with M-2.6 with a S/N > 10; (3.) High signal to noise ratio – 100 times the S/N ratio compared with conventional geophones; and (4.) Outstanding high temperature performance tested to 320°C (608°F). While the goal of building 1000 levels was not reached, a six-level FOSS array was manufactured and tested in the lab, in Texas. The latest RPSEA/DOE sensor, now generation 6 with 16 sensors, has been in the field for Chevron and Battelle Memorial Institute. The sensor has a TRL 6.

Phase 2 of the project was not funded. However, DOE did pick up the proposed joint industry project (Paulsson, RPSEA, Southwestern Energy, Fluidion, and NETL) to improve the project sensor, add micro-seismic energy sources for real-time fracture detection, and continued the project for four years, to end in 2018 (DOE Award DE-FE0024360). Industry interest in what the ultra-sensor can detect with micro sources has been high. Several operators have inquired about commercial use once the detectors have been readied. The sensor coupled with micro-seismic sources is a TRL 3. Tests in the lab and in a water based tank have been successful.

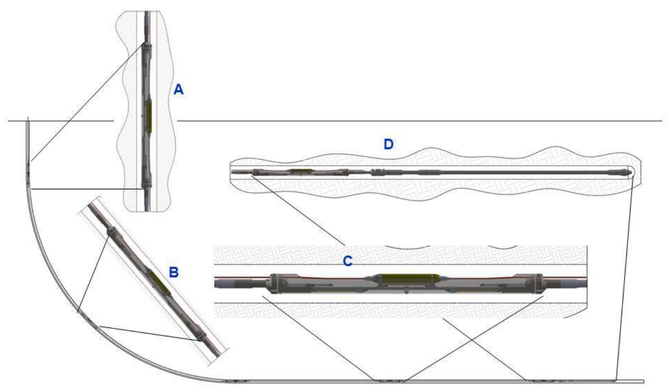


Figure 45: Depiction of vertical or horizontal deployment in a typical oil well.

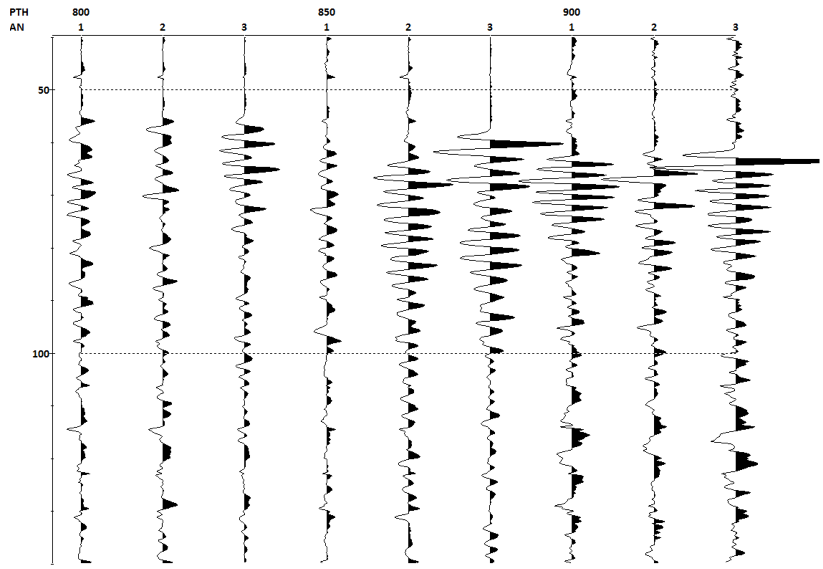


Figure 46: Shot 0.65 gram @ 1,200 ft.: Three 3C Pods, Post-Rotation (Depth 800 – 900 ft., Filter: 80-100-1500-2000 Hz) No AGC applied. Test in Pearland, Texas, generation 3 tool, showing repeatable frequencies above 1200 HZ, signal to 1500 HZ, recordings to about 2000 HZ.

Historically, the geophysical industry, including most oil and service companies, have utilized the Society of Exploration Geophysicists (SEG) to create a "perfect data" set for testing and improving the latest and leading edge seismic technologies. Although past efforts have created examples from real data, water tank models, computer derived geometry models, and 2D synthetic data, 3D data sets have remained computationally challenging. Geophysical technologies have significantly advanced in the last 10 years and they have benefited from the latest SEG JIP updates through the SEG SEAM Corporation. However, the newest SEAM JIP needed extra funding to add seismic elastic data to the set of simulations on a large synthetic data model containing turbidite and sub-salt reservoirs, most commonly found in the deep waters of the GOM.

The goal of that project, "Geophysical Modeling for Studying Acquisition and Processing Methods in the Deepwater Gulf of Mexico – Phase 1", 07121-2001-01, was to contribute to the evolution of geophysical imaging technology by providing realistic benchmark geological models and associated synthetic seismic and potential field data to allow the industry and researchers to assess seismic (and other data) acquisition and processing techniques for generating images of hydrocarbon reservoirs beneath massive, complex salt bodies located in deepwater regions. Synthetic (i.e., near theoretically "perfect") geophysical datasets were acquired by numerical simulation over the SEAM numerical earth model, a realistic representation of a 60-block area of the sub-salt exploration challenge in the deepwater Gulf of Mexico (Figures 47, 48). The basis for the extraordinary geologic model was provided by Hess, and edited by the Working Project Group. The following datasets were created by the SEAM/RPSEA efforts:

1. Acoustic Seismic with Absorbing Sea Surface Datasets: This variable density dataset was "acquired" over a large area of the SEAM model, selected so as to optimize research into

techniques for removing the adverse effects of surface reflections from seismic data and for the development of imaging algorithms for sub-salt exploration and development challenges.

2. Controlled-Source Electromagnetic (CSEM), Magneto Telluric (MT), and Gravity Datasets: These complementary datasets are available in a form that, when combined with the acoustic and elastic seismic, will enable research into joint inversion methods for enhanced subsurface interpretation of structure, rock and fluid properties.

3. Tilted Transverse Isotropic (TTI) Dataset: This dataset includes 'streamer' pressure sensor data in addition to 4 component data collected in 4 'boreholes' penetrating the seafloor. These data provide the opportunity to test imaging algorithms that take account of the anisotropic character (e.g. directionally-dependent properties) of the Earth's subsurface.

4. Elastic Seismic Dataset: This dataset was acquired over a carefully selected sub-area of the SEAM model to facilitate research into the identification of elastic effects on data quality, the development of approaches to remove elastic "noise" from acoustic datasets, and improved methods for elastic data processing. The dataset includes seafloor 4 component, wellbore 4 components, as well as 'streamer' pressure sensor data.

Prior to conducting the simulations, SEAM developed methodologies for ensuring that the resulting simulations would have close fidelity to the basic physics of wave propagation in heterogeneous regions representative of the Earth's subsurface. The Phase 1 data were quality controlled, archived, and distributed to the SEAM participating companies and was subsequently made available to the public after September 1, 2013 at www.seg.org/SEAM. A large number of software improvements occurred within the industry over the course of this project. More than 50 professional papers resulted from the work. Several workshops were and continue to be made on the subject. Universities were given access to the data. New acquisition of data in the millions of dollars occurred based on improvements to the technologies demonstrated. The project was supported by RPSEA as a resource effort pre-Macondo (TRL 7).

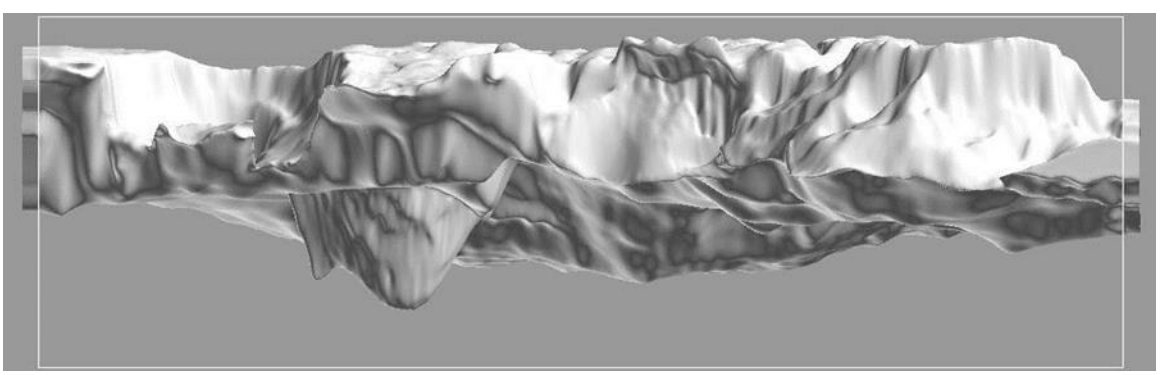


Figure 47: View towards the west of the eastern flank of the main SEAM synthetic salt body. Overhangs are seen from this perspective as well as the root stalk of the salt that ties to the mother salt which is not shown. The white rectangle measures 40 km by 15 km with north to south running right to left. ***From Fehler and Keliher, 2011.***

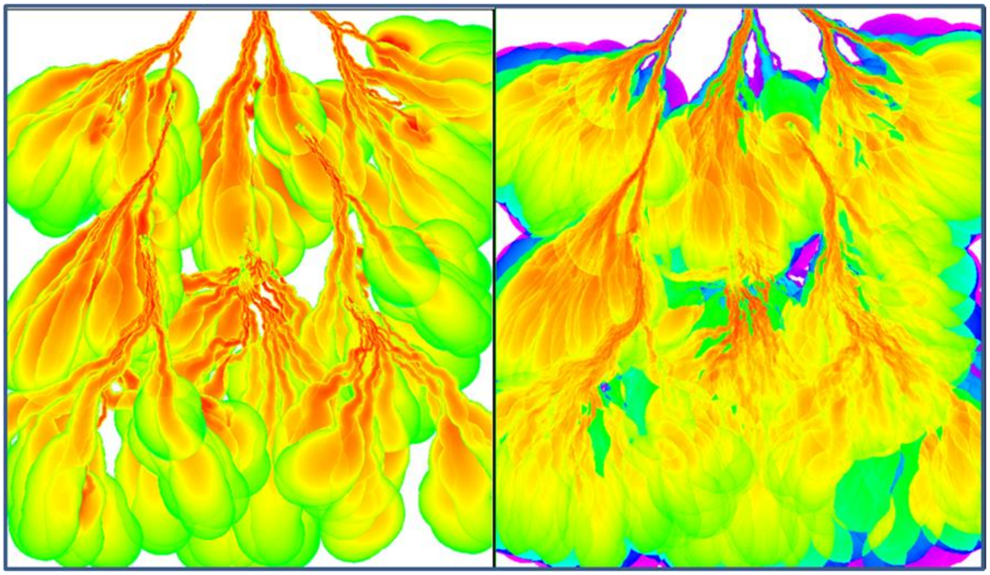


Figure 48: Turbidite model for the SEAM GOM study.

> *Post Deepwater Horizon incident evaluations by the Coast Guard and others showed that pore pressure information, especially that resulting from seismic data, was not commonly trusted by rig personnel. A poll of SEAM participants by RPSEA showed an interest in determining a better solution for using seismic data to predict pore pressure by employing velocity and density relationships to pore pressure prediction [ppp] ahead of the drill bit. RPSEA built a consensus, submitted the idea to DOE, developed an RFP and investigated pore pressure prediction from the "perfect" data set created in the SEAM/RPSEA Phase 1 project.*

The objectives of the Pressure Prediction and Hazard Avoidance through Improved Seismic Imaging project, 12121-6002-02, were to: 1) Deliver a benchmark simulated seismic dataset that will be used by industry and academic research institutes to investigate improved approaches for prediction of shallow hazards and deep over-pressured reservoirs; and 2) Reduce both safety and environmental drilling risk through improved pre-drill pressure prediction methodologies that are derived from iterative interpretations of the Phase 1 GOM simulated dataset (from project 07121-2001), enhanced for pore pressure-rock physics-seismic models (Figures 49, 50).

The project consisted of two main elements: (1) model construction and (2) seismic simulation. Model construction involved first building a complex geological model of a region that contained physically realistic pore pressure scenarios. Then rock physics had to be applied to define elastic properties of the rocks that could be used for seismic simulation. Separate reports have been prepared by various vendors that worked under contract to the project to conduct various elements of the project like basin simulation, rock physics, downscaling, seismic simulation, and quality control. These reports contain significant detail (TRL 2). A part of the project also focused on Time Lapse imaging of producing reservoirs (Figure 51). The goal here was to study the feasibility of using modern numerical methods to build a complete simulation framework for understanding, predicting and detecting the changes in an oilfield reservoir that occur after wells are drilled and begin to produce — the changes in the rocks, pore fluids, and pressures that accompany reservoir flow and production.

The technical effort consisted of a six-month feasibility study, organized by SEAM with the help of the Society of Petroleum Engineers (SPE). The core project team consisted of technical staff representing SEAM, SPE, RPSEA, and Chevron (TRL 2). During the construction of the pore pressure model, than 20 2D basin simulations were conducted using one cross-section of the SEAM Phase 1 model to better understand the relationship between pore pressure generating mechanisms and the resulting distributions of pore pressures and rock porosity. Parameters for the 3D basin simulation were assessed based on the outputs of those simulations. The interaction between those involved in basin simulation with those involved directly with pore pressure prediction in the Gulf of Mexico led to a tremendous exchange of knowledge. A series of 3D basin simulations were conducted during the construction of the geological model. State-of-the-art approaches for rock physics were modified and applied to transform the geological model into a geophysical model that could be used for simulation of acquired datasets.

The RPSEA/SEAM Pore Pressure Prediction project is continuing past the Sept. 2016 end date using participant funding. More work will be performed on improved data processing, rock physics, pore pressure analyses, additional simulations and use of 3D subsets of the simulations to test how different acquisition geometries impact the reliability of pore pressure estimates. Data and reporting will be made available to members effective Oct. 2016. Data sets will be made available to universities next, then to the public for the cost of data copying and distribution in Oct. 2017. The project extension to the case study for time dependent effects on seismic measurements during reservoir production was a natural addition to the pore pressure project, since once the first well is in a reservoir one can see pressure changes with 4D seismic imaging and improved reservoir and geomechanical modeling. A multi-company, multi-million dollar project called “Life of Field” has been created as a result of the successful completion of the RPSEA extension project One of the many benefits of this project will be to will help us better understand how to detect and manage stranded oil and gas. This project has tremendous upside for reducing offshore geohazard risk and warrants additional funding.

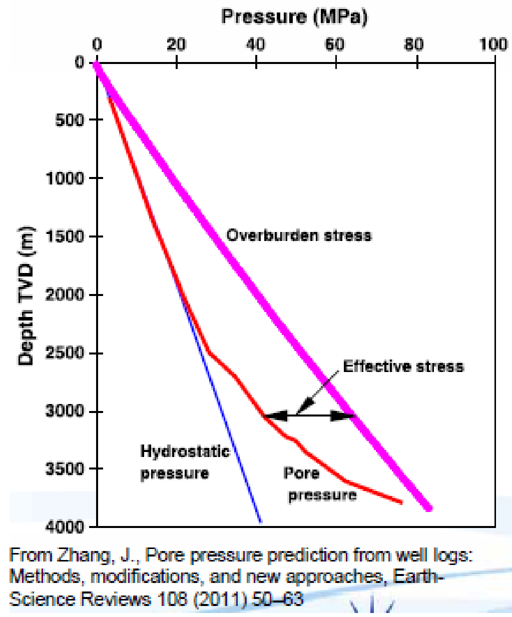


Figure 49: Graph depicting pore pressure creep with depth.

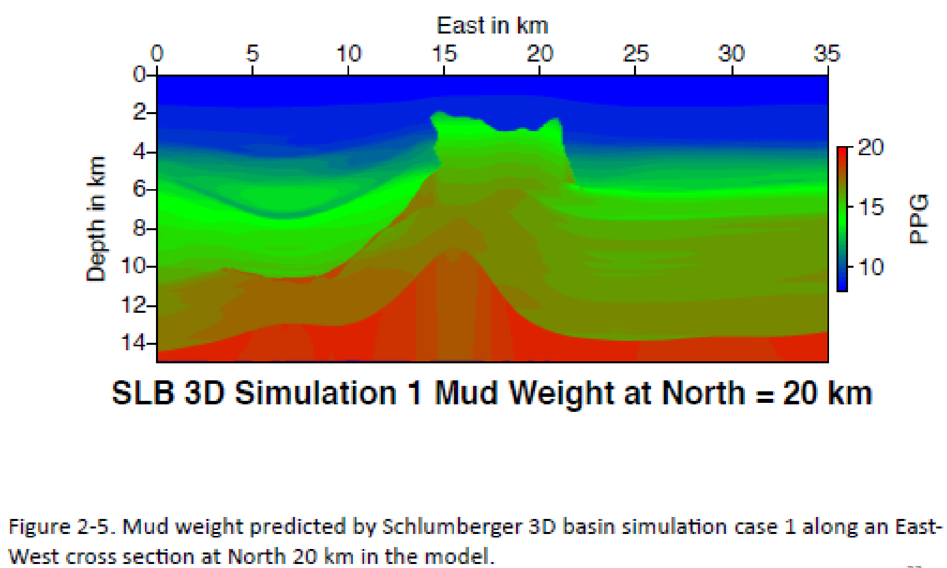


Figure 50: 2D mud weight prediction along E-W direction in study area.

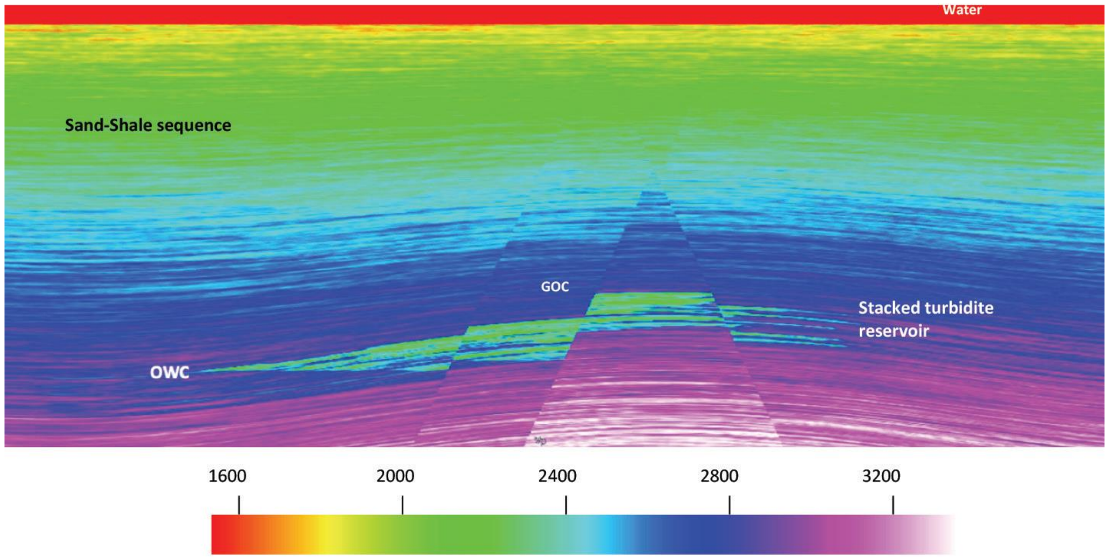


Figure 51: Central vertical section through the SEAM Time Lapse model. The full geologic model is 12.5 × 12.5 km in horizontal extent and is 5 km thick. The reservoir consists of 80 distinct turbidite fans, each 5 m thick, and separated by a 20 m thick shale layer. The reservoir is embedded in a sand-shale sequence typical of the Gulf of Mexico. The geologic sequence was gently arched and faulted along three high-angle faults. Vertical exaggeration is 2:1.

f. Met-ocean

"Gulf of Mexico 3-D Operational Ocean Forecast System Pilot Project," 08121-2801-02, evaluated several ocean circulation numerical models for their possible use in an operational forecast system for the Gulf of Mexico, including currents associated with the Gulf Loop Current and the large clockwise eddies it sheds on the time scale of several months to a few years. A single model, a.k.a., Gulf of Mexico – Long Range Ensemble Forecasting System (GOMLREFS), was created based on hind-casting for a real-time demonstration, evaluation, and further development of the forecast system (Figure 52). The model successfully predicted two major loop events two months prior to their occurrence, in less than two years. It has now been commercialized and has been running in real-time with minimal interruption since January 2013, producing 60-day forecasts once per week. Standard products (animations/plots) and value added products (RACs, trajectories) are processed and posted to the web automatically. It is now being used by all maritime industry to predict current behavior well in advance, so that industry is well prepared for any events. In addition, the model has been transitioned into the (U.S.) Naval operational system for its use. It achieved a TRL of 7.

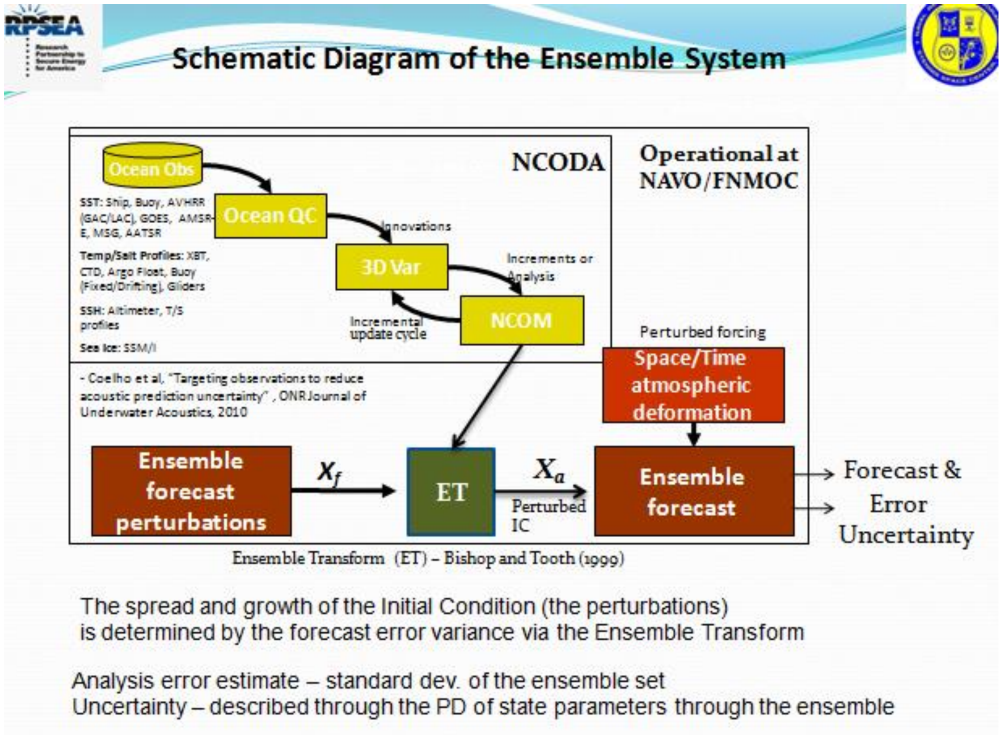


Figure 52: Ensemble system schematic for forecasting in the GOM.

"Effect of Climate Change on Hurricane Activity," Project 07121-1801, and its follow-on "Effect of Climate Variability and Change in Hurricane Activity in the North Atlantic," Project 10121-4802-01, studied the effects of the past 80 years of climate activity on North Atlantic tropical storms and predicted future storms strengths and locations (Figures 53, 54). The first project predicted an accelerating increase in the number of North Atlantic hurricanes over the next 50 years; an equator-ward shift in the region of maximum storm activity and formation; with a slight increase of average intensity, but a more marked increase in the number and intensity (Category 3+) of the most intense hurricanes in the North Atlantic basin. However, results were not as clear for the Gulf of Mexico because of the relative limited number of storms that form in or enter the Gulf and the computational complexities of estimating that resulted in nearly two-week runs. Following the completion of the first project, the model was tested and forecasted the intensity of and landfall location of Hurricane Sandy to within 5 mph and 3 miles, respectively, according to the PI. The follow-on project verified a future increase in the proportion of major hurricanes, which has already started. Future major hurricanes are expected to increased wind speed and decreased storm size, which, when coupled with increases in extremes of met-ocean variables, should lead to increases in wave height. The simulation model is now in use and is included along with other existing models to predict hurricane tracks and parameters (TRL 7). The result of this work suggested that the oil and gas industry should remain diligent, but no major changes in operations are called for. A new research program, the Engineering for Climate Extremes Partnership, has grown out of interactions between NCAR, RPSEA, and others. Some of the techniques pioneered here are being included in the applications under the associated Global Risk, Resilience and Impacts Toolbox, where they can be accessed in the future.

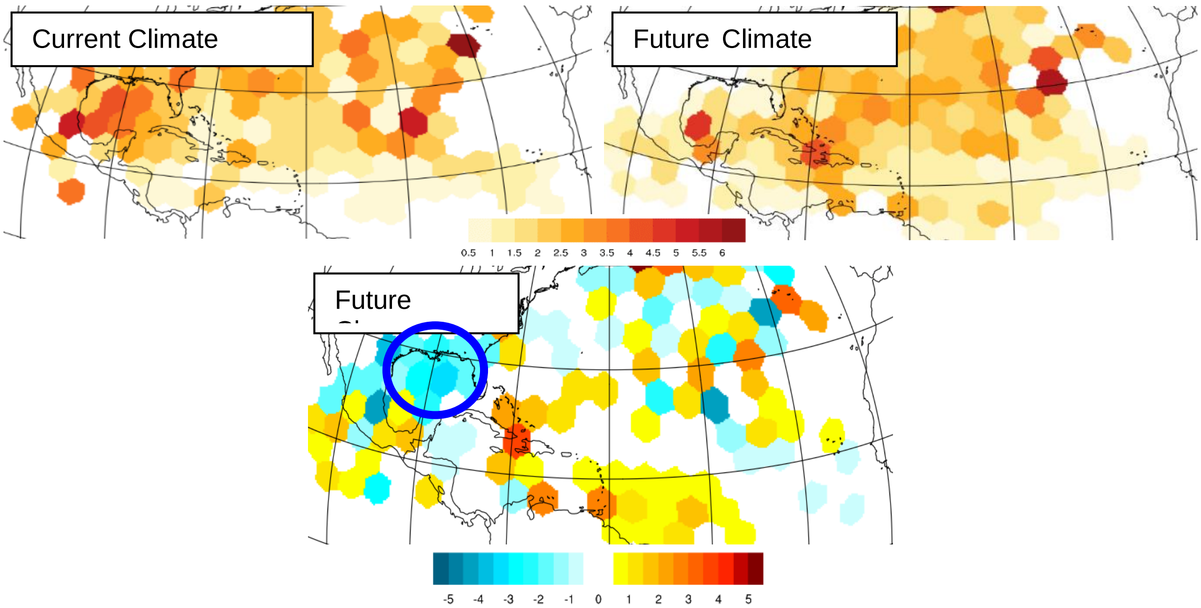


Figure 53: Hurricane damage potential for (top left) simulated current climate, (top right) simulated future climate representative of the 2050s, and (bottom) the future change (future – current). The simulations used are dynamical model simulations at 36km for the periods 1995-2005 and 2045-2055 generated under RPSEA project 07121-1801.

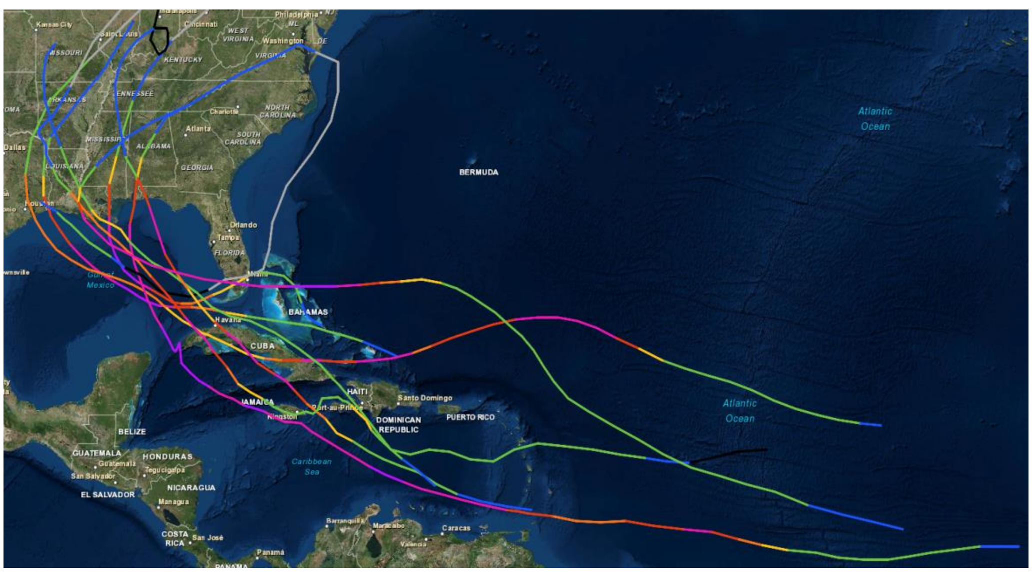


Figure 54: Tracks of the 10 case study hurricanes (figure generated at: coast.noaa.gov/hurricanes/): Andrew (1992), Lili (2002), Ivan (2004), Dennis (2005), Katrina (2005), Rita (2005), Gustav (2008), Ike (2008), Ida (2009), and Isaac (2012).

"Synthetic Hurricane Risk Model for the Gulf of Mexico," Project 10121-4801-01, developed a database containing the tracks and key hurricane parameters associated with the tracks that included the central pressure, maximum wind speed, one or two values of the radius to maximum winds, and the Holland B parameter. It also modeled a 100,000-year set of simulated hurricane tracks that were then used to develop design wind speeds and wave heights associated with return periods up to 10,000 years, by incorporating historical data representative of the average climate of the last 30 to 100 years (Figure 55). This model improved upon on the model developed under previous funding from NSF, FEMA, the USACE, and the API. Finally, the synthetic track model was re-developed using warm climate scenarios developed in RPSEA Project 07121-1801 and 10121-4802-01 (see above) to predict future tropical storm risks. Although the final model created in this study can reasonably reproduce distributions of translational velocity and storm heading, as well as central pressure versus return period hazard curves across the Gulf of Mexico, it required minor tuning of both tracking and intensity parameters to achieve agreement in the distributions of these key historical and simulated parameters at landfall. The minor tuning was largely applied to storms tracking north towards the Louisiana/Mississippi coastline, and to storms tracking northwest towards the Texas coastline. The largest discrepancies in the 100-year return period hourly mean wind speeds occur south of 24°N, in the western portion of the Gulf of Mexico. As a result, the TRL is 5 because it can replace earlier versions, but additional work is required to understand and account for these discrepancies.

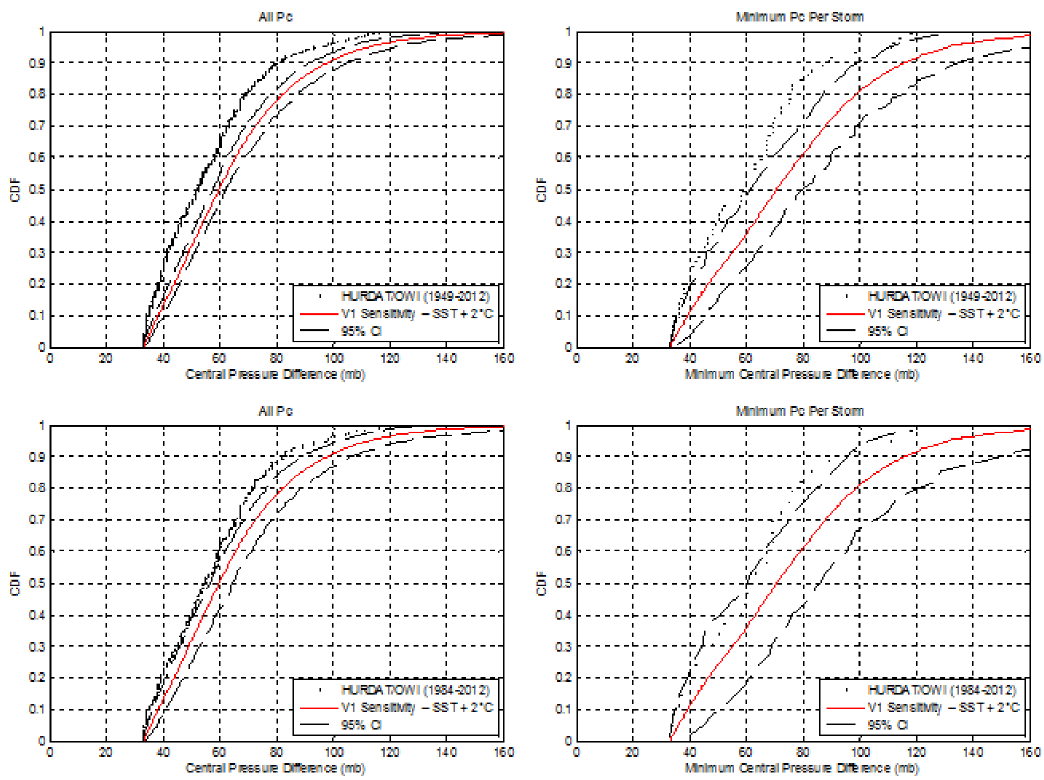


Figure 55: Modeled and historical (1900 - 2012) gulf-wide distributions of all central pressure differences and of minimum central pressure differences per storm. The black dots represents the observed/hindcast data, the solid red line represents the modeled values, and the two dashed lines represent the 95% confidence bounds obtained from re-sampling the model results. The model results are from the SST increased by 2°C sensitivity assessment.

<u>"Hi-Res Environmental Data for Enhanced UDW Operations Safety," Project 11121-5801-01</u>, was designed to better understand the physical mechanisms that cause periods of elevated current velocities, including the effects of tropical storms on areas of relatively higher sea surface temperature (e.g., Loop Current or associated eddy) and vice-versa (Figures 56, 57). It was divided into three distinct areas. Buoy-moored Acoustic Doppler Current Profilers (ADCPs) were successfully deployed to focus on high resolution measurement, analysis, and modeling of near bottom currents in areas of complex local bathymetry. However, the near-bed ADCPs in both downward and upward looking orientations were

unable to collect data closer than about 10 meters above the seabed. In all other locations, the ADCPs agreed well with numerical models, thus proving that they can be used to verify or tune models, as long as there is no seabed interference (TRL 7). Secondly, Airborne Expendable Current Profilers (AXCP) were also deployed to focus on high resolution measurement, analysis, and modeling of near surface currents (100 - 300 m) and were proven for future use (TRL 5), but they could not be used as planned during a combined tropical storm – loop current/eddy event because the opportunity did not present itself during the project performance period. Thirdly, the real-time capability of the Remote Ocean Current Imaging System (ROCIS) was demonstrated, thus for the first time allowing for an accurate real-time surface current measurement service using an aerial platform to produce survey maps of greater than 300 kilometers per day. The ROCIS tool has since been commercialized and is in use, for a TRL of 7.

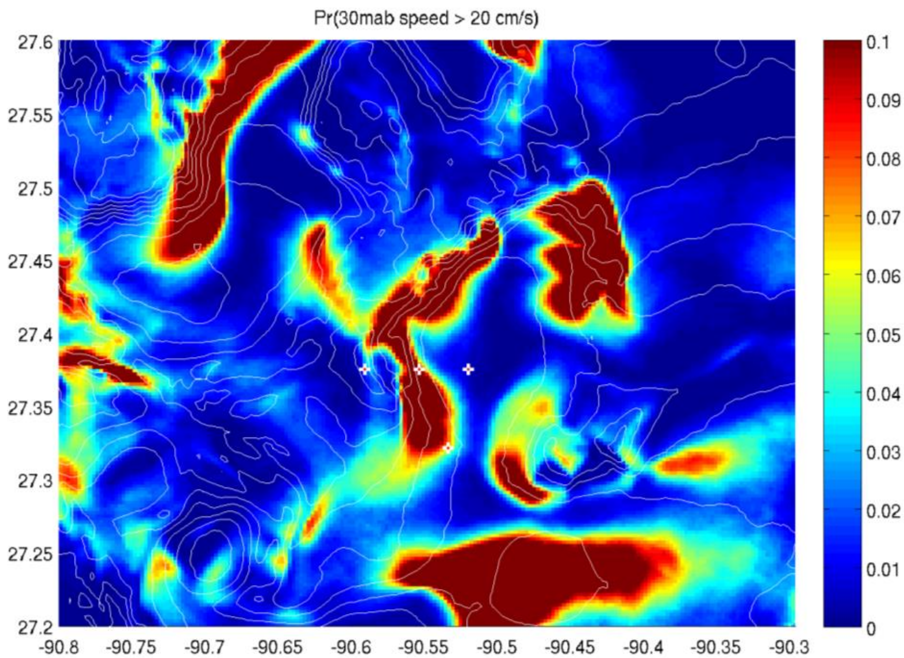


Figure 56: Probability of the instantaneous speed at 30mab exceeding 20 cm/s computed from the NCOM using ACDPs. The locations of the moorings are shown by the red dots.

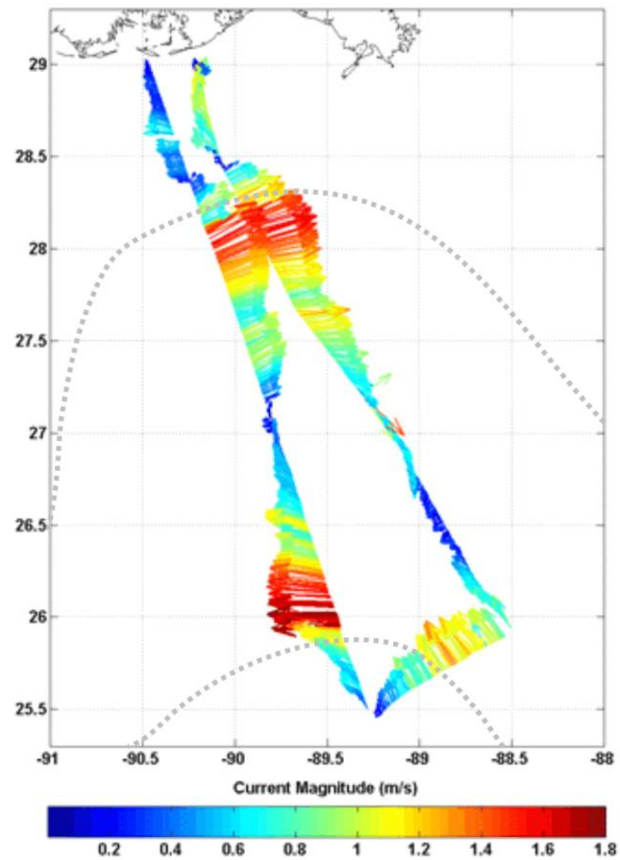


Figure 57: Result of ROCIS pass in GOM of inaugural commercial application in late 2015.

g. Subsea Systems

"Ultra-High Conductivity Umbilicals – Phase 1," Project 07121-1302, along with its follow-on "Ultra-High Conductivity Umbilicals – Phase 2," Project 10121-4302-01, sought to prove the concept of a reliable lighter-weight electrical subsea umbilical, constructed of carbon-nanotubes (CNT's), to replace traditional copper-wired systems. The projects' objectives were achieved: CNT wire was produced in continuous mode with a 10^{-5} Ω•cm resistivity and were shown to increase their conductivity with increased pressure up to 5000 psig (Figure 58). The wire system is 1/6th the diameter of copper systems and up to six times stronger. A carbon nanotube growth furnace and wire take-up system was developed and simplified, resulting in a dramatic increase in collected wire length (TRL 7). The final prototype conductor was comprised of carbon nanotubes in wire form and jacketed with an electrically insulating polymer that adds abrasion resistance and ease of handling (TRL 3). Further optimization will be required to provide a comparable resistivity to that of copper-based systems of 10^{-6} Ω•cm resistivity with exceptional strength. Ultimately, this product may be capable of a tenfold improvement (10^{-7} Ω•cm resistivity) to copper systems, thus theoretically reducing electric line losses for any long distance cable from 35 percent per 100 miles to 3.5 percent. The subcontractor is seeking but at the time of this report, has been unable to secure additional funding for follow-on research.

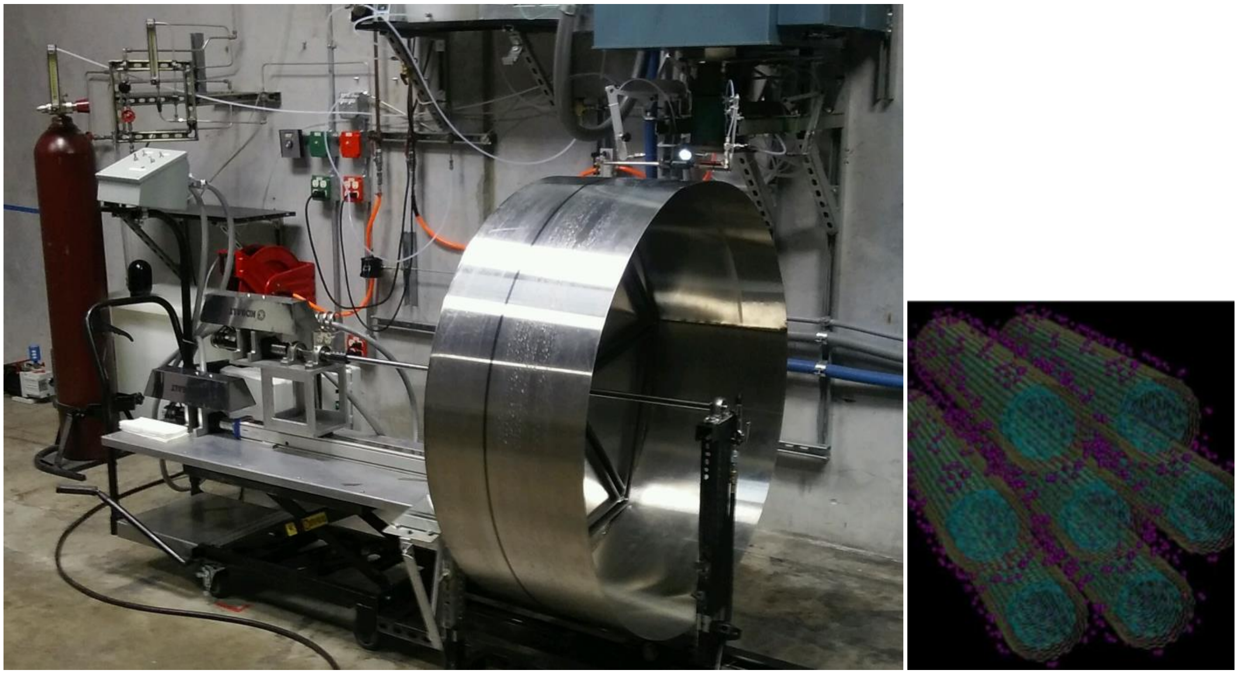


Figure 58: Photo of newly manufactured carbon nanotube wire on a drum spool.

<u>“Subsea Systems Engineering Integration,” Project 07121-1901</u>, resulted in the development of an architectural model on which subsea processing simulations can be developed. It features a general purpose process simulator with minimal architectural overhead that puts all the functionality in user-developed unit models (Figure 59). A MATLAB version was developed as a bottom-up tool to help drive the development. The simulator has the capability to interface with commercial codes such as AspenTech’s HYSYS, where it resides as an open-sourced tool for industry use. A TRL of 3 was achieved because of limited testing and comparison to live situations. Additional work will be needed so that the tool can more closely simulate desirable produced flow management requirements, as well as compare to real produced fluids.

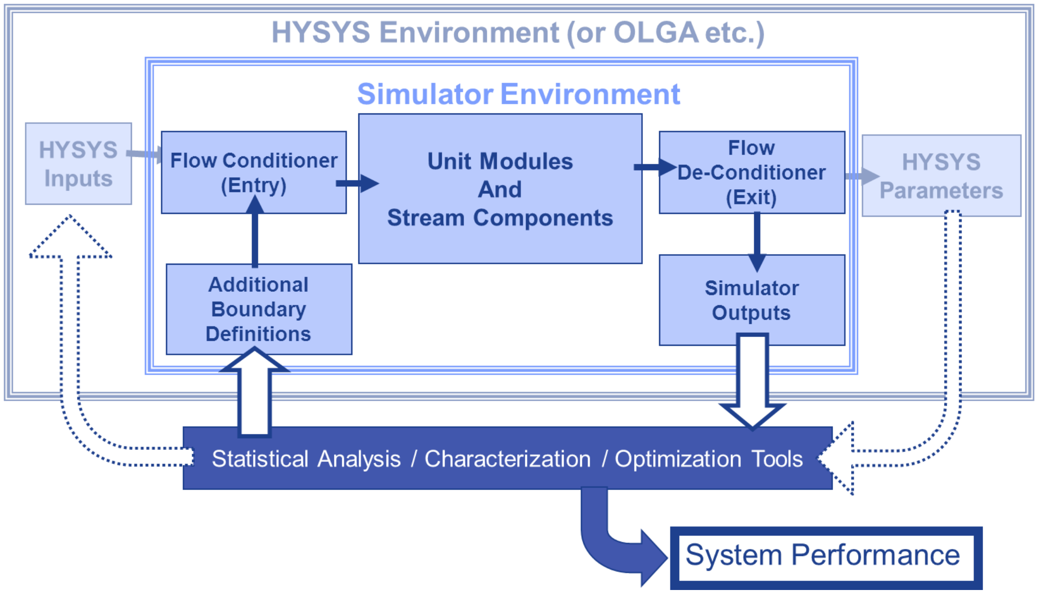


Figure 59: Schematic of interface of characterization tools with simulator.

"Deep Sea Hybrid Power System," Project 07121-1902, considered numerous power generation/energy conversion and energy storage technologies to support the exploration and production of oil and gas reserves remotely located offshore in the deep ocean. The top two candidates for power generation were both based on the small modular pressurized water reactor. One candidate couples the pressurized water reactor with a secondary steam-turbine-generator system, and the other candidate couples the pressurized water reactor with a solid-state thermoelectric generator. Two versions of sodium-beta batteries, sodium/sulfur and sodium/nickel-chloride (a.k.a. ZEBRA batteries), were the leading candidates for subsea energy storage (Figure 60). Follow-on project work was recommended by RPSEA but rejected by DOE. The value of this project was its ability to capture and consolidate all known potential power generation and storage options so that additional research could be performed. A follow-on subsea power generation and distribution project RFP in 2010 resulted in proposals that were not as highly rated as other proposals competing for funds, and as such were not selected. During the interim period, Siemens, Honeywell, and GE Power have all made strides in developing subsea power grids and limited storage, yet none of their technologies is the leapfrogging type that is necessary for sustained high level power generation and storage.

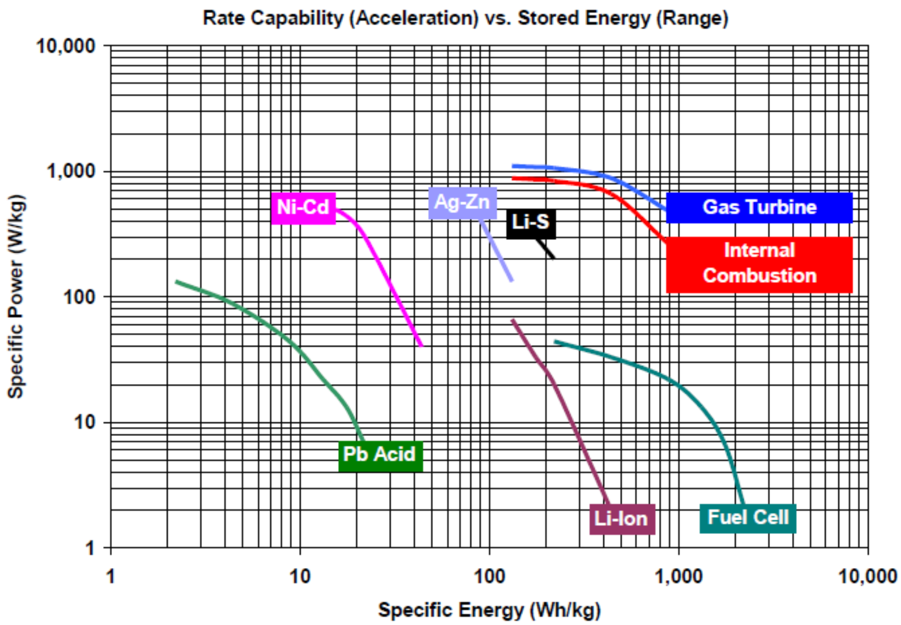


Figure 60: Graph of specific power vs. specific energy for competing non-nuclear energy conversion and storage systems.

"Ultra-Reliable Deepwater Electrical Power Distribution System and Power Components," Project 08121-2901-01, and its follow-on "Subsea DC Connectors for Environmentally Safe and Reliable Powering of UDW Subsea Processing," Project 12121-6302-01, were aimed at providing sufficient power to ultra-long distance subsea environments (>100 miles). Due to these distances, many believe that direct current power will be more efficient and effective than alternating current systems, which are largely in use today. The objective of the first project was to design an electrical power transmission and distribution (T&D) system to enable subsea oil and gas production for a typical field development scenario, and design, build, and qualify critical components in a system lab demonstration. After completion of preliminary trade-off studies, detailed design, development, and validation tests were carried out for four components: control of modular stacked direct current (MSDC) architecture, system protection, thermal management and packaging, and DC connector. Prototype hardware (Figure 61) was built and recommended lab bench scale tests were successfully performed, thus proving the feasibility of MSDC and its claimed benefits (TRL 3). Work is continuing outside of the RPSEA Program to develop the MSDC system for commercial trials. One of the recommendations of this work was to develop a DC connector capable of reliable operation in a UDW environment, which was the objective of the follow-on project. The second project assessed technical requirements and technology gaps for subsea high voltage direct current (HVDC) connectors, designed and constructed an electrical HVDC prototype unit, and successfully tested it under simulated subsea conditions (TRL 3). Additional testing in a subsea environment will be required to make this product field ready, and the manufacturer is discussing options with several end users.

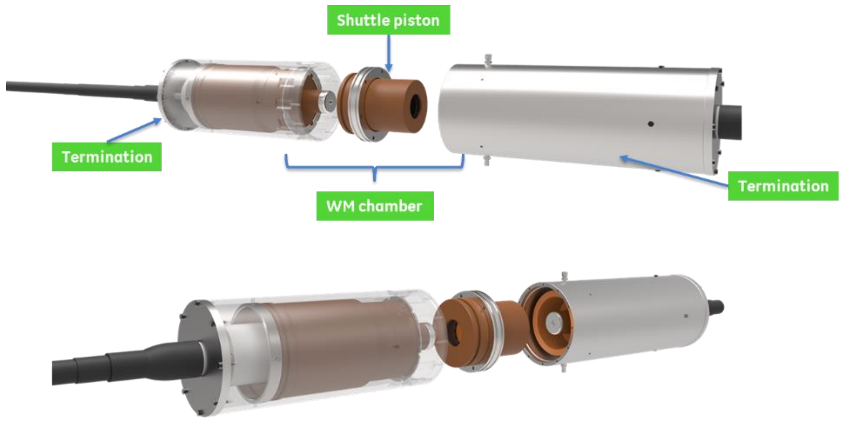


Figure 61: Final prototype of subsea DC wet-mate connector.

“Wireless Subsea Communications,” Project 08121-2902-03, investigated the use of electromagnetic (RF) technologies for high speed communications in deepwater subsea applications, such as data communications between various fixed subsea assets, as well as communications to mobile assets such as remotely operated vehicles (ROVs). The feasibility of high data rate communications was proven with a sea trial demonstrating a data rate of approximately 5 Mbps over a distance of 10 cm using a mechanism that is more tolerant to variation in alignment and environment while utilizing small antenna elements (TRL 3). Physics based models were developed and verified for the signal propagation (Figure 62). This has the potential to replace connectors required for subsea applications and also allow temporary connection of mobile devices such as ROVs. Additional simulation and analysis predicted channel capacities near 50 Mbps depending on the power of transmission, which will require verification. Other recommendations include analyzing the effectiveness of channel coding algorithms in the RF conduction channel, including combinations of various encoders.

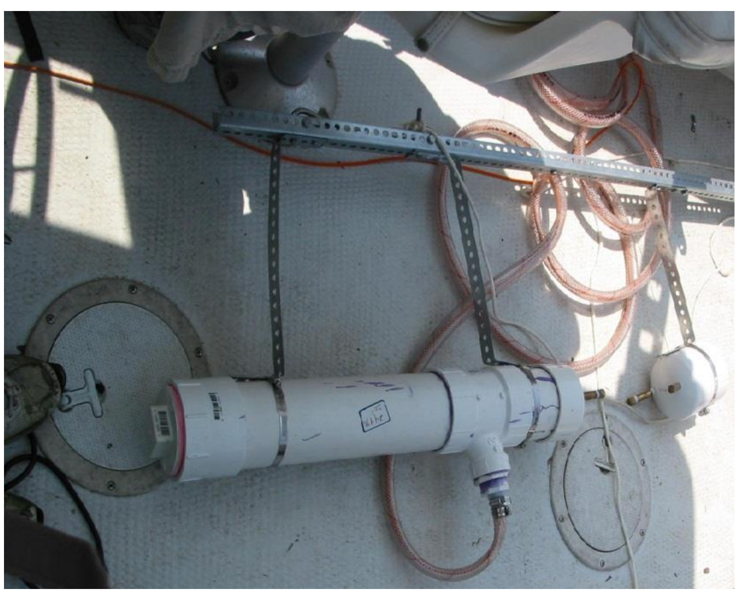


Figure 62: Photo of frame holding prototypes of wireless subsea receiver (Left) and transmitter (Right) containers.

The general objective of "Improvements to Deepwater Subsea Measurements," Project 07121-1301, and its follow-on "More Improvements to Deepwater Subsea Measurements," Project 04304-01, was to address gaps in industry's ability to deploy and operate multiphase and wet gas meter technology in deepwater production systems (Figures 63-66). The initial project included a prototype ROV-conveyed sampling and clamp-on flow measurement system; an extensive catalog of the effects of fouling – both erosion and scale buildup – on meter performance (TRL 3); an anonymous performance comparison of Virtual Flow Meter (VFM) offerings from six vendors; development of a 1.25-inch diameter high-pressure high-temperature differential pressure sensor; and testing and documentation of a software simulation tool, now shared with industry, for estimation of the uncertainty of flow measurement in various configurations applicable to deepwater production systems (TRL 7). The second project sought to improve on results from the initial project.

- A measurement method was proven in a lab setting whereby Electrical Capacitance Tomography can be used with composite pipe to measure fluid flow by component (TRL 3); work continues on this emerging technology by Cameron.
- A mud density monitoring system was developed and tested but was found to be incapable of identifying nuances derived from changing flow characteristics in live well situations.
- Continued comparisons of Virtual Flow Meters (VFM's) under actual live well conditions indicated strengths and weaknesses of each of five participating commercial company's software and/or human interface. The evaluation revealed that in properly trained hands VFM's can act as substitutes for flow measurement devices, and they can be sufficiently accurate without all desired measurements, provided they are periodically tuned to changing fluid conditions. Individual results were provided to the software developers so that they might improve their products.
- An improved prototype of a subsea sampling system was constructed and successfully lab tested underwater with an ROV, for a TRL of 3. An actual field test to further evaluate its capabilities and limitations was outside the scope of this project. An accompanying Sampling Best Practices document was created and has been shared with API and industry.
- A reduced size (0.95-inch diameter) high pressure – high temperature differential pressure transmitter was developed and tested to 15,000 psig and 250C under laboratory conditions (TRL 3). Further testing is required at the upper pressure end, as well as reliability testing, before the product can be commercialized. Development of this technology is being continued outside the Section 999 funding to evaluate the potential for "behind pipe" mud density measurements downhole.

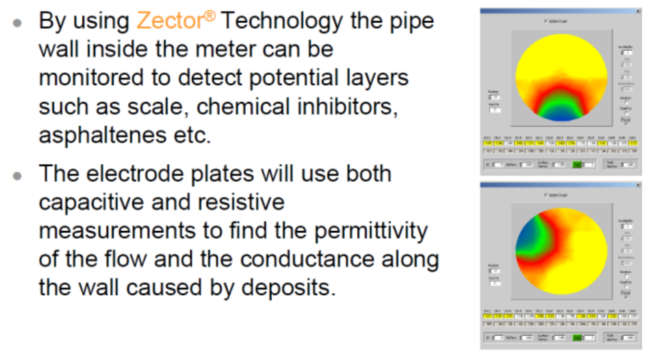


Figure 63: Pipe cross-section visualization of scale detection using electrical impedance.

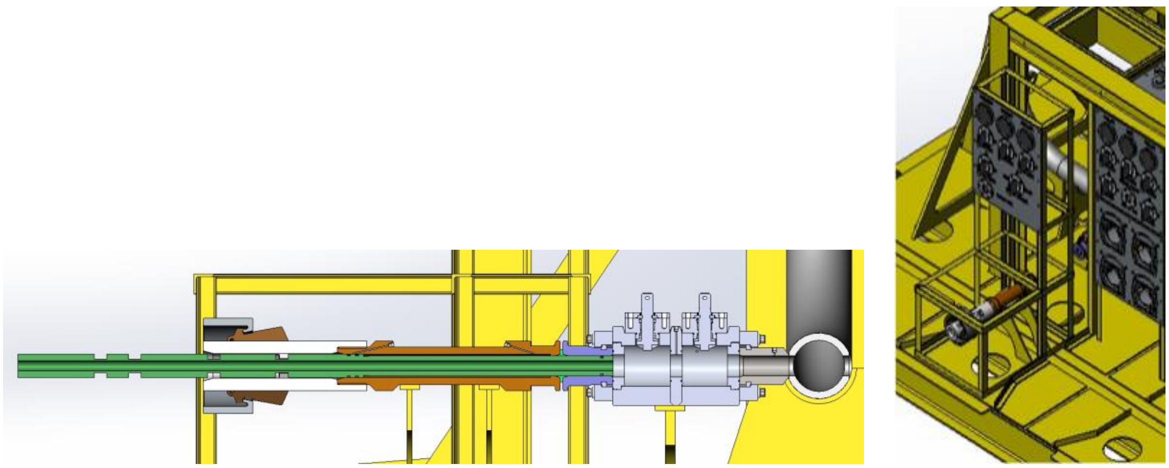


Figure 64: Cross-sectional schematic of ROV-conveyed sensor carrier (green cylindrical tool at center) (Left) and Concept skid with installation port (in brown) (Right).

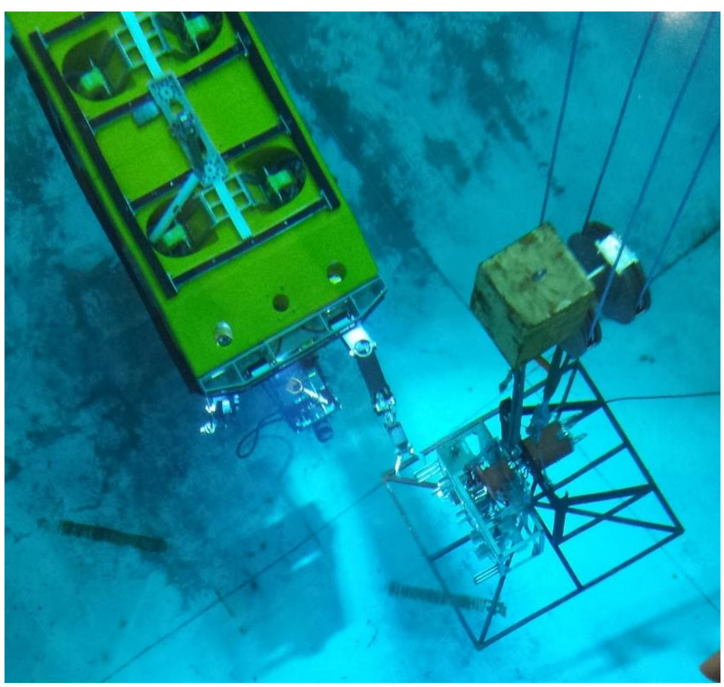


Figure 65: ROV approaching sampling system. Inset: Photo of sampling system.

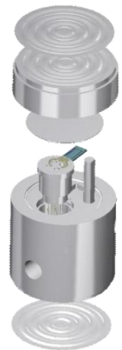


Figure 66: Downhole HP/HT differential pressure cell interior showing the oil displacement rod.

"Technologies of the Future for Pipeline Monitoring and Inspection," Project 08121-2902-02, provided a system for monitoring and maintaining deepwater pipelines which can predict and allow proactive measures to be taken to avoid the problems associated with pipeline fouling or plugging or other deleterious conditions in the pipeline. A small-scale sensing capsule prototype was designed, constructed, and tested in multiple pipelines that can measure fluid conditions, map pipeline features, and identify potential wall buildup or defects. The tool can be used in pipelines where conventional in-line-inspection tools cannot traverse, while significantly reducing deployment cost and risk. It can also be used to provide near real-time monitoring of critical pipeline characteristics. The pill-shaped housing containing the sensing elements collected data on multiple variables, including pressure, temperature, 3-axis tilt, and acceleration. The sensor pill device was initially attached to a smart pig (Figure 67) and indicated similar results (TRL 5). It was also deployed in a free-floating arrangement without a carrier pig in the flow loop filled with water, enabling it to travel the length of the line without a pig, thus indicating a potential inspection solution for pipelines that cannot be pigged and small diameter utility lines (TRL 3). Following this project the device has been repeatedly tested in pipelines, and improvements to its detection capability continue. It has not yet been commercialized.

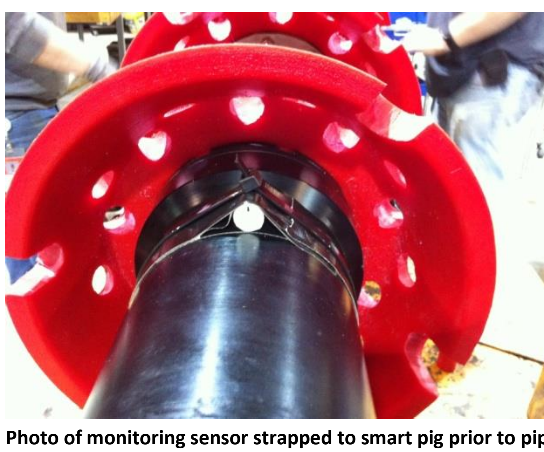


Figure 67: Photo of monitoring sensor strapped to smart pig prior to pipeline test.

The trio of projects, "Autonomous Inspection of Subsea Facilities, Project 09121-3300-05; "High Resolution 3D Laser Imaging for Inspection, Maintenance, Repair, and Operations," Project 09121-3300-

06; and “Autonomous Underwater Inspection Using a 3D Laser,” Project 10121-4903-02, were developed to improve subsea inspection, maintenance and repair (IMR) capabilities in UDW. The first project resulted in the development of a UDW capable autonomous underwater vehicle (AUV) that could be deployed for IMR and retrieved much more efficiently than traditional ROV’s. The Marlin AUV prototype was successfully tested in several field trial scenarios (TRL 7) and now provides industry with a commercial capability to complete subsea inspections in hours instead of days (Figure 68). It also can provide accurate 3D geo-registered models within hours of completing an inspection. Autonomous detection of structural changes in real-time is achievable, providing industry with an on-site assessment of platform structural integrity and/ or a post-storm damage assessment.

The objective of the second project was to develop and test 3D laser scanning, or LiDAR, for subsea terrestrial surveys, construction, as-built analysis, and large-scale retro-fits. Prototypes were constructed and ultimately successfully field tested with ROV’s under a variety of conditions, achieving movement resolutions of better than +/- 5mm at down to 2990 meter water depths (TRL 7). Two units, the SL1 and SL2, have since been commercialized and are in high demand. The third project was designed to marry the first two, utilization of 3D laser imaging from an AUV with 3D mapping and change detection, to allow for fast deployment in emergencies and greatly reduce the cost of IMR operations. The 3D laser was successfully integrated into the system, but the field trial revealed processing issues related to ground truth measurement accuracy and speed; the problem has since been resolved with software enhancements (TRL 7). The LiDAR system is now being coupled with several companies’ AUV’s on a regular basis (Figure 69).

Figure 68: Photo of Lockheed Martin’s commercialized Marlin AUV’s *(courtesy of Lockheed Martin)*.

The SL2's Integrated Tilt SL2 - Electronics Canister

Figure 69: Photo of 3D at Depth's commercialized SL2 subsea LiDAR sensor system *(courtesy of 3D at Depth)*.

<u>"Sensors and Processing for Pipe, Riser, Structure, and Equipment Inspection to Provide Detailed Measurements, Corrosion Detection, Leak Detection, and/or Detection of Heat Plumes from Degraded Pipeline Insulation," Project 09121-3300-08</u>, had several objectives. ROV-based and/or AUV-based acoustic metrology and inspection sensor capabilities for underwater structures were to be developed that could make detailed physical measurements of underwater structures and/or detect and identify external corrosion, pitting, and biologic fouling, and/or detect and quantify gas or petroleum product leaks, and/or detect heat plumes resulting from cracked or degraded pipeline insulation. Ultimately, through lab tests and field trials of prototypes, this spool piece metrology was advanced from TRL 4 to TRL 7. Its ability to search wide areas for natural gas and liquid leak detection in open water increased for a TRL 3 to TRL 5. And it demonstrated heat leak detection and mapping, for a TRL improvement from a 2 to a 4. Measurement is independent of water clarity, a real plus. As implied by the TRL of 7, this tool, now owned by Teledyne, is now being used by industry for subsea metrology (Figure 70).

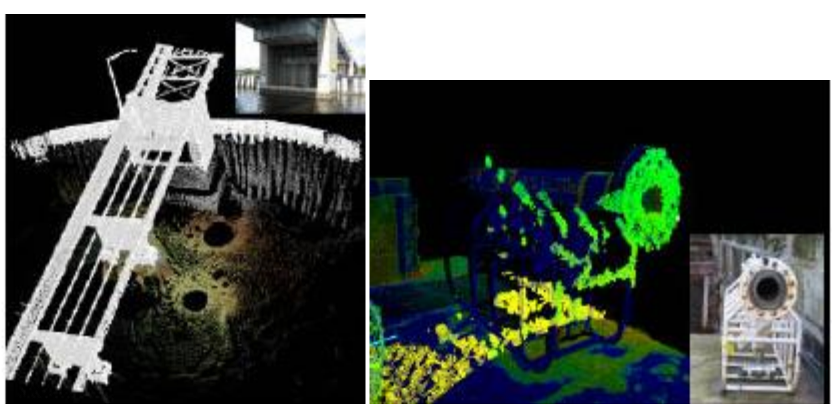


Figure 70: Results of commercialized 3D multi-beam subsea scanning sonar *(courtesy of Teledyne Blueview)*.

"Ultra Deep Water Seabed Discharge of Produced Water and/or Solids," Project 09121-3100-01, compared worldwide regulations, standards and HSE requirements governing produced water disposal, identified constituents of produced water (PW) and quantified their adverse contribution in satisfying regulations, summarized seabed conditions and aquatic life with regard to their potential impact upon discharging PW, developed cost estimates and impact assessments of individual components and hypothetical systems, and defined an initial conceptual subsea processing design incorporating discharge of produced water and/or solids (Figure 71).

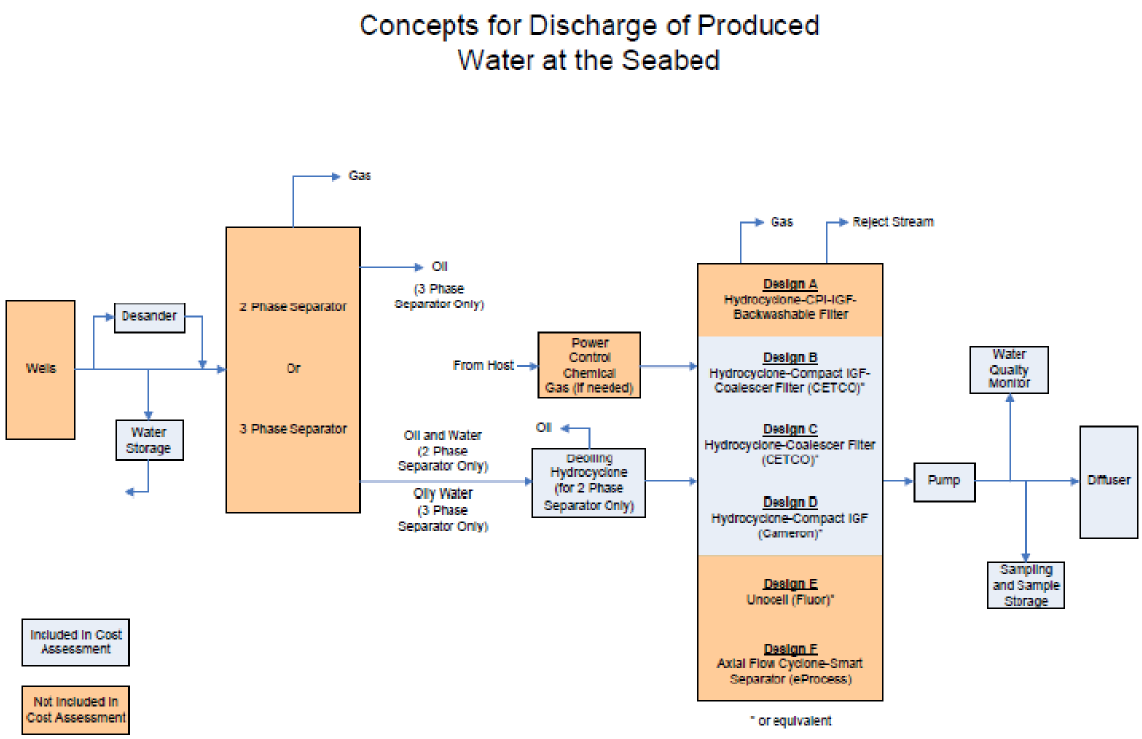
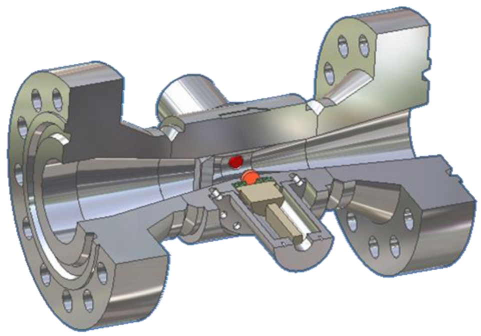


Figure 71: Block diagram of optional concepts for subsea produced water treatment systems (April 2012).

As a result of this work, a follow-on project "Subsea Produced Water Sensor Development," Project 12121-6301-03, developed and designed subsea produced water quality monitoring sensors to measure the quality of produced water separated at the seafloor. After developing requirements, an evaluation of oil-in-water technologies resulted in four sensors being flow loop tested that have the most potential for becoming robust, reliable and accurate subsea produced quality sensors. Measurement accuracy under parameters for various water compositions and physical characteristics, fouling mitigation effectiveness, and memory effect under transient conditions were evaluated. The test results showed that the sensor technologies tested were robust, had good and acceptable accuracies (comparison with a hexane extraction method that was correlated to EPA Method 1664B) under test conditions similar to those at which the instruments were calibrated, had well-defined trends in respect of the parameter effects, were able to mitigate mild fouling, and had minor memory effects in some sensors. As a result:

Digitrol's light scattering sensor is now at a TRL 6, J.M. Canty's microscopic imaging sensor is at a TRL 3, ProAnalysis' laser induced fluorescence sensor is at a TRL 3, and the newly developed Clearview Subsea's CLFM is at TRL 3 (Figure 72). Weaknesses in each product will have to be addressed and strengthened through further testing, and most importantly, regulatory compliance criteria for subsea sensors as well as the criteria for evaluating and accepting online sensors as a tool for regulatory compliance need to be addressed before any of these products can become commercial.



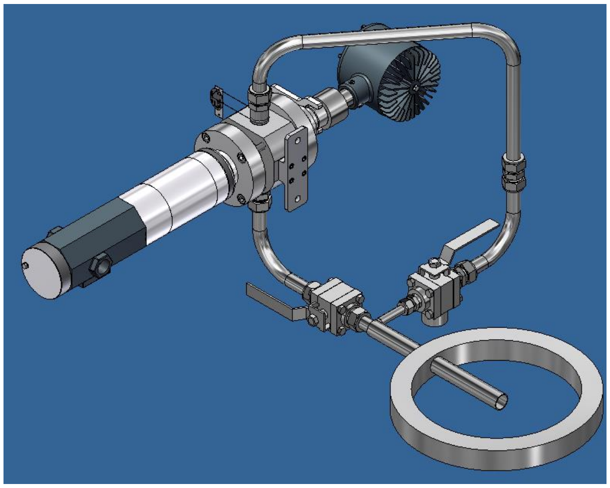


Figure 72:
Digitrol sensor (Top Left);
JM Canty Produced Water Quality Monitor prototype (Top Right);
Proanalysis OIWM Probe prototype (Bottom Left); and
Measurement Section with Sapphire Windows, Connection to Sample Piping, and Connection to Cleaning Water Piping portion of Clearview Subsea Confocal Laser Fluorescence Microscopy prototype (Bottom Right).

<u>"Construction and Testing of Deepwater Permanent Subsea Pressure Compensated Chemical Reservoir," Project 11121-5302-01</u>, successfully developed a functional and lab qualified subsea chemical storage and injection system prototype design (Figure 73) with an effective 3,000+ barrel chemical storage volume (TRL 3). Additional testing of the design at higher pressures and with various chemicals, and up-scaling will all be required before it can reach commercialization. Pumps, valves, and control systems will also need to be modified to meet the marine specification necessary to the system. Also, a subsea

deployment and retrieval system using lay barges (a.k.a., Shuttle System) has been conceptualized (Figure 74) and simulated under realistic field conditions (TRL 3). Actual field testing of prototypes and up-scaling will also be required before this process can be considered a viable one for use. If the subsea chemical reservoir is successfully developed for commercial use, it can eliminate the need for a chemical umbilical; and with the addition of a subsea pig launcher the need for a second flowline might be eliminated. The shuttle system concept developed in this project has a significant side benefit if proven successful, as it can result in a step change in operational economics to deploy large and heavy loads to the seafloor. This project is seeking private industry funding.

Figure 73: Subsea compensated chemical reservoir scale model prototype test apparatus (yellow) with fluid tanks and controls.

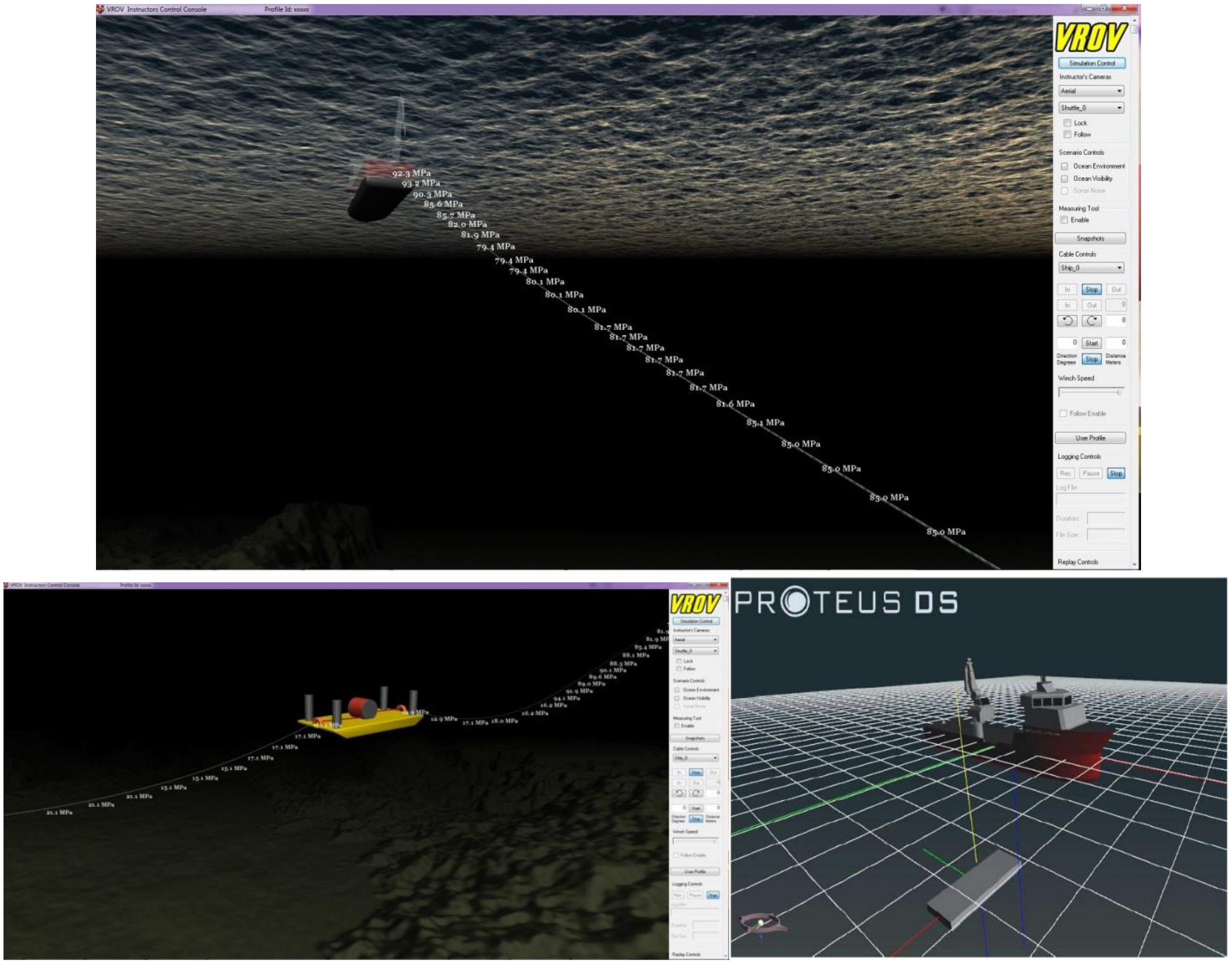


Figure 74: Screen-shots from GRI Simulations Inc. simulations based on Dynamic Simulation Analysis project models.

h. ***Technology Readiness Levels – Ultra-Deepwater Program Element***

Technology Readiness Level (TRL) definitions can be found in Attachment 1. They are taken from DNV's definitions, which use a 0 to 7 determination of maturity.

Attachment 3 is a table of each offshore ultra-deepwater project depicting its DNV TRL as of this writing. Technologies from the following 25 projects are either already deployed (i.e., commercialized, TRL 6) or considered fully proven (I.e., market penetrated, TRL 7).

1. 07121-1701: Development of a Research Report and Characterization Database of Deepwater and Ultra-Deepwater Assets in the Gulf of Mexico, including Technical Focus Direction, Incentives, Needs Assessment Analysis and Concepts Identification for Improved Recovery Technology [report] (TRL 7)
2. 07121-2001: Geophysical Modeling for Studying Acquisition and Processing Methods in the Deepwater Gulf of Mexico – Phase 1 (TRL 7)
3. 08121-2201-02: Heavy Viscous Oil PVT [analysis process] (TRL 7)
4. 08121-2502-01: Modeling and Simulation of Managed Pressure Drilling for Improved Design, Risk Assessment, Training and Operations (TRL 6)
5. 08121-2801-02: GOMEX 3-D Operational Ocean Forecast System Pilot Project (TRL 7)
6. 08121-2902-06: Enumerating Bacteria in Deepwater Pipelines in Real-Time at a Negligible Marginal Cost Per Analysis: A Proof of Concept Study (TRL 7)
7. 09121-3300-02: Displacement & Mixing in Subsea Jumpers – Experimental Data and CFD Simulations (project 07121-1601a follow-on) [predictive software] (TRL 7)
8. 09121-3300-05: Autonomous Inspection of Subsea Facilities (TRL 7)
9. 09121-3300-06: High Resolution 3D Laser Imaging for Inspection, Maintenance, Repair, and Operations (TRL 7)
10. 09121-3300-08: Sensors and Processing for Pipe, Riser, Structure, and Equipment Inspection to Provide Detailed Measurements, Corrosion Detection, Leak Detection, and/or Detection of Heat Plumes from Degraded Pipeline Insulation [spool piece metrology] (TRL 7)
11. 09121-3500-01: Intelligent Production System for Ultra Deepwater with Short Hop Wireless Power and Wireless Data Transfer for Lateral Production Control and Optimization (TRL 6)
12. 09121-3500-07: Deepwater Subsea Test Tree and Intervention Riser System (TRL 6)
13. 09121-3700-02: A 1,000 Level Drill Pipe Deployed Fiber Optic 3C Receiver Array for Deep Boreholes (TRL 6)
14. 10121-4204-01: Corrosion and Scale at Extreme Temperature and Pressure [detection equipment] (TRL 6)
15. 10121-4304-01: More Improvements to Deepwater Subsea Measurement (project 07121-1301 follow-on) [virtual flow model comparison evaluation] (TRL 7) / [meter fouling diagnosis evaluation] (TRL 6)
16. 10121-4401-02: Ultra-Deepwater Riser Concepts for High Motion Vessels (TRL 7)
17. 10121-4406-01: Effects of Fiber Rope - Seabed Contact on Subsequent Rope Integrity (TRL 7)

18. 10121-4505-01: Coil Tubing Drilling and Intervention System Using Cost Effective Vessel (project 08121-1502-01 follow-on) [riser system] (TRL 6)
19. 10121-4802-01: Effect of Climate Variability and Change in Hurricane Activity in the North Atlantic (project 07121-1801 follow-on) (TRL 7)
20. 10121-4903-02: Autonomous Underwater Inspection Using a 3D Laser (projects 09121-3300-05 & 09121-3300-06 follow-on) (TRL 7)
21. 11121-5404-03: VIM Study for Deep Draft Column Stabilized Floaters (projects07121-1401a, 07121-1402b, & 10121-4405-02 follow-on) [best practices report] (TRL 6)
22. 11121-5801-01: Hi-Res Environmental Data for Enhanced UDW Operations Safety [bottom current measurement & modeling system] (TRL 7) / [Remote Ocean Current Imaging System development] (TRL 7)
23. 12121-6301-03: Subsea Produced Water Sensor Development [Digitrol sensor] (TRL 6)
24. 12121-6502-01: Reliability of Annular Pressure Buildup (APB) Mitigation Technologies (TRL 6)
25. 12121-6503-01: Development of Best Practices and Risk Mitigation Measures for Deepwater Cementing in SBM and OBM (TRL 6)

Details about these projects and their results can be found in the individual project reports.

IV. TECHNOLOGY TRANSFER

Technology Transfer has been a cornerstone of the RPSEA program. Subcontractors were required to submit a technology transfer plan for at least 1.5% of the gross project costs as part of their proposals. As the projects were awarded, RPSEA worked with the subcontractors to assure that the research results would be transferred to a defined audience(s). In addition, each subcontract award normally provided that 1% of the gross awards would be held back by RPSEA to conduct a broader technology transfer effort. This was successfully accomplished through publications, the RPSEA website, meetings, trade shows, technical conferences, and regional and national workshops held throughout the contract period. Each subcontract normally included the following language:

> *Technology Transfer activities will consist of both project and program level activities amounting to not less than 2.5% of the total cost of the project. The total cost of the project is the value of funds provided by RPSEA plus the value of all subcontractors cost share. The contractor shall nominate work /activities for 1.5% of the total cost for project level technology transfer activities. These work /activities may include participation in quarterly TAC meetings, writing technical papers and, as appropriate, participation in agreed to conferences and workshops. RPSEA will reserve 1% of the total cost for program level technology transfer activities. Technology transfer activities will also be detailed in the Project Management Plan. The contractor will report the cost associated with project level technology transfer activities on each monthly report.*

The RPSEA technology transfer process was adapted to the target audience in as much as the efforts for transferring program results to smaller independent operators requires a much different approach than that utilized to reach the ultra-deepwater community. The common and most successful element however involved the use of advisors, which included peers, members of academia, and end users (normally operators), to develop the program and progress the selected projects towards maturity. The RPSEA mechanism brought industry together to create a common understanding on technical issues impacting oil and gas exploration and production. RPSEA was highly regarded for its ability to bring various segments of industry and government together for discussion. This ability contributed to the success of the technology transfer effort.

RPSEA Technology Transfer efforts have included the following elements.

> Overall, RPSEA was directly involved in 579 meetings, forums, workshops and technology conferences across the United States were held with a total participation of 12,414 people, resulting in 84,720 hours of participant commitment. This does not include complementary activities by the RPSEA contractors.

Hosted 58 technology forums and workshops attended by over 3,200 people to address critical research needs for specific resources or regional areas and to disseminate project results in an effective and efficient manner. This participation amounts to more than 23,000 hours of participant commitment.
Hosted 29 program technology conferences across the United States, attended by approximately 2,500 people, where researchers presented project progress, technical challenges and technology benefits to participants in an interactive meeting environment.
Involved over 6,700 participants in over 490 meetings of the advisory committee and working project group process that has resulted in over 27,000 hours of volunteer effort.
Coordinated roadmaps for the ultra-deepwater, unconventional resources and small producer research communities engaging the leading subject matter experts.
Participated, exhibited, sponsored or supported more than 270 oil and gas industry functions.
Engaged approximately 1,450 personnel (627 students and 822 staff) from 72 universities and over 2,800 industry personnel from 455 organizations participating in the RPSEA funded projects.

As a part of compilation for the RPSEA final report and the "Best of RPSEA" program meeting held in August 2016, RPSEA developed a database of all reports and articles written based upon the 170 final project reports. This database has over 5,000 articles which is easily searchable and will be posted to the RPSEA website. Many of these articles document Program successes.

The Onshore Program utilized one of most effective technology transfer organizations in the Petroleum Technology Transfer Council (PTTC). This is particularly the case for technology that lends itself to independent producers, an audience which the PTTC reaches throughout the U.S. The project team worked with the PTTC to implement outreach efforts, as well as to assist in providing materials and speakers at appropriate workshops and publications. PTTC also has assisted RPSEA with its website and in organizing a variety of meetings.

The Offshore Program dealt with a smaller and more varied audience, as is evident to anyone who has attended the Offshore Technology Conference (OTC).   RPSEA worked with a variety of organizations, including OTC, SPE, AGI, AAPG, IADC, API, IPAA, and others in facilitating technology transfer efforts. Those organizations' publications and conferences have been a major outlet for RPSEA program results.

In addition, the Offshore Program benefited from RPSEA's excellent working relationship with the DeepStar consortium. RPSEA and DeepStar shared many common members as well as objectives. The RPSEA program developed a network to assure that the program's findings were applied. Program findings were exchanged in meetings, workshops, and "during the breaks", where peers share information and new ideas.

The energy trade press also embraced RPSEA as a “go to” source for their readers to keep abreast of new technology. Not only did the press work with RPSEA and contractors to transfer information via their publications, but most also did so in digital media, social media, and through their own commercial conferences, normally focused on specific technology challenges.

Academia also played an important role in the RPSEA technology transfer success. The following is a list of the 81 universities who have participated in the RPSEA program:

UNIVERSITY NAME		
Amherst College	Northwestern University	University of Alaska Fairbanks
California Institute of Technology	Ohio State University	University of Arizona
Cambridge University	Ohio University	University of Arkansas
Clemson University	Oklahoma State University	University of California Berkeley
Colorado School of Mines	Portland State University	University of California Davis
Colorado State University	Princeton University	University of California, Los Angeles
Columbia University	Rensselaer Polytechnic Institute	University of Colorado
Drexel University	Rice University	University of Hannover
Duke University	Saitama University	University of Houston
Florida Atlantic University	Sam Houston State University	University of Kansas
Florida International University	Southern Methodist University	University of Kentucky
Fort Lewis College	Stanford University	University of Manchester, UK
Georgia Institute of Technology	Tertiary Oil Recovery Project - University of Kansas	University of Massachusetts
Imperial Collage London	Texas A&M University	University of Michigan
Iowa State University	Texas A&M University – Kingsville	University of New Mexico
Jackson State University	Texas A&M University Agri-Life Extension Service	University of North Dakota
Louisiana State University	Texas Tech University	University of Pittsburgh
Massachusetts Institute of Technology	The Board of Regents of the University of Oklahoma	University of South Carolina
Mesa State University	The Pennsylvania State University	University of South Florida
Midland College	The University of Nottingham	University of Southern California
Mississippi State University	The University of Oklahoma	University of Texas Department of Petroleum and Geosystems Engineering
Missouri University of Science and Technology	The University of Texas at Arlington	University of Utah
Montana State University	The University of Texas at Austin	University of Wyoming
New Mexico Institute of Mining and Technology	The University of Texas of the Permian Basin	Utah State University
New Mexico State University	The University of Tulsa	West Virginia University
North Carolina State University	The University of Vermont	Western Michigan University
Northeastern University	University of Alabama at Birmingham	Wright State University

A. Technology Transfer Outreach Events

Successful technology transfer and the uptake of technology within an organization can be enhanced by familiarity with RPSEA's ongoing process and the projects funded by RPSEA. RPSEA participated, exhibited, sponsored, or otherwise supported over ***270 industry events***:

- American Association of Drilling Engineers Annual Conference 2011 through 2014
- American Association of Drilling Engineers Completions Group Meeting 2009
- American Association of Drilling Engineers Emerging Completions 2009
- American Association of Petroleum Geologists (AAPG) Annual Convention 2008 through 2015
- American Association of Petroleum Geologists (AAPG) Eastern Section Gas Shales Workshop 2011
- American Association of Petroleum Geologists (AAPG) Eastern Section Meeting 2011 and 2016
- American Association of Petroleum Geologists (AAPG) Rocky Mountain Section Meeting 2010 through 2012
- American Institute of Chemical Engineers Annual Conference 2008, 2012, and 2013
- American Rock Mechanics Association Workshop 2007 and 2011
- Annual Convention of the Gulf Coast Association of Geological Societies 2007
- Annual Gas Shale Summit 2008
- Arctic Technology Conference 2012 and 2014
- ARPA-E U.S. Investments in Natural Gas Technology 2016
- Aspen Science Center Critical Path Energy Summit 2010
- Barnett Shale Produced Water Conference 2007
- BOEMRE Information Transfer Meeting 2011
- BOEMRE Offshore Energy Safety Advisory Committee 2011
- BOMA Optimizing Mature Assets 2007
- BSEE Best Available Safety Technology Meeting 2015
- Center for International Energy and Environmental Policy 2009
- Center for Offshore Safety Forum 2015 and 2016
- Clean Gulf 2011 through 2013
- Clean Technology Conference and Expo 2009
- CO_2 Flooding Conference 2007 through 2014 and 2016
- Deep Foundations Institute Annual Conference 2012
- DeepGulf Conference 2010 and 2012
- Deep Offshore Technology (DOT) Conference 2007 and 2013
- Deepwater Operations Forum 2011 through 2013
- Department of Energy Headquarters Project Briefings 2013 and 2014
- Developing Unconventional Gas (DUG) Conference 2007 through 2012
- Developing Unconventional Gas (DUG) East Conference 2011and 2012
- Developing Unconventional Gas (DUG) Midcontinent Conference 2016
- Disappearing Roads Competition 2008 and 2010

- Energy and Environment Subcommittee Meeting 2008
- Energy Day 2012, 2013, and 2016
- Energy Technology Venture Capital Conference 2007 and 2008
- Energy in Transition Houston Technology Center (HTC) 2008
- Environmentally Friendly Drilling (EFD) System – Europe 2010
- EFD annual sponsors meeting 2017 through 2016
- EFD – PTTC regional workshop series on Flare Mitigation and Solutions 2015
- EFD workshop series on Power by Natural Gas 2014-2015
- Florida Independent Petroleum Producers Association (FLIPPA) Annual Meeting 2007
- FMC User Group Forum 2012
- Gas Shales Summit 2008 and 2010
- Geological Society of America (GSA) Annual Conference 2009 and 2010
- Global New Energy Summit 2009
- Global Technology Summit 2008
- Greater Houston Partnership Energy Summit 2009 and 2012
- Greater Houston Partnership Marketing in the Oilfield Conference 2009
- Groundwater Protection Council 2016
- Hart Energy Offshore Executive Conference – Gulf of Mexico 2015
- Hart's Research and Development in Exploration 2008
- Houston Gas Processors Association 2010
- Houston Small Business Administration 2007
- Independent Oil and Gas Association of New York 2007
- Independent Petroleum Association of America (IPAA) Annual Meeting 2016
- Independent Petroleum Association of America (IPAA) Crude Oil Committee Mid-Year Meeting 2007 and 2009
- Independent Petroleum Association of America (IPAA) Offshore Committee 2007 and 2009
- Industry Technology Facilitator (ITF) Reservoir Imaging in Difficult Environments 2009
- Independent Petroleum Association of Mountain States (IPAMS) Annual Meeting 2007
- Insight Gas Shales Summit 2008
- International Association of Drilling Contractors (IADC)/Drilling Engineering Association (DEA) Forums 2007 through Fall 2016
- International Association of Drilling Contractors (IADC)Advanced Rig Technology Conference 2015
- International Association of Drilling Contractors (IADC) Drilling Onshore Conference 2009
- International Association of Drilling Contractors (IADC) Health, Safety, Environment & Training Conference 2011
- International Coalbed & Shale Gas Symposium 2008 through 2011
- International Petroleum and Biofuels Environmental Conference 2009
- INTSOK 2007 through 2009

- Interstate Oil and Gas Compact Commission (IOGCC) Annual Meeting 2008, 2012, 2014, 2015,2016
- Interstate Oil and Gas Compact Commission (IOGCC) Mid-Year Conference 2007, 2015, 2016
- Interstate Oil and Gas Compact Commission (IOGCC) Woodford Summit 2011
- Kongsberg User Group Forum 2012
- Louisiana Oil and Gas Association (LOGA) 2009
- Marine Technology Society Houston Chapter meetings 2008 and 2013
- Massachusetts Institute of Technology Natural Gas Advisory Committee 2008 through 2010
- Massachusetts Institute of Technology CO2 Enhanced Oil Recovery Symposium 2010
- Mid-America Regulatory Conference (MARK) 2008
- More Bytes & More Barrels –Digital Energy Conference & Exhibition 2008 and 2009
- New Mexico Oil and Gas Day 2009
- North American Prospect Expo (NAPE) 2007 through 2013
- North American Prospect Expo (NAPE) Summer 2011,2012, and 2016.
- Ocean Energy Safety Institute Forums 2014 through 2016
- Offshore Arctic Technology Conference 2016
- Offshore Technology Conference (OTC) 2007 through 2016
- Oklahoma Clean Energy Commission 2010
- Oklahoma Independent Petroleum Association (OIPA) Annual Meeting 2008 and 2009
- Oklahoma State University Energy Conference 2010
- Pennwell Unconventional Gas Conference 2009 and 2011
- Project Management Institute Annual Conference 2010
- Re-energize America Conference 2010
- Residual Oil Workshop 2009
- Rice Alliance Business Plan Competition 2008 and 2009
- Rice Alliance Energy and Clean Technology Venture Forum 2007 through 2010
- Rice Nanotechnology Venture Forum 2008 and 2009
- Rice University Congressional Field Hearing 2008
- Rocky Mountain Energy Epicenter Technology Conference 2008 through 2015
- Science Engineering Fair of Houston 2008 through 2010
- Society of Exploration Geophysicists (SEG) Annual Meeting 2007 through 2015
- Society of Petroleum Engineers (SPE) Delivering and Using Emerging Technology in the E&P Business Workshop 2009
- Society of Petroleum Engineers (SPE) Coiled Tubing & Well Intervention 2012 and 2014
- Society of Petroleum Engineers (SPE) Colloquium on Petroleum Engineering Education 2010
- Society of Petroleum Engineers (SPE) Hydraulic Fracturing Conference 2011 through 2014
- Society of Petroleum Engineers (SPE) Life of Field Surveillance for Unconventional Gas Workshop 2007
- Society of Petroleum Engineers (SPE) Seismic While Drilling Applied Technology Workshop 2007

- Society of Petroleum Engineers (SPE) National Academy of Engineering Gulf of Mexico Ultra-Deepwater Drilling & Completions Regulations Summit 2011
- Society of Petroleum Engineers (SPE) Annual Technical Conference & Exhibition 2007 through 2013 and 2015
- Society of Petroleum Engineers (SPE) Deepwater Completions & Operations Symposium 2011 and 2012
- Society of Petroleum Engineers (SPE) Digital Energy Conference 2009
- Society of Petroleum Engineers (SPE) E&P Health, Safety, Security & Environmental Conference 2011, 2013, and 2014
- Society of Petroleum Engineers (SPE) Human Factors & Safety Summit 2012
- Society of Petroleum Engineers (SPE) North American Unconventional Gas Conference 2011 and 2012
- Society of Petroleum Engineers (SPE) Reducing Environmental Impact of Unconventional Resources Applied Technology Workshop 2012
- Society of Petroleum Engineers (SPE) R&D Symposium 2011
- Society of Petroleum Engineers (SPE) Reservoir Stimulation Symposium 2013
- Society of Petroleum Engineers (SPE) Subsea Standardization Applied Technology Workshop 2013
- Society of Petroleum Engineers (SPE) Tight Sands Workshop 2009
- Society of Petroleum Engineers (SPE) Unconventional Resources Conference 2011, 2013, and 2014
- Society of Petroleum Engineers (SPE) Eastern Regional Meeting 2011Society of Petroleum Engineers Dallas Section (SPE DAL) General Meeting 2012
- Society of Petroleum Engineers Gulf Coast Section (SPE GCS) General; Drilling; Completions & Production; Projects, Facilities, & Construction; HSE; and Waste Management Meetings 2011 through 2016
- Southern Methodist University Geothermal Conference 2009 and 2011
- Subsea Tieback Forum 2010 through 2016
- Sustainable Opportunities Summit 2010
- SW Petroleum Show 2008
- Texas Alliance Expo and Annual Meeting 2008 through 2011
- Texas Independent Producers and Royalty Owners Association Annual conference 2010 and 2013
- Texas Renewable Energy Industries Association 2008
- Texas Society of Professional Engineers (TSPE) Annual Conference 2013
- Texas Society of Professional Engineers Houston Chapter (TSPE HOU) General Meetings 2010 through 2013
- The Making of Energy Policy: Where Are We Going? Conference 2008
- The University of Tulsa Energy Management Program 2008 and 2009
- Topsides, Platforms & Hulls Conference & Exhibition 2013, 2014, and 2016
- University of Colorado at Boulder Renewable & Sustainable Energy Institute Conference 2009

- URTeC 2013 through 2016
- U.S. – Mexico Border Energy Forum 2009
- Washington Post Energy Conference 2007
- West Slope Colorado Oil & Gas Association (WSCOGA) Annual Meeting 2010 and 2011
- World Energy Technology Summit 2010
- Young Professionals in Energy (YPE) website sponsor 2008 and 2009
- RPSEA Sensor Forum 2012
- Best of RPSEA, RPSEA Conferences and Workshops, RPSEA TAC meetings

V. EXPENDITURES

A. Administrative Expenditure Summary

The administrative cost for the entire project was $33,188,348, which includes $30,055,417 in Federal funding from NETL and $3,132,931 in Cost Share provided by RPSEA. Below is a detail of expenditures by task:

NETL Task 1	Management Plan	440,215.25
NETL Task 2	Annual Plan	1,691,146.38
NETL Task 3	Project Solicitation	1,518,255.24
NETL Task 4	Project Selection	2,207,356.47
NETL Task 5	Subcontract Award	2,211,958.19
NETL Task 6	Project Management	5,578,242.02
NETL Task 7	Communications	2,010,560.98
NETL Task 8	Tech Transfer	2,027,851.50
NETL Task 9	Metrics Reporting	183,439.36
NETL Task 10	Additional Activities	15,319,322.62
	Total	33,188,348.00

B. Research and Development Expenditure Summary

The research and development expenditure total was $323 million, which includes $217 million from DOE and $98.5 million in cost share. Nearly $8.2 million was spent on technology transfer for the program. Below is a detail of each of these costs by project program areas:

Program	Total Project Cost	Tech Transfer	Cost Share	NETL Costs
Ultra Deep Water	**138,736,490.84**	**3,455,909.85**	**34,380,984.97**	**100,899,596.02**
Unconventional	**148,233,977.86**	**4,030,592.46**	**49,166,574.78**	**95,036,810.62**
Small Producers	**36,788,664.46**	**761,522.07**	**14,984,719.50**	**21,042,422.89**
Total	**323,759,133.16**	**8,248,024.38**	**98,532,279.25**	**216,978,829.53**

The amounts above are subject to change based on the final closeout of all subcontract awards.

VI. CONCLUSIONS

The Section 999 Program, which was designed to be a 10-year program managed by a public-private partnership, was reduced to an 8-year funded program after the 2005 Energy Policy Act was rescinded by Congress in the 2014 Fiscal Year Budget. However, NETL continued to fund the administration of the program through fiscal year 2016 so that existing projects could be completed in a manner that would not risk the loss of potentially valuable research results. NETL determined that RFPs were actually only released for 6 years of the planned 10-year program, as new awards and solicitations could not be released for years 7 & 8 because there had to be enough time to select and award projects in a manner that would allow adequate time for the projects to be completed.

The objectives of the original program's defined elements were subsequently modified by the Department of Energy to refocus the research on safety, environmental sustainability, and associated risk reduction, primarily because of public reaction to the Deepwater Horizon catastrophe. Modifications to the award priorities also were made due to increased concerns surrounding hydraulic fracturing, wellbore integrity, freshwater protection, induced seismicity, water usage, and associated upheavals to communities and their infrastructure, as well as greenhouse gas emissions and climate change.

Each of these alterations and re-directions disrupted some of the projects and led to delays. Nevertheless, 170 projects were undertaken within the RPSEA program at an approximate $215 million Federal funding share, with an additional cost share from industry and research universities and organizations of $100 million. Of this $315 million in R&D spending, approximately 2.5 percent (~$8 million) was utilized in efforts to transfer the technologies to industry. The Program has directly resulted in commercial utilization of over 30 products or processes thus far, and the development of many more has been accelerated. These advancements will lead to safer operations at a reduced cost, and many of them have resulted or will result in improved recoveries and production of the Nation's hydrocarbon resources.

This Program, which involved the selection of RPSEA to administer the public-private partnership, was the first of its kind in the oil and gas business. As such, many lessons have been learned that can be applied to similar future endeavors. Below are a few of these lessons

Program Development

- The Energy Policy Act 999 Program legislative language was ambiguous, resulting in certain fundamental disagreements between parties about the Program's administration, oversight requirements, the proper contracting mechanism, and decision-making authority. As a result, the Program was slow to start, and certain processes encumbered RPSEA beyond what it had anticipated in its proposal.

- Partnering with Government entities was new to RPSEA employees and many RPSEA members, who were not familiar with certain restrictions and requirements that are not normally required in private partnerships. Likewise, Government agencies like DOE are not experienced in partnering with multi-member organizations such as RPSEA, and are more comfortable contracting with single private concerns or academic institutions. The learning process slowed down the Program and resulted in some frustrations between NETL and RPSEA early on.

However, through common goal setting and increased direct communication the issues were resolved.

- Regarding goal setting, one of the most frustrating and long lasting issues this Program encountered involved the changes in oversight and administrative processes between NETL and DOE HQ, which resulted in a considerable amount of non-productive time. As noted, public concern over certain events caused the Federal government to direct RPSEA to change the focus of the Program from its original objective of increasing reserves and recoveries to one of safety and environmental risk reduction. This resulted in lengthened decision time for awards which cost contractors time, money, and in some cases lost opportunities for technology demonstration sites.

- Because of these issues, administrative costs and required resources were much greater than expected. The RPSEA consortium structure was able to pay for these added costs through member dues.

Subcontracting

- Conveying all of the legal requirements of a government contract is more complicated than private contracts, and for prospective RPSEA subcontractors this proved to be a difficult challenge. Many of the subcontractors that were selected had no experience in Federal contracting requirements, and they underestimated the scrutiny and required documentation required before an award could be made. As a result, several entities ultimately declined to participate after they had been selected. Others found it much more difficult to obtain approval, and in several cases had to rely heavily on RPSEA contracting specialists for extensive assistance. As time progressed, RPSEA improved its messaging to inform and instruct subcontractors about the particulars surrounding Federal contracting, which helped quite a few of the smaller subcontractors. In hindsight, RPSEA and NETL should have conducted workshops for potential Program subcontractors early in the process and then on a regular basis. This should also include instructions on NEPA and property acquisitions/management.

- It took a long time for a consistent process and approach to be developed, and that could have potentially been avoided with better communication at earlier stages. Improved communication between RPSEA's and NETL's contract management teams eventually developed an efficient way of doing business.

- Negotiating subcontracts with other National Labs proved to be quite frustrating, time consuming, and in some cases prevented individual labs from participating in projects. A workable contract mechanism that is acceptable to all National Labs needs to be in place to encourage lab participation.

- Timing of payments was another area where improvements would be important. Many subcontractors, especially smaller ones with limited financial resources, found difficulty in the time lapse between invoice submittal and payment. This issue was exacerbated if insufficient supporting information had been provided with an invoice and it missed the monthly cut-off date for RPSEA's submittal to DOE for payment. Over the course of the Program, RPSEA improved its methods of communication and explanation of required supporting documentation with subcontractors, so that the issue was minimized. And both RPSEA and NETL relaxed their deadlines somewhat for invoice submittals to accommodate subcontractors. Despite everyone's best efforts on several occasions RPSEA had to prepay subcontractors before receiving payment from DOE – in effect providing subcontractors with a "float" period and absorbing the financial risks. On a related note, RPSEA was required to provide upfront funding to National Labs that were selected to perform projects, per Federal regulations. On several occasions the National Lab overspent its allotted funds, and RPSEA had difficulty seeking refunds, having to employ NETL management assistance without any other recourse. These issues could be resolved in future programs with early communication between all parties.

Administration

- Technology transfer funding for the Program was set at a minimum of 2.5 percent of R&D spending. Early in the Program RPSEA decided to stipulate a minimum 1.5 percent for project level technology transfer and 1.0 percent for program level technology transfer, the latter which would be deducted as part of each monthly invoice.
    - The effect of the 2.5 percent technology transfer requirement became evident when increases in funds were requested. Because the nature of this rule applied to all funds rather than just to the DOE portion of funding, subcontractors were discouraged from adding additional cost share R&D funds. If the technology transfer requirement could be relaxed such that it is a percentage of DOE funds only, researchers might be more apt to contribute cost share during the course of a project. This is a lesson learned, as contractors should not be penalized for conducting and documenting added technology transfer and cost share.
    - Project level technology transfer occurred throughout the course of each Project, yet tracking by subcontractors was inconsistent, especially for projects in the first two years. RPSEA improved its process of notifying the subcontractors and tracking technology transfer alongside them, so that the issue was minimized for later projects.
    - Program level technology transfer, as it turned out, was problematic, too. When the Program began, RPSEA assumed that it could utilize these funds to plan and conduct open workshops and conferences, draft technical manuscripts and presentations, and address audiences about technologies being developed within the Program. DOE interpreted the rule differently, believing that these functions were project management functions, and therefore program level technology transfer funds could not be used by RPSEA employees, who would instead have to be paid out of administration funds. In due course, it was decided that RPSEA could bid the technology transfer functions out to a third party, and this was done. However, the increased

oversight and supervision required, plus a 10 percent third party fee, resulted in an ineffective use of funds.
    - During the course of the Program, RPSEA decided to offset some of its technology transfer costs by charging a minimal fee for registration to some of its major events, while billing the entire cost to DOE as part of the program. After two years of doing so, RPSEA was informed that it had to reimburse those fees to the Federal government, which resulted in a loss of about $75,000 in collected payments. RPSEA had planned on using those funds to partially offset its technology transfer costs for the events, which could have ultimately led to more funds available for additional technology transfer activities. Since technology transfer was a fundamental objective of the Program, RPSEA believes that it would have made more sense to retain those funds for utilization later, thus adding to its program level technology transfer abilities. This issue should be resolved in future programs as RPSEA was in effect penalized for doing additional technology transfer.

- Program end dates made it very difficult to add funding to R&D projects, manage projects to their natural end, or manage the technology transfer funds efficiently. It became evident early in the Program's implementation that final year funding would limit the duration of new projects. Furthermore, completing technical requirements for projects at the end of the Program would be virtually impossible, leaving no time for project and Program closeout work. And, since technology transfer funds could not be assured, either from a project or a program level, until all spending could be completed and invoiced, targeting technology transfer funds simply could not be accomplished. A better alternative would be for a Program such as this to include: 1) a 6-month to 1 year start-up time with administration funds provided to cover, and 2) an appropriate (2 to 3 years) time period after R&D funding is complete with funding to allow for all research and administrative work to be completed.

Communication

- Developing volunteer teams (PAC, TAC, etc.) required quite a bit of effort. RPSEA spent a considerable amount of time introducing the concept to potential stakeholders. Utilizing Forums prior to initial project selection gained the attention of interested parties and garnered support from subject matter experts, who were later to become the nucleus of the TACs. Engaging these interested parties, project selection, in RFP development, subcontractor selection, and funding opportunities required the development of processes that were refined throughout the Program duration. RPSEA found that frequently member representatives were interested in one aspect of the Program, for example assisting in project selection, but not interested in another aspect, such as subcontractor selection or engagement. In such cases RPSEA redoubled its efforts in identifying multiple contacts within many organizations and attempted to keep everyone informed via various communication tools (i.e., magazine articles, technical papers, presentations, TAC meetings, email messages, Facebook, interactions with technical and professional societies, radio and TV interviews, phone calls, and face-to-face meetings). This should be an important feature of any future program designed to rely on volunteer input from industry representatives.

- Engagement of RPSEA members with subcontractors did not prove to be difficult once the former were engaged in recommendations. However, because of RPSEA's strict enforcement of its rule to disallow any vote if a proposal on the subject had mentioned a possible collaboration with the member, several (PAC or TAC) representatives of companies who were not allowed to participate in project selection became upset. Upon investigation, we found that in an effort to improve their chance of selection, in some cases, the proposer would mention that they had discussed their proposal with someone within the same company as the PAC or TAC representative and found a passing interest. This statement alone resulted in the disqualification of the representative as a voting member of the TAC or PAC. The issue was never resolved to everyone's satisfaction, but RPSEA believes that it should continue a policy to guard against favoritism, whether real or implied. A clear conflict of interest policy should be included in all activities.

- One of the greatest lessons of this Program was the value obtained from the RPSEA consortium consisting of many stakeholders. RPSEA had to be flexible enough to serve its many customers (members), plus nonmember contractors and well defined stakeholders. The stakeholders included regulators, associations, and, because of the source of funding, the public. Therefore, RPSEA had to become adept at balancing these sometime competing interests. In doing so RPSEA successfully attempted to be fair and impartial, meet the letter and the intent of the law, and avoid angering or disassociating anyone. All reports have been carefully documented to be science based and objective.

- One of the prime reasons for the success of this Program was because it allowed subcontractors to retain any intellectual property (IP) that was developed in their respective projects. Most other research programs, whether private or university based, insist on retaining or sharing IP. That approach is a disincentive to commercialization and thus uptake of the technology. In this Program, however, the subcontractors were free to determine the best use of IP. In most cases, they kept it themselves. In a few cases, they shared it with cost share partners or separately contracted with cost share partners to provide the latter with future incentives on the use of IP.

- Communication was also enhanced by RPSEA's location in the Houston area. This is where most the oil and natural gas industry is located, in particular that portion focused on offshore development. It would have been difficult, if not impossible, if the program and most program managers were not located in Houston. Web based meetings are useful but the accomplishments and interactions between project working groups can only be fully successful in face-to-face discussions. RPSEA was fortunate to have access to meeting rooms and facilities contributed by members. NETL having a program oversight office in Houston also contributed to overall success and improved communication. RPSEA projects have been successful by having a regional diversity with regional expertise. However, future Programs need to strongly consider the home location as a prime reason for an award.

Value Determination

- RPSEA touted its member benefits frequently:
  - Eligibility to serve on the Board of Directors and Executive Committee and direct the future of RPSEA
  - Participation on advisory committees to focus research priorities and select awards
  - Access to technical forums, workshops, membership meetings and other activities at a member rate
  - Leveraging research capability across many entities instead of using organization funds on specific and possibly redundant research
  - Advance information and updates, as well as full access to reports, including operational research and request-for-proposal solicitations through newsletters, e-mails, publications, reports and the members-only pages of the website
  - Access to research for organizations that don't have internal research capability
  - Invitations to give presentations at forums, meetings and conferences, and exhibit in RPSEA's booth at industry events
  - Opportunities to network and form strategic alliances and collaborations within the RPSEA network.

  Depending on one's point of view, value could be derived from any number of the above. For example, by serving on a PAC, TAC, or Working Project Group a member representative could have been involved with a project selection, a subcontractor selection, or even specific requirements within a project that his/her company might need. As a RPSEA member he/she has access to private and intermediate reports, as well as some free technical papers, that can provide insights into the development of a new technology. Pooling stretched financial and intellectual resources to solve a particular problem, especially when those resources could be supplemented with Federal funds, proved to be a huge benefit. Gaining access to previously unknown companies or individuals - whether inside or outside of the industry, at research institutions, or with state or Federal regulators - was a tremendous benefit to our members. RPSEA provided countless opportunities to our subcontractors to provide updates, draft manuscripts for publication, and otherwise address industry and others at numerous events, including SPE, SEG, AAPG, COGA, and OTC. And, as noted in the project section above, the collaborative nature of this Program has led to a multitude of alliances, some which were developed for our projects, and others developed post-project, to incubate, accelerate, and advance technologies.

- Determining value as a result of volunteer participation could be seen in several ways. Firstly, the sheer number of people who were allowed to participate by their respective organizations suggests that the Program provided value. People's time is valuable, especially to those whose expertise is in demand. While it is not possible to quantify that value in terms of financial gain, an indication may be derived from the number of volunteer hours. Secondly, RPSEA believes that the process of inclusiveness, collaboration, and guidance provided by thousands of subject matter experts, managers, researchers, and other interested parties to this Program is possibly the single most important attribute in terms of project successes and advancements. Without their participation, we believe that the results would still be somewhat positive, but nowhere near what the Program has achieved through this unique public-private partnership.

- Defining and measuring success in any R&D program is difficult. In this Program, RPSEA had specific objectives that included reduced safety and environmental risks, improved reserves identification and recoveries, and other aspects related to energy security for the American public. Success could be attributed to the participation level of interested parties. However, a more definitive derivation comes from the use or potential use of technologies developed during the course of the Program. The examples of projects that have led to commercial product now on the market points towards successful endeavors thus far. Additional measures of success can be taken by examining Technology Readiness Levels of individual projects, as well as industry uptake, especially in today's low product price environment, of these projects through follow-on development.

- Value quantification for research projects is often difficult, since no one knows the final cost of the work, or even if it will be successful, until a product has been commercialized. In addition, attempts to determine market demand for a technology are subject to market fluctuations, including product prices, as well as the use of other competitive technologies.
  - Early in the Program NETL attempted to determine value using a Federal computer model. Value was combined with value assigned to research done under NETL's Complementary Program, and on average it was estimated that there was a 4:1 value-to-Federal spending ratio, implying a $1 billion value for $250 million in Federal funding for research and administration. RPSEA believes that this number is low since RPSEA projects can document the addition of billions of barrels of new reserves both on and offshore, while the technologies developed from the projects are saving the industry millions of dollars each day.
  - A risk-based internal estimate was made of the 2007 – 2011 Ultra-Deepwater Program element in early 2014, using $100 per barrel oil pricing and $5 per MCF gas pricing. It was recognized that product prices were by far the most sensitive in the analysis, affecting market demand, market penetration, and value. Even though those assumptions are out of line in today's terms, it is worth noting that the value-to-total R&D spending ratio estimate was 215:1. This estimate, while far from complete and based on optimistic product price assumptions, is indicative of the potential impact and volatility in value estimates that exists.

  It is safe to say that the RPSEA Program has had and will continue to have a significant positive impact in terms of safer and less environmentally risky hydrocarbon extraction for the public.

- Cooperation and coordination between RPSEA, the public-private partnership that was selected to administer this Program, and NETL, which managed the Program for DOE, was critical to its success. The efforts put forth by personnel at NETL had a direct and positive impact on the success of this Program. The Program Manager provided insights to keep projects on track on numerous occasions. The Contracts Manager, especially towards the critical end of the Program, and her staff all were very helpful in guiding the Program to a safe conclusion. All current NETL Project Managers, who were pressed into service after the Program had been rescinded in 2014, were willing to dig into their respective projects, interact with RPSEA and the subcontractors on a regular basis, and provide their wisdom and assistance as warranted. RPSEA applauds their work and is thankful that they were there alongside.

Projects

A total of 170 projects were completed through this program. Of these projects, 35 have achieved a TRL of 6 or greater, signifying that they are commercial. A total of 29 projects have a TRL of 5, suggesting that they are a minimal distance from commercialization; the vast majority of these developments will achieve commercial readiness in due time either on their own or with the financial assistance of one or two operating companies. Quite a few projects resulted in TRL's of 3 (lab tested) or 4 (environment or simulated environment tested), levels which have traditionally been called "the valley of death" because so many promising technologies are left to die at these TRL's. In order for them to achieve their full potential and close their respective technological gaps, they may need additional financial support. The lists below are prioritized, based on RPSEA's knowledge, for those projects which we believe offer the most potential to improve safety or otherwise reduce ESH risks and will likely benefit from additional funding (from top to bottom). Several TRL 3 – 4 projects are left out because we believe that they are being advanced already and will not need external funding. Specific information about each project, including its objectives and identified gaps, can be found online in its Final Project Report at http://www.rpsea.org/ under the Program Element.

Onshore Programs

1. Advancing a Web-based Tool for Unconventional Natural Gas Development with Focus on Flowback and Produced Water Characterization, Treatment and Beneficial Use
2. Near Miscible CO2 Application to Improve Oil Recovery for Small Producers
3. Characterization of Potential Sites for Near Miscible CO2 Applications to Improve Oil Recovery in Arbuckle Reservoirs
4. Relationships between Induced Seismicity and Fluid Injection: Development of Strategies to Manage Fluid Disposal in Shale Hydrocarbon Plays
5. Basin-Scale Produced Water Management Tools and Options – GIS based models and statistical analysis of shale gas/tight sand reservoirs and their produced water streams, Uinta Basin
6. Maintenance for Paraffin Management in Production Tubing Using Non-Invasive Ultrasonic Technology
7. Measurement of Hydrocarbon and Greenhouse Gas Emissions from Uncharacterized Area Sources

8. A Portable, Two Stage, Antifouling Hollow Fiber Membrane Nanofiltration Process for the Cost-Effective Treatment of Produced Water
9. Enhanced Oil Recovery from the Bakken Shale Using Surfactant Imbibition Coupled with Gravity Drainage

Ultra-Deepwater Program

1. Development of Advanced CFD Tools for the Enhanced Prediction of Explosion Pressure Development in Early Project Phase and Deflagration to Detonation Transition Risk on US GOM Drilling and Production Facilities
2. Pressure Prediction and Hazard Avoidance through Improved Seismic Imaging [pressure prediction model; time lapse pressure prediction model]
3. Riser Lifecycle Monitoring System for Integrity Management [software and business process system integration; RLMS hardware]
4. Smart Cementing Materials and Drilling Fluids for Real Time Monitoring of Deepwater Wellbore Enhancement
5. Instrumented BOP Ram: Drill Collar/ Tool Joint Locator
6. Ultra-High Conductivity Umbilicals: Polymer Nanotube Umbilicals
7. More Improvements to Deepwater Subsea Measurement [downhole HP/HT flow measurement sensor]
8. Corrosion and Scale at Extreme Temperature and Pressure [model]
9. A 1,000 Level Drill Pipe Deployed Fiber Optic 3C Receiver Array for Deep Boreholes
10. Concepts Identification for Improved Recovery Technology [IOR/ EOR technologies in UDW]
11. Hydrate Modeling & Flow Loop Experiments for Water Continuous & Dispersed Systems [internal pipeline coating]
12. Sensor for Pipe, Riser, Structure, and Equipment Inspection to Provide Detailed Measurements, Corrosion Detection, Leak Detection, and/or Detection of Heat Plumes from Degraded Pipeline Insulation [heat detection]
13. Hydrate Modeling & Flow Loop Experiments for Water Continuous & Dispersed Systems [hydrate model improvements]
14. Hydrate Characterization & Dissociation Strategies
15. Deepwater Permanent Subsea Pressure Compensated Chemical Reservoir [shuttle system analysis]
16. Low Cost Flexible Production System for Remote Ultra-Deepwater Gulf of Mexico Field Development
17. Composite Drilling Riser for Ultra-Deepwater High Pressure Wells
18. Construction and Testing of Deepwater Permanent Subsea Pressure Compensated Chemical Reservoir [subsea chemical storage & injection system]
19. Deepwater Reverse-Circulation Primary Cementing
20. Deep Draft Column Stabilized Drilling & Production Floaters
21. Hydrate Modeling & Flow Loop Experiments for Water Continuous & Dispersed Systems [external fiber optic acoustic sensor]

VII. RECOMMENDATIONS

The following recommendations have been developed from lessons learned by the RPSEA management team with the hope that there will be future public/private partnerships for oil and gas R&D and those future programs will be even more successful by taking into consideration these recommendations.

Program Development

- Future programs need to have people in place at the start who understand the processes surrounding negotiating a Federal government contract and can “hit the ground running” when selected for large multi-disciplined awards like the Section 999 Program. Contract mistakes or misunderstandings such as those that occurred early in this Program should be avoided by referring to and learning from them.

- Partnering with Government entities requires patience and finesse, as well as sound leadership. Future opportunities to partner with government should expect that open lines of communication and direct involvement in a Program are a must. Information and direction should flow freely between the Government contracting officer and the “RPSEA” Program Administrator. A process should be in place that allows for quick and fair resolution of questions or disagreements concerning interpretations of certain restrictions and requirements. Finally, a common set of goals should be developed and pursued.

- Once a Program is in place, the Program Administrator should be allowed to conduct its function as administrator, so that it can utilize the knowledge and wisdom of its subject matter experts, who comprise its TACs and PACs, to develop its prioritized projects. These projects must adhere to the objectives of the Program, and once those objectives are set they should not be changed. The RFP and project selection process must be streamlined. Once again, as long as the objectives of the Program are being met, the contractor should allow the recommendations to pass through without alteration.

- Care needs to be taken by the Program Administrator to ensure that sufficient funds are available to allow for a smooth startup of the Program. If any of the above points are not followed, the Program Administrator needs to have additional resources available to it to cover over-expenditures.

- The RPSEA onshore program included the Small Producers Element and the Unconventional Natural Gas Resources Element, and yielded a broad span of benefits in terms of the impacts on environmentally sustainable domestic oil and natural gas production and its positive impact on the economy, jobs, taxes and wealth creation. While the focus of these two onshore programs were on small producers and unconventional natural operators, in reality, the small producer program results had a significant impact on mid to large independents. Both programs developed environmental technologies and efficiencies that impact all onshore oil and gas operations. Most of the technologies developed for the unconventional natural gas element had an equal impact on *oil* and natural gas. Future program should include onshore oil and gas (for example) and focus on broader safety and environmental benefits such as associated natural gas from oil production, sometimes flared or underutilized. This was somewhat addressed in the program but should have had a higher profile. Future programs could benefit from a more integrated onshore program, where focused “silo” programs may miss many synergistic opportunities.

Subcontracting

- Future Federal programs require subcontract management expertise that is willing and able to assist awardees in Federal contracting requirements. That said, the scrutiny and required documentation expectations required before award should be discussed and determined by all parties; this could allow a Program Administrator to determine if it wishes to accept a selection, costs that may be involved and that may not have been anticipated, and development of a plan to educate some of its subcontractors and explain the requirements to them in concrete terms.

- The Program Administrator should ensure that contracting requirements and interpretations of Federal regulations can be discussed and do not lead to much more paperwork and wasted time. On a related note, there should have a clear line of oversight authority, as additional levels of management over the Program Administrator or decision-making authority add to costs and delay, and at times reduces the value of the research.

- Awards need to be disciplined and flexible. If a project is not achieving its objective, the project needs to be modified or stopped. The process should require the end user (or end user oversight advisors) to be involved throughout the program from concept to finish. Once the subcontractors understand that this disciplined approach is being followed, the funding will result in more success. DOE oversight of this process needs to be well defined up front.

- A common subcontracting template should be developed for all National Labs to address their concerns and avoid needless waste associated with multiple contractual negotiating forms.

- Future Program subcontracting should be done by pre-qualified specialists. In the case of a program that contains multiple subcontracts, the need for close collaboration with program and project managers and complete understanding of the Program administrator’s structure and culture precludes that subcontracting personnel should be housed and employed by the Program Administrator. Furthermore, subcontract staff should be structured to work directly with the subcontractors and specifically assigned government contract specialists, and any issue arising from a disagreement should rise to the Program Administrator's and the government's contract managers to deliberate. These actions will lead to vast improvements in communication and efficiency, leading to shortened negotiation timelines.

- It needs to be made clear to subcontractors that awards are not grants, i.e., lump sums are not awarded to the subcontractors. A strict set of deliverable items, many tied to timelines, must be met and be acceptable to the Program Administrator prior to ongoing invoice payments. Moreover, the Program Administrator must have full authority to enforce terms of its subcontracts.

- The Program Administrator needs to clarify to subcontractors that the strength of this public-private partnership is in its utilization of subject matter experts who are intimately involved in projects. As such, subcontractors must involve industry advisory committee members and keep them informed. The process of assuring advisors with the end users involved in the project improves the chances for commercial success.

- The Program Administrator, along with government organization, needs to better educate subcontractors about Federal requirements regarding invoice submissions, especially the need for proper receipt and back-up materials, as a precursor for payment. Also, subcontractors need to be made aware that the process of invoice payment, requires acceptable invoice packages within a small monthly window, normally takes 60 to 75 days, and subcontractors should have sufficient financial resources to handle an additional 30 days or longer withheld payment if their paperwork is not in order.

- The process of providing upfront funding to National Labs that were selected to perform projects is unfair to other subcontractors, has resulted in overspending, provides a Program Administrator with no direct recourse for payment, and should therefore be modified or discontinued.

Administration

- Technology transfer - Future programs should include contractual and sub contractual specification about the minimum amount of technology transfer spending required by project and a fixed amount to be provided to a Program Administrator for programmatic technology transfer. Technology transfer minimum spending should be tied to the government share of R&D spending, rather than to total R&D spending for projects, so that subcontractors are not discouraged from increasing cost share by an additional technology transfer spending burden. Additional documented technology transfer efforts by the contractor should be considered cost share. There needs to be incentive, not penalties, for documenting additional cost share and technology transfer.

- The Program Administrator needs to stress the importance of tracking and managing technology transfer costs to its subcontractors and develop a more reliable process. For example, a semiannual review of technology transfer spending, coupled with a revised technology transfer plan as warranted, could be beneficial.

- Regarding program level technology transfer, future programs should specify that the Program Administrator technical managers will be able to charge certain duties to it rather than be required to charge to project management. Technology transfer duties may include planning and conducting open workshops and conferences, drafting technical manuscripts and presentations, and addressing audiences about technologies being developed within the Program. If the Program Administrator needs to hire a third party to assist in these functions, it can continue to do so, but at its discretion on an as-needed basis.

- Furthermore, DOE should allow the Program Administrator to charge admission for its sponsored events to supplement its costs, and the Program Administrator should be allowed to retain those funds for additional technology transfer, so long as it spends all of its technology transfer funds by the end of the program.

- The Government should consider project R&D schedules, as well as technology transfer spending targets, when designing programs. An alternative approach would allow for an appropriate (2 to 3 years) time period after R&D funding is complete, perhaps coupled with pre-funding technology transfer as suggested above, for all administrative work to be completed.

- The public private partnership is best accomplished with a balance of industry (operators, service companies, researchers) academia, and not for profit organizations. This balance assures proper program governance and focus. The location of Houston as the primary program office provided extremely beneficial.

Communication

- Forums should continue to be used as conduits to share ideas and develop a nucleus of stakeholder support for future programs.

- The Program Administrator should work to maintain its advisory structure and engage volunteers periodically to keep them active and interested until additional programs are developed. Additionally, the Program Administrator needs to recognize that some of its members are more interested in one aspect, or one functional area, than in others, i.e., project selection, RFP development, subcontractor selection, onshore water treatment, and/or offshore field abandonment.

- Communication with constituencies should continue by various means, e.g., magazine articles, technical papers, presentations, TAC meetings, conferences, email messages, Facebook, interactions with technical and professional societies, radio and TV interviews, phone calls, and face-to-face meetings.

- Engagement of the Program Administrator organization members with subcontractor proposers on relevant topics prior to the latter's selection must continue to result in disallowing the members' companies from voting for awardees recommendations. Along the same vein, the Program Administrator must stress to potential bidders that they will disqualify companies from voting by suggesting that those companies will be part of the subcontracting team, but by the same token they must notify the Program Administrator in their proposal if that is the case. The goal here should be to avoid the slightest hint of a conflict of interest with special interests or preferences.

- Future programs should include a focus of engagement and communication between the Program Administrator and the government contractor that allows and encourages the latter to participate as observers in projects. This will result in direct knowledge transfer and improve the general understanding of program needs, as well as indicate genuine interest.

- A Program Administrator should continue to learn from its experiences and develop its best practices to retain its unique cultural identity. Moreover, a Program Administrator must fortify its role as a public-private partnership that successfully balances sometime competing interests and serves the public. It must remain fair and impartial, meet both the letter and the intent of the law, and avoid angering or disassociating anyone inasmuch as possible.

Value Determination

- Value determination for members should continue to be stressed. Whether it is access to new technologies, networking, or decision-making ability, any Program Administrator needs to value the collaborative and cooperative nature of the program that has made it so highly successful.

- Any Program Administrator should continue to attract and track organizational members and individuals, their participation, time, talent, and other contributions, and their feedback, since access to its members are its single most important asset. Perhaps just as important is the process and methodology that the Program Administrator should continue to employ, whereby collaborative efforts and guidance is provided by thousands of subject matter experts, managers, researchers, and other interested parties develop and build upon ideas, and execute projects to satisfactory levels.

- Future programs should include key defined indicators of success. Examples of success must include the objectives of a program; however, they might also include participation levels, advancements in Technology Readiness Levels, product commercialization, percentage of projects that succeed or fail, and the like.

- Value quantification methodologies for research projects should also be determined prior to program initiation if possible. The government contractor may have an existing method, but it should be incumbent on the Program Administrator to determine if a separate method might be beneficial, for itself, as well as for individual projects. By all visible means the current Program has been a success. Yet, expectations for faster uptake of projects and commercialization have been dampened due to lower product prices; therefore it is recommended that future value quantification measures be able to account for variations in factors that might affect it.

- Future programs should continue to allow subcontractors to retain any intellectual property rights that may be developed as part of the research. This will encourage additional participation and improve innovation.

- Cooperation and coordination between a Program Administrator and NETL are keys to a Program's success. Any future program should try to ensure that the contractor's Program Manager is knowledgeable and adept at managing large programs, and has the patience and communication skills necessary to work with a multi-member Program Administrator. Similar to the Section 999 Program, the contractor's Contracts Manager must also have strong communication skills, and the contracts staff must be willing to work with the Program Administrator to effectively develop and manage the programs. The contractor's technical personnel must be willing to learn and provided sufficient time and resources to interact with the Program Administrator and its members, as well as with subcontractors, similar to NETL Project Managers when they were pressed into service.

Projects

RPSEA recommends that the U.S. Department of Energy, as well as NETL, review the lists of prioritized projects that are provided in the Conclusions segment of this report, and consider funding through RPSEA; most of these rated TRL 3 to 5. These lists have been prioritized based on a combination of their success thus far, their potential for commercialization, their importance, and their genuine need for additional cash infusion to avoid losing momentum.

ATTACHMENT 1

Technology Readiness Level Definitions

Basis: API RP17N

TRL Designation		
Conception	TRL 0	**Unproven Idea** (paper concept, no analysis or testing)
Proof-of-Concept	TRL 1	**Proven Concept** (functionality demonstrated by analysis or testing)
	TRL 2	**Validated System Concept** (breadboard tested in "realistic" environment)
Prototype	TRL 3	**Prototype Tested** (prototype developed and tested)
	TRL 4	**Environment Tested** (prototype tested in field realistic environment)
	TRL 5	**System Integration Tested** (prototype integrated with intended system and functionally tested)
Field Qualified	TRL 6	**Technology Deployed** (prototype deployed in field test or actual operation)
	TRL 7	**Proven Technology** (production unit successfully operational for >10% of expected life)

ATTACHMENT 2
Technology Readiness Levels – RPSEA Onshore Projects

Project Number	Project Title	Proposing Entity	Technology Readiness Level (TRL) as of 10/2016
07122-07	Novel Concepts for Unconventional Gas Development in Shales, Tight Sands and Coalbeds	Carter Technologies Co	1
07122-09	Application Of Natural Gas Composition To Modeling Communication Within And Filling Of Large Tight-Gas-Sand Reservoirs, Rocky Mountains	Colorado School of Mines (CSM)	4
07122-12	An Integrated Framework for the Treatment and Management of Produced Water	Colorado School of Mines (CSM)	4
07122-14	Biogeochemical Factors Enhancing Microbially Generated Methane in Coal Beds	Colorado School of Mines (CSM)	1
07122-15	Reservoir Connectivity and Stimulated Gas Flow in Tight Sands	Colorado School of Mines (CSM)	5
07122-16	New Albany shale Gas	Gas Technology Institute	4
07122-17	Geological Foundation for Production of Natural Gas from Diverse Shale Formations	Geological Survey of Alabama	3
07122-22	Petrophysical studies of unconventional gas reservoirs using high-resolution rock imaging	Lawrence Berkeley National Laboratory	4
07122-23	A Self-Teaching Expert System For The Analysis, Design And Prediction Of Gas Production From Shales	Lawrence Berkeley National Laboratory	3
07122-27	Enhancing Appalachian Coalbed Methane Extraction by Microwave- Induced Fractures	Pennsylvania State University	3

07122-29	Gas Condensate Productivity in Tight Gas Sands	Stanford University	3
07122-33	Advanced Hydraulic Fracturing Technology For Unconventional Tight Gas Reservoirs	Texas Engineering Experiment Station (TEES)	3
07122-35	Optimizing Development Strategies To Increase Reserves In Unconventional Gas Reservoirs	Texas Engineering Experiment Station (TEES)	3
07122-36	Novel Fluids for Gas Productivity Enhancement in Tight Formations	The University of Tulsa	1
07122-38	Improvement of Fracturing in Gas Shales	The University of Texas at Austin	5
07122-41	Improved Reservoir Access Through Refracture Treatments In Tight Gas Sands And Gas Shales	The University of Texas at Austin	5
07122-43	Optimization Of Infill Well Locations In Wamsutter Field	The University of Tulsa	1
07122-44	Gas Production Forecasting From Tight Gas Reservoirs: Integrating Natural Fracture Networks and Hydraulic Fractures	University of Utah	4
07122-45	Paleozoic Shale-Gas Resources of the Colorado Plateau and Eastern Great Basin, Utah: Multiple Frontier Exploration Opportunities	Utah Geological Survey	4
07123-01	Low Impact Testing of Oil Field Access Roads: Reducing the Environmental Footprint in Desert Ecosystems	Texas Engineering Experiment Station (TEES)	6
07123-02	Preformed Particle Gels For Mitigating Water Production And Extending The Life Of Mature Oil Wells And Further Improve Particle Gel Technology	The University of Missouri	3
07123-03	Near Miscible CO2 Application to Improve Oil Recovery for Small Producers	The University of Kansas Center for Research	4

07123-04	Enhancing Oil Recovery from Mature Reservoirs Using Radial-jetted Laterals and High-volume Progressive Cavity Pumps	The University of Kansas Center for Research	4
07123-05	Cost-Effective Treatment Of Produced Water Using Co-Produced Energy Sources For Small Producers	New Mexico Institute of Mining and Technology	6
07123-06	Seismic Stimulation to Enhance Oil Recovery	Lawrence Berkeley National Laboratory	1
07123-07	Reducing Impacts of New PIT Rules on Small Producers	New Mexico Institute of Mining and Technology	7
08122-05	Barnett and Appalachian Shale Water Management and Reuse Technologies	Gas Technology Institute	5
08122-15	Novel Gas Isotope Interpretation Tools to Optimize Gas Shale Production	California Institute of Technology	3
08122-35	The Environmentally Friendly Drilling Systems Program	Houston Advanced Research Center (HARC)	7
08122-36	Pretreatment and Water Management for Frac Water Reuse and Salt Production	GE Global Research	5
08122-40	Stratigraphic Controls On Higher-Than-Average Permeability Zones In Tight-Gas Sands, Piceance Basin	Colorado School of Mines (CSM)	3
08122-45	Coupled Flow-Geomechanical-Geophysical-Geochemical (F3G) Analysis of Tight Gas Production	Lawrence Berkeley National Laboratory	3
08122-48	Sustaining Fracture Area and Conductivity of Gas Shale Reservoirs for Enhancing Long-Term Production and Recovery	Texas Engineering Experiment Station (TEES)	4
08122-53	Multiazimuth Seismic Diffraction Imaging for Fracture Characterization in Low-Permeability Gas Formations	The University of Texas at Austin	4

08122-55	Evaluation of Fracture Systems and Stress Fields Within the Marcellus Shale and Utica Shale and Characterization of Associated Water-Disposal Reservoirs: Appalachian Basin	The University of Texas at Austin	4
08123-02	Field Demonstration of Alkaline Surfactant Polymer Floods in Mature Oil Reservoirs Brookshire Dome, Texas	Layline Petroleum 1, LLC	5
08123-07	Mini-Waterflood: A New Cost Effective Approach to Extend the Economic Life of Small, Mature Oil Reservoirs	New Mexico Institute of Mining and Technology	4
08123-10	Electrical Power Generation from Produced Water: Field Demonstration of Ways to Reduce Operating Costs of Small Producers	Gulf Coast Green Energy	7
08123-12	Evaluation and Modeling of Stratigraphic Control on the Distribution of Hydrothermal Dolomite Reservoir away from Major Fault Planes	Western Michigan University	3
08123-16	Development Strategies for Maximizing East Texas Oil Field Production	The University of Texas at Austin	4
08123-19	Commercial Exploitation and the Origin of Residual Oil Zones: Developing a Case History in the Permian Basin of New Mexico and West Texas	The University of Texas of the Permian Basin	6
09122-01	Gas Well Pressure Drop Prediction Under Foam Flow Conditions	The University of Tulsa	5
09122-02	Characterizing Stimulation Domains, for Improved Well Completions in Gas Shales	Higgs-Palmer Technologies	5
09122-04	Marcellus Gas Shale Project	Gas Technology Institute	5
09122-06	Prediction of Fault Reactivation in Hydraulic Fracturing of Horizontal Wells in Shale Gas Reservoirs	West Virginia University Research Corporation	4

09122-07	Cretaceous Mancos Shale Uinta Basin, Utah: Resource Potential and Best Practices for an Emerging Shale Gas Play	Utah Geological Survey	5
09122-11	Simulation of Shale Gas Reservoirs Incorporating Appropriate Pore Geometry and the Correct Physics of Capillarity and Fluid Transport	Board of Regents of the University of Oklahoma	5
09122-12	Integrated Experimental and Modeling Approaches to Studying the Fracture-Matrix Interaction in Gas Recovery from Barnett Shale	The University of Texas at Arlington	4
09122-29	Using Single-molecule Imaging System Combined with Nano-fluidic Chips to Understand Fluid Flow in Tight and Shale Gas Formation	The University of Missouri	3
09122-32	A Geomechanical Model for Gas Shales Based on the Integration of Stress Measurements and Petrophysical Data from the greater Marcellus Gas System	Pennsylvania State University	5
09122-41	Improved Drilling and Fracturing Fluids for Shale Gas Reservoirs	The University of Texas at Austin	3
09123-03	Field Testing and Diagnostics of Radial-Jet Well-Stimulation for Enhanced Oil Recovery from Marginal Reserves	New Mexico Institute of Mining and Technology	7
09123-09	Enhanced Oil Recovery from the Bakken Shale Using Surfactant Imbibition Coupled with Gravity Drainage	University of North Dakota	4
09123-11	Treatment and Beneficial Reuse of Produced Waters Using A Novel Pervaporation-Based Irrigation Technology	University of Wyoming	4
09123-14	Green Oil™ Co2-Enhanced Oil Recovery For America’s Small Oil Producers	Pioneer Astronautics, Inc.	5
09123-18	Characterization of Potential Sites for Near Miscible CO2 Applications to Improve Oil Recovery in Arbuckle Reservoirs	The University of Kansas Center for Research	4

09123-20	Creating Fractures Past Damage More Effectively With Less Environmental Damage	DaniMer Scientific, LLC	3
10122-06	The Technology Integration Program: An Extension of the Environmentally Friendly Drilling Systems	Houston Advanced Research Center (HARC)	6
10122-07	NORM Mitigation and Clean Water Recovery from Marcellus Frac Water	GE Global Research	5
10122-19	Lowering Drilling Cost, Improving Operational Safety and Reducing Environmental Impact	CSI Technologies, LLC	7
10122-20	Development of Non-Contaminating Cryogenic Fracturing Technology for Shale and Tight Gas Reservoirs	Colorado School of Mines (CSM)	3
10122-39	Novel Engineered Osmosis Technology: A Comprehensive Approach to the Treatment and Reuse of Produced Water and Drilling Wastewater	Colorado School of Mines (CSM)	5
10122-42	A Geomechanical Analysis of Gas Shale Fracturing and Its Containment	Texas Engineering Experiment Station (TEES)	4
10122-43	Diagnosis of Multiple Fracture Stimulation in Horizontal Wells by Downhole Temperature Measurement for Unconventional Oil and Gas Wells	Texas Engineering Experiment Station (TEES)	3
10122-47	Predicting Higher-Than-Average Permeability Zones in Tight-Gas Sands, Piceance Basin: An Integrated Structural and Stratigraphic Analysis	Colorado School of Mines (CSM)	3
10123-03	Game Changing Technology of Polymeric-surfactants for Tertiary Oil Recovery in the Illinois Basin	Power Environmental Energy Research Institute (PEER)	3
10123-17	Identifying and Developing Technology for Enabling Small Producers to Pursue the Residual Oil Zone (ROZ) Fairways of the Permian Basin, San Andres	The University of Texas of the Permian Basin	6

11122-07	Conductivity of Complex Fracturing in Unconventional Shale Reservoirs	Texas A&M Engineering Experiment Station (TEES)	4
11122-20	Advanced Hydraulic Fracturing	Gas Technology Institute	5
11122-27	Relationships between Induced Seismicity and Fluid Injection: Development of Strategies to Manage Fluid Disposal in Shale Hydrocarbon Plays	The University of Texas at Austin	4
11122-31	Development of Plasma Technology for Water Management of Frac/Produced Water	Drexel University	3
11122-42	Prevention and Remediation of Sustained Casing Pressure and other Isolation Breaches	CSI Technologies, LLC	4
11122-45	Reducing the Environmental Impact of Gas Shale Development: Advanced Analytical Methods for Air and Stray Gas Emissions and Produced Brine Characterization	GSI Environmental Inc.	5
11122-53	Advancing a Web-based Tool for Unconventional Natural Gas Development with Focus on Flowback and Produced Water Characterization, Treatment and Beneficial Use	Colorado School of Mines (CSM)	4
11122-55	Development of Geographic Information System (GIS) - Based Tool for Optimized Fluid Management in Shale Gas Operations	Colorado State University	6
11122-56	Understanding and Managing Environmental Roadblocks to Shale Gas Development: An Analysis of Shallow Gas, NORMs, and Trace Metals (Texas)	The University of Texas at Austin	5
11122-57	Advanced Treatment of Shale Gas Frac Water to Produce NPDES Quality Water	Southern Research Institute	4

11122-60	Cost-Effective Treatment of Flowback and Produced Waters via an Integrated Precipitative Supercritical (IPSC) Process	The University of Ohio	3
11122-63	Petrophysics and Tight Rock Characterization for the Application of Improved Stimulation and Production Technology in Shale	Oklahoma State University	3
11122-71	Water Handling and Enhanced Productivity from Gas Shales	University of Southern California	3
11122-73	Development of Subsurface Brine Disposal Framework in the Northern Appalachian Basin	Battelle Memorial Institute	6
11123-03	Cost-Effective Treatment of Produced Water Using Co-Produced Energy Sources Phase II: Field Scale Demonstration and Commercialization	New Mexico Institute of Mining and Technology	7
11123-08	Basin-Scale Produced Water Management Tools and Options – GIS based models and statistical analysis of shale gas/tight sand reservoirs and their produced water streams, Uinta Basin, Utah	Utah Geological Survey	5
11123-09	Maintenance for Paraffin Management in Production Tubing Using Non-Invasive Ultrasonic Technology	Battelle Memorial Institute, Pacific Northwest Division	4
11123-14	Study and Pilot Test of Preformed Particle Gel Conformance Control Combined With Surfactant	The University of Missouri	4
11123-15	Hybrid Rotor Compression for Multiphase and Liquids-Rich Wellhead Production Applications	OsComp Systems, Inc.	5
11123-23	Field Demo of Eco-Friendly Creation of Propped Hydraulic Fractures	DaniMer Scientific, LLC	2
11123-24	Reduction of Uncertainty in Surfactant-Flooding Pilot Design using Multiple Single Well Tests, Fingerprinting and Modeling	The Board of Regents of the University of Oklahoma	4

11123-28	Field Demonstration of Chemical Flooding of the Trembley Oilfield, Reno County, Kansas	The University of Kansas Center for Research	5
11123-32	Water Management in Mature Oil Fields using Advanced Particle Gels	The University of Texas at Austin	3
12122-15	Measurement of Hydrocarbon and Greenhouse Gas Emissions from Uncharacterized Area Sources	Utah State University	5
12122-52	Connectivity Between Fractures and Pores in Hydrocarbon-rich Mudrocks	The University of Texas at Austin	4
12122-91	4D Integrated Study Using Geology, Geophysics, Reservoir Modeling & Rock Mechanics to Develop Assessment Models for Potential Induced Seismicity Risk	The Board of Regents of the University of Oklahoma	4
12122-95	Reconciling Top-down and Bottom-up Greenhouse Gas and Air Pollutant Emission Estimates from Unconventional Gas Development in the Denver-Julesburg Basin	Colorado School of Mines	4
12123-16	A Portable, Two Stage, Antifouling Hollow Fiber Membrane Nanofiltration Process for the Cost-Effective Treatment of Produced Water	New Mexico Institute of Mining and Technology	5
12123-18	Water Treatment System for Effective Acid Mine Drainage Water Use in Hydraulic Fracturing	PPG Industries (DBA Monroeville Chemicals Center)	2
12123-42	Reducing the Impacts of Deterioration of Cement Integrity on Small Producers	Rice University	5

ATTACHMENT 3

Technology Readiness Levels – RPSEA Ultra-Deepwater Projects

Project Number	Project Title	Proposing Entity	Technology Readiness Level (TRL) as of 10/2016
07121-1201	Wax Control in the Presence of Hydrates	University of Utah	0
07121-1301	Improvements to Deepwater Subsea Measurements	Letton-Hall Group	(see 10121-4304-01)
07121-1302	Ultra-High Conductivity Umbilicals	NanoRidge Materials, Inc.	(see 10121-4302-01)
07121-1401	Composite Riser for Ultra Deepwater High Pressure Wells	Lincoln Composites Inc.	3
07121-1402a	Ultra Deepwater Dry Tree System for Drilling and Production	Floatec	1
07121-1402b	Ultra Deepwater Dry Tree System for Drilling and Production	Houston Offshore Engineering	(see 11121-5404-03)
07121-1403	Fatigue Performance of High Strength Riser Materials in Sour Environments	Southwest Research Institute	1
07121-1603a	Flow Phenomena in Jumpers-Relation to Hydrate Plugging Risk	University of Tulsa	(see 09121-3300-02)
07121-1603b	Hydrate Characterization & Dissociation Strategies	University of Tulsa	3
07121-1603c	Design investigation of extreme high pressure, high temperature, (XHPHT), subsurface safety valves (SSSV)	Williams Marsh Rice University	1

07121-1603d	Robotic MFL Sensor for Monitoring and Inspection of Deepwater Risers	Williams Marsh Rice University	1
07121-1701	Development of a Research Report and Characterization Database of Deepwater and Ultra-Deepwater Assets in the Gulf of Mexico, including Technical Focus Direction, Incentives, Needs Assessment Analysis and Concepts Identification for Improved Recovery Technology [report; IOR/ EOR technologies in UDW]	Knowledge Reservoir, LLC	7, 1-3
07121-1801	Effect of Climate Change on Hurricane Activity	National Center for Atmospheric Research	(see 10121-4802-01)
07121-1901	Subsea Systems Engineering Integration	GE Global Research Center (GE-GRC)	3
07121-1902	Deep Sea Hybrid Power System	Houston Advanced Research Center	1
07121-2001	Geophysical Modeling for Studying Acquisition and Processing Methods in the Deepwater Gulf of Mexico – Phase 1	SEAM Corporation	7
08121-1502-01	Coil Tubing Drilling and Intervention System Using Cost Effective Vessel	Nautilus International, LLC	(see 10121-4505-01)
08121-2101-02	New Safety Barrier Testing Methods	Southwest Research Institute	1
08121-2201-02	Heavy Viscous Oil PVT	Schlumberger	7
08121-2301-03	Deepwater Open Water Riser Intervention System (RIS)	DTC International, Inc.	2
08121-2501-02	Early Reservoir Appraisal Utilizing a Well Testing System	Nautilus International, LLC	2

08121-2502-01	Modeling and Simulation of Managed Pressure Drilling for Improved Design, Risk Assessment, Training and Operations	Stratamagnetic Software, LLC	6
08121-2701-03	Ultra-Deepwater Resources to Reserves Development and Acceleration Through Appraisal	The University of Texas at Austin	2
08121-2801-02	GOMEX 3-D Operational Ocean Forecast System Pilot Project	Portland State University	7
08121-2901-01	Ultra-Reliable Deepwater Electrical Power Distribution System and Power Components	GE Global Research	(see 12121-6302-01)
08121-2902-02	Technologies of the Future for Pipeline Monitoring and Inspection [sensor attached to pipeline pig; free floating sensor]	University of Tulsa	5, 3
08121-2902-03	Wireless Subsea Communications	GE Global Research	3
08121-2902-04	Replacing Chemical Biocides with Targeted Bacteriophages in Deepwater Pipelines and Reservoirs	Phage Biocontrol, LLC	5
08121-2902-06	Enumerating Bacteria in Deepwater Pipelines in Real-Time at a Negligible Marginal Cost Per Analysis: A Proof of Concept Study	Livermore Instruments Inc.	7
08121-2902-07	Fiber Containing Sweep Fluids for Ultra Deepwater Drilling Applications	University of Oklahoma	1
09121-3100-01	Ultra Deep Water Seabed Discharge of Produced Water and/or Solids	Fluor Offshore Solutions	(see 12121-6301-03)
09121-3300-02	Displacement & Mixing in Subsea Jumpers – Experimental Data and CFD Simulations (07121-1603a follow-on) [predictive software; methanol override prediction]	University of Tulsa	7, 2
09121-3300-05	Autonomous Inspection Of Subsea Facilities	Lockheed Martin	7

09121-3300-06	High Resolution 3D Laser Imaging for Inspection, Maintenance, Repair, and Operations	3D at Depth	7
09121-3300-08	Sensors and Processing for Pipe, Riser, Structure, and Equipment Inspection to Provide Detailed Measurements, Corrosion Detection, Leak Detection, and/or Detection of Heat Plumes from Degraded Pipeline Insulation [spool piece metrology; leak detection; heat detection]	Blueview Technologies	7, 5, 4
09121-3300-10	Development of Carbon Nanotube Composite Cables for Ultra-Deepwater Oil and Gas Fields	Los Alamos National Lab	0
09121-3500-01	Intelligent Production System for Ultra Deepwater with Short Hop Wireless Power and Wireless Data Transfer for Lateral Production Control and Optimization	Tubel, LLC	6
09121-3500-02	Fatigue Testing of Shrink-fit Riser Connection for High Pressure Ultra Deepwater Risers	Subsea Riser Products	2
09121-3500-07	Deepwater Subsea Test Tree and Intervention Riser System	DTC International, Inc.	6
09121-3500-10	Gyroscope Guidance Sensor for Ultra-Deepwater Applications	Laserlith	3
09121-3700-02	A 1,000 Level Drill Pipe Deployed Fiber Optic 3C Receiver Array for Deep Boreholes	Paulsson, Inc.	6
10121-4202-01	Hydrate Modeling & Flow Loop Experiments for Water Continuous & Dispersed Systems [hydrate model; internal pipeline coating; external fiber optic acoustic sensor]	Colorado School of Mines	3, 3, 3
10121-4204-01	Corrosion and Scale at Extreme Temperature and Pressure [model, detection equipment]	Tomson Technologies, LLC (formerly Brine Chemistry Solutions, LLC)	3, 6
10121-4302-01	Ultra-High Conductivity Umbilicals: Polymer Nanotube Umbilicals (07121-1302 follow-on)	NanoRidge Materials, Inc.	3

10121-4304-01	More Improvements to Deepwater Subsea Measurement [electrical capacitance tomography-composite pipe flow measurement system; subsea fluid sampling system; ROV-conveyed measurement system, downhole HP/HT flow measurement sensor; virtual flow model comparison evaluation; meter fouling diagnosis evaluation]	Letton-Hall Group, LLC	3, 3, 3, 4, 7, 6
10121-4306-01	All Electric Subsea Autonomous High Integrity Pressure Protection System (HIPPS) Architecture	GE Global Research	3
10121-4401-02	Ultra-Deepwater Riser Concepts for High Motion Vessels	Stress Engineering	7
10121-4402-01	Qualification of Flexible Fiber-Reinforced Pipe for 10,000-Foot Water Depths	GE Global Research	3
10121-4402-02	Qualification of Flexible Fiber-Reinforced Pipe for 10,000-Foot Water Depths	DeepFlex	3
10121-4404-03	Low Cost Flexible Production System for Remote Ultra-Deepwater Gulf of Mexico Field Development	Doris	4
10121-4405-02	Ultra-deepwater Dry Tree System for Drilling and Production in the Gulf of Mexico	Det Norse Veritas	(see 11121-5404-03)
10121-4406-01	Effects of Fiber Rope - Seabed Contact on Subsequent Rope Integrity	Stress Engineering	7
10121-4407-01	Deepwater Direct Offloading Systems	Remora Technology	0
10121-4501-01	Smart Cementing Materials and Drilling Muds for Real Time Monitoring of Deepwater Wellbore Enhancement	University of Houston	3

10121-4502-01	Deepwater Reverse-Circulation Primary Cementing	CSI Technologies, LLC	2
10121-4504-01	Intelligent Casing-Intelligent Formation Telemetry System	University of Oklahoma	2
10121-4505-01	Coil Tubing Drilling and Intervention System Using Cost Effective Vessel (08121-1502-01 follow-on) [riser system; integrated system with small vessel]	Nautilus International LLC	6, 2
10121-4801-01	Synthetic Hurricane Risk Model for the Gulf of Mexico	Applied Research Associates	5
10121-4802-01	Effect of Climate Variability and Change in Hurricane Activity in the North Atlantic (07121-1801 follow-on)	University Corporation for Atmospheric Research	7
10121-4903-02	Autonomous Underwater Inspection Using a 3D Laser	Lockheed Martin	7
11121-5101-01	Human Factors Evaluation of Deepwater Drilling, including Literature Review	Pacific Science & Engineering Group	5
11121-5302-01	Construction and Testing of Deepwater Permanent Subsea Pressure Compensated Chemical Reservoir [subsea chemical storage & injection system; shuttle system]	Safe Marine Transfer, Inc.	3, 3
11121-5402-01	Riser Lifecycle Monitoring System for Integrity Management [software and business process system integration; RLMS hardware]	GE Global Research	2, 4
11121-5404-03	VIM Study for Deep Draft Column Stabilized Floaters (10121-4405-02 follow-on) [deep-draft column floating drilling & production vessel; best practices report]	Houston Offshore Engineering	3, 6
11121-5503-01	Instrumented BOP Ram: Drill Collar/ Tool Joint Locator	GE Global Research	3

11121-5801-01	Hi-Res Environmental Data for Enhanced UDW Operations Safety [bottom current measurement & modeling system; Remote Ocean Current Imaging System development]	Fugro Global Environmental & Ocean Sciences, Inc.	7, 7
12121-6002-02	Pressure Prediction and Hazard Avoidance through Improved Seismic Imaging [pressure prediction model; time lapse pressure prediction model]	SEAM Corporation	2, 2
12121-6301-03	Subsea Produced Water Sensor Development [Digitrol sensor, JM Canty Sensor, ProAnalysis sensor, CLFM sensor]	Clearview Subsea, LLC	6, 3, 3, 3
12121-6302-01	Subsea DC Connectors for Environmentally Safe and Reliable Powering of UDW Subsea Processing (08121-2901-01 follow-on)	GE Global Research	3
12121-6402-01	Methodology and Algorithm Development for the Evaluation of Ultra-Deepwater or Arctic Floating Platform Performance under Hazardous Sea Conditions	Offshore Dynamics, Inc.	1
12121-6403-01	Development of Advanced CFD Tools for the Enhanced Prediction of Explosion Pressure Development in Early Project Phase and Deflagration to Detonation Transition Risk on US GOM Drilling and Production Facilities	GexCon US	4
12121-6502-01	Reliability of Annular Pressure Buildup (APB) Mitigation Technologies	Blade Energy Partners, Ltd.	6
12121-6503-01	Development of Best Practices and Risk Mitigation Measures for Deepwater Cementing in SBM and OBM	CSI Technologies, LLC	6

VIII. APPENDICES

A. APPENDIX A – MEMBER LIST

FORMER AND CURRENT MEMBERS OF RPSEA Alphabetical Order – Total 302		
2-H Offshore Inc.	BMT Scientific Marine Services Inc.	DCP Midstream, LP
3D at Depth, LLC	Boeing Company	DeepFlex Inc.
Acergy US Inc.	BP America, Inc.	DeepStar
Acute Technological Services, Inc.	BreitBurn Energy Company	Deepwater Structures Incorporated
Advanced Resources International, Inc.	Bretagne LLC	Deepwater XLP Technology, LLC
Advantek International Corp.	Brownstein Hyatt Farber Schreck, LLP	Delco Oheb Energy, LLC
AeroVironment, Inc.	Cameron	Devon Energy Corporation
AGR Subsea, Inc.	Campbell Applied Physics	DNV GL Group
Alcoa Oil and Gas	Capstone Turbine Corporation	DOF Subsea USA
Allen Energy Consultants LLC	CARBO Ceramics, Inc.	DOFERO Consultancy, LLC
Altira Group LLC	C-FER Technologies	Doris, Inc.
American Bureau of Shipping	Chesapeake Energy Corporation	Drilling & Production Company
American Gas Association	Chevron Corporation	Drilling Technological Innovations LLC
American Pioneer Ventures Ltd.	City of Sugar Land	Duke University
AMOG Consulting, Inc.	Clariant Corporation	Dynamic Tubulars Systems, Inc.
Anadarko Petroleum Corporation	Clearview Subsea LLC	EnCana Oil & Gas (USA) Inc.
Apache Corporation	Colorado Oil & Gas Association	EnerCrest, Inc.
Apex Spectral Technology, Inc.	Colorado School of Mines	Energy Corporation of America
APIteq Americas LLC	Colorado State University	Energy Valley, Inc.
APS Technology, Inc.	Columbia University	Energy Ventures US, Inc.
At Balance Americas L.L.C.	Committee for Sustaining Oklahoma's Energy Resources	Entropy Risk Management Technologies, Inc.
Athens Group Holdings	Concurrent Technologies Corporation	Ergon Exploration, Inc.
Baker Hughes, Inc.	ConocoPhillips Company	ExxonMobil
Barnett Shale Water Conservation and Management Committee	Conquest Drilling Fluids, Inc.	Fairfield Industries Inc.
Bastion Technologies Inc.	Conservation Committee of California Oil & Gas Producers	Far East Energy Corporation
Battelle Memorial Institute	Consortium for Ocean Leadership	Florida International University
BG Group PLC	Consultate L.L.C.	Fluor Corporation
BHP Billiton Petroleum	Consumer Energy Alliance	Foro Energy, Inc.
Big Cat Energy Corp.	Correlations Company	Fugro Global Environmental and Ocean Services, Inc
Bill Barrett Corporation	Crane Corporation	Future Pipe Industries, Inc
BJ Services Company	CSI Technologies, LLC	Gas Technology Institute
Blade Energy Partners, Ltd.	Cubility	GE Oil & Gas

General Marine Contractors, LLC	Interstate Oil and Gas Compact Commission	Natural Carbon, LLC
Genesis	iRobot Corporation	Nautilus International LLC
Geotrace Technologies	Jackson State University	Nautronix, Inc.
GexCon US	Jacobs Engineering Group Inc.	Neptec USA
Granherne, Inc.	Jet Propulsion Laboratory/California Institute of Technology	New England Research, Inc.
Greater Fort Bend Economic Development Council	Johnson Performance	New Mexico Institute of Mining and Technology
Greensburg Oil, LLC	Julander Energy Company	New Mexico Oil & Gas Association
GSI Environmental, Inc.	K. Stewart Energy Group, LLC	New Mexico State University
Gunnison Energy Corporation	KC Harvey Environmental, LLC	Nexen Energy
Halbouty Integrated Technologies	KeyLogic Systems	NGAS Resources, Inc.
Halliburton	Keystone Public Affairs, LLC	NGO Development Corporation
Hamilton Group	Knowledge Reservoir, LLC	NiCo Resources, LLC
Hart Energy Publishing, LP	Kongsberg Oil & Gas Technologies, Inc.	Noble Corporation
Harvard Petroleum Company, LLC	Kvaerner	Noble Energy, Inc.
Hess Corporation	Laserlith Corporation	Northwestern University
HIMA Americas, Inc.	Lawrence Berkeley National Laboratory	Novatek International Inc.
Hoerbiger Corporation of America Inc.	Lawrence Livermore National Laboratory	Oak Ridge National Laboratory
Hogan Lovells US LLP	Leede Operating Company, LLC	Ocean Power Technologies, Inc.
Houston Advanced Research Center	Letton-Hall Group	Oceaneering International, Inc.
Houston Offshore Engineering, LLC	Lockheed Martin Corporation	Octave Reservoir Technologies
Houston Technology Center	Los Alamos National Laboratory	Oilfield Technology Needs Assessment
HW Process Technologies, Inc.	Louisiana State University	Oklahoma Independent Petroleum Association
HydroConfidence Inc.	M&B Engineering, Inc.	Oklahoma State University
HydroFlame Technologies, LLC	M&H Energy Services	OneSubSea
Houston Advanced Research Center	MAP Royalty, Inc.	OptaSense, Inc
Houston Offshore Engineering, LLC	Marathon Oil Corporation	OsComp Systems, Inc.
Houston Technology Center	Massachusetts Institute of Technology	OTM Consulting Inc.
HW Process Technologies, Inc.	Maxwell Resources Corporation	Oxane Materials, Inc.
HydroConfidence Inc.	Merrick Systems	Panther Energy Company, LLC
HydroFlame Technologies, LLC	MesoCoat, Inc.	Paulsson, Inc.
Idaho National Laboratory	Mississippi State University	Peritus International Inc.
Independent Petroleum Association of America	Modumetal, Inc	Petris Technology
Independent Petroleum Association of New Mexico	Nalco Company	Petrobras America, Inc.
InTechSys, LLC	Nance Resources, Inc.	Petroleum Technology Transfer Council
Integrated Ocean Drilling Program	NanoRidge Materials	PetrolValves LLC
Intelligent Agent Corporation	National Oilwell Varco, Inc.	Pioneer Natural Resources Company

PowerIn, LLC	Spatial Energy	Total E-U-E
Praxair, Inc.	SR2020 Inc.	Tubel Energy LLC
Prolific - Technology Consulting Group, LLC	SRI Consulting Business Intelligence	U.S. Geothermal Inc.
Propel Inc.	SRI International	University of Alabama
Providence Technologies, Inc.	Stanford University	University of Alaska Fairbanks
QO Inc	Statoil	University of Colorado at Boulder
Quanelle, LLC	Strata Production Company	University of Houston
Quest Integrated, Inc.	Stress Engineering Services	University of Michigan
Quest Integrity Group, LLC	Subsea Engineering Technologies, LLC	University of South Carolina
Quest Knight Enterprises	Subsea Riser Products	University of South Florida
Quest Offshore Resources	Talon International Inc	University of Southern California
Radoil, Inc.	Technip USA	University of Utah
Rice University	Technology International, Inc.	University of Wyoming
Robert L. Bayless, Producer LLC	Tejas Research & Engineering, LP	Utah Geological Survey
Rock Solid Images	Teledyne Blueview, Inc.	Ute Energy LLC
Roxar, Inc.	Teledyne CDL Inc	Ute Indian Tribe
RPS Group Plc	Tenaris	VersaMarine Engineering LLC
RTI Energy Systems	Texas A&M University	Vetco Gray, Inc.
RTI International	Texas Energy Center	Vista Resources, Inc.
Sandia National Laboratories	Texas Independent Producers & Royalty Owners Association	Water Standard
Schlumberger Limited	Texas Tech University	Watt Mineral Holdings, LLC
Science Applications International Corporation	The Discovery Group, Inc.	Weatherford International Ltd.
Sembmarine SSP Inc.	The Dow Chemical Company	WellDog, Inc.
SET Laboratories, Inc.	The Fleischaker Companies	West Virginia University
Shell International Exploration & Production	The Ohio State University	Westcott & Washington
Siemens Corporation	The Pennsylvania State University	Western Energy Alliance
Simmons & Company International	The Research Valley Partnership, Inc.	Western Standard Energy Corporation
SiteLark LLC	The University of Kansas	WFS Subsea
Society of Exploration Geophysicists	The University of Oklahoma	Williams Production RMT Company
Society of Petroleum Engineers Gulf Coast Section	The University of Texas at Austin	Woods Hole Oceanographic Institution
Southern Methodist University	The University of Tulsa	WorleyParsons Group
Southern Research Institute	Thunder Exploration, Inc.	Wright State University
Southgate Resources	Titanium Engineers, Inc.	Xodus Group Inc.
Southwest Research Institute	Tomson Technologies	Ziebel
Southwestern Energy Company	Total E&P Research & Technology USA, Inc.	

B. APPENDIX B – SUMMARY LIST OF SUBCONTRACTED PROJECTS

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
07121-1201	University of Utah	Wax Control in the Presence of Hydrates	9/2/2008	8/31/2011
07121-1301	Letton-Hall Group, LLC	Improvements to Deepwater subsea measurements	10/27/2008	5/15/2012
07121-1302	NanoRidge Materials, Inc.	Ultra-High Conductivity Umbilical's	12/5/2008	5/30/2010
07121-1401	Lincoln Composites Inc.	Composite Riser for Ultra Deepwater High Pressure Wells	12/5/2008	12/30/2013
07121-1402a	FloaTEC, LLC	Ultra Deepwater Dry Tree System for Drilling and Production	12/8/2008	3/27/2009
07121-1402b	Houston Offshore Engineering	Ultra Deepwater Dry Tree System for Drilling and Production	12/5/2008	6/30/2010
07121-1403	Southwest Research Institute	Fatigue Performance of High Strength Riser Materials in Sour Environments	12/15/2008	3/16/2012
07121-1603a	The University of Tulsa	Flow Phenomena in Jumpers-Relation to Hydrate Plugging Risk	9/22/2008	3/21/2010
07121-1603b	The University of Tulsa	Hydrate Characterization & Dissociation Strategies	9/22/2008	9/21/2010

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
07121-1603c	William Marsh Rice University	Design investigation of extreme high pressure, high temperature, (XHPHT), subsurface safety valves (SSSV)	10/16/2008	10/15/2010
07121-1603d	William Marsh Rice University	Robotic MFL Sensor for Monitoring and Inspection of Deepwater Risers	10/16/2008	6/1/2012
07121-1701	Knowledge Reservoir, LLC	Development of a Research Report and Characterization Database of Deepwater and Ultra-Deepwater Assets in the Gulf of Mexico, including Technical Focus Direction, Incentives, Needs Assessment Analysis and Concepts Identification for Improved Recovery Tech	2/3/2009	12/15/2010
07121-1801	National Center for Atmospheric Research	Effect of Global Warming on Hurricane Activity	2/23/2009	4/1/2011
07121-1901	GE Global Research	Subsea Systems Engineering Integration	12/3/2008	7/31/2011
07121-1902	Houston Advanced Research Center (HARC)	Deep Sea Hybrid Power System	10/31/2008	10/31/2010

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
07121-2001	SEAM Corporation	Geophysical Modeling Methods	6/15/2009	6/30/2013
07122-07	Carter Technologies Co	Novel Concepts for Unconventional Gas Development in Shales, Tight Sands and Coalbeds	7/24/2008	2/19/2009
07122-09	Colorado School of Mines (CSM)	Application Of Natural Gas Composition To Modeling Communication Within And Filling Of Large Tight-Gas-Sand Reservoirs, Rocky Mountains	8/25/2008	12/31/2012
07122-12	Colorado School of Mines (CSM)	An Integrated Framework for the Treatment and Management of Produced Water	9/19/2008	6/30/2011
07122-14	Colorado School of Mines (CSM)	Biogeochemical Factors Enhancing Microbial Generated Methane in Coal Beds	9/12/2008	6/12/2012
07122-15	Colorado School of Mines (CSM)	Reservoir Connectivity and Stimulated Gas Flow in Tight Sands	9/19/2008	7/1/2012
07122-16	Gas Technology Institute	New Albany shale Gas	7/23/2008	11/30/2010
07122-17	Geological Survey of Alabama	Geological Foundation for Production of Natural Gas	7/31/2008	8/18/2011

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
		from Diverse Shale Formations		
07122-22	Lawrence Berkeley National Laboratory	Petrophysical studies of unconventional gas reservoirs using high-resolution rock imaging	12/3/2008	11/30/2012
07122-23	Lawrence Berkeley National Laboratory	A Self-Teaching Expert System For The Analysis, Design And Prediction Of Gas Production From Shales	12/3/2008	11/30/2011
07122-27	Pennsylvania State University	Enhancing Appalachian Coalbed Methane Extraction by Microwave-Induced Fractures	11/21/2008	5/31/2010
07122-29	Stanford University	Gas Condensate Productivity in Tight Gas Sands	12/8/2008	12/7/2011
07122-33	Texas Engineering Experiment Station (TEES)	Advanced Hydraulic Fracturing Technology For Unconventional Tight Gas Reservoirs	9/3/2008	9/2/2012
07122-35	Texas Engineering Experiment Station (TEES)	Optimizing Development Strategies To Increase Reserves In Unconventional Gas Reservoirs	8/26/2008	1/31/2012

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
07122-36	The University of Tulsa	Novel Fluids for Gas Productivity Enhancement in Tight Formations	9/2/2008	12/31/2011
07122-38	The University of Texas at Austin	Improvement of Fracturing in Gas Shales	4/29/2009	8/31/2012
07122-41	The University of Texas at Austin	Improved Reservoir Access Through Refracture Treatments In Tight Gas Sands And Gas Shales	8/27/2008	6/30/2013
07122-43	The University of Tulsa	Optimization Of Infill Well Locations In Wamsutter Field	9/2/2008	9/15/2011
07122-44	University of Utah	Gas Production Forecasting From Tight Gas Reservoirs: Integrating Natural Fracture Networks and Hydraulic Fractures	9/2/2008	12/31/2012
07122-45	Utah Geological Survey	Paleozoic Shale-Gas Resources of the Colorado Plateau and Eastern Great Basin, Utah: Multiple Frontier Exploration Opportunities	8/6/2008	5/1/2012
07123-01	Texas Engineering Experiment Station (TEES)	Low Impact Testing of Oil Field Access Roads: Reducing the Environmental Footprint in Desert Ecosystems	9/3/2008	12/15/2013

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
07123-02	The University of Missouri	Preformed Particle Gels For Mitigating Water Production And Extending The Life Of Mature Oil Wells And Further Improve Particle Gel Technology	7/31/2008	3/31/2011
07123-03	The University of Kansas Center for Research	Near Miscible CO2 Application to Improve Oil Recovery for Small Producers	5/21/2008	10/31/2010
07123-04	The University of Kansas Center for Research	Enhancing Oil Recovery from Mature Reservoirs Using Radial-jetted Laterals and High-volume Progressive Cavity Pumps	8/25/2008	7/31/2012
07123-05	New Mexico Institute of Mining and Technology	Cost-Effective Treatment Of Produced Water Using Co-Produced Energy Sources For Small Producers	8/6/2008	1/5/2012
07123-06	Lawrence Berkeley National Laboratory	Seismic Stimulation to Enhance Oil Recovery	9/8/2008	12/31/2014
07123-07	New Mexico Institute of Mining and Technology	Reducing Impacts of New PIT Rules on Small Producers	8/6/2008	8/5/2012

RPSEA Research Awards (with Period of Performance)				
Proposal Number	**Proposing Entity**	**Proposal Title**	**Period of Performance**	
			Start Date	**End Date**
08121-1502-01	Nautilus International, LLC	Coil Tubing Drilling and Intervention System Using Cost Effective Vessel	10/1/2009	4/30/2011
08121-2101-02	Southwest Research Institute	New Safety Barrier Testing Methods	1/19/2010	4/19/2012
08121-2201-02	Schlumberger	Heavy Viscous Oil PVT	7/27/2011	11/26/2014
08121-2301-03	DTC International, Inc.	Deepwater Riserless Intervention System (RIS)	1/6/2010	7/31/2014
08121-2501-02	Nautilus International, LLC	Early Reservoir Appraisal Utilizing a Well Testing System	10/20/2009	3/31/2011
08121-2502-01	Stratamagnetic Software, LLC	Modeling and Simulation of Managed Pressure Drilling for Improved Design, Risk Assessment, Training and Operations	10/19/2009	4/18/2011
08121-2701-03	The University of Texas at Austin	Ultra-Deepwater Resources To Reserves Development And Acceleration Through Appraisal	1/28/2010	5/31/2014
08121-2801-02	Portland State University	GOMEX 3-D Operational Ocean Forecast System Pilot Project	3/11/2010	7/31/2014
08121-2901-01	GE Global Research	Ultra-Reliable Deepwater Electrical Power	11/24/2009	11/23/2013

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
		Distribution System and Power Components		
08121-2902-02	The University of Tulsa	Technologies of the Future for Pipeline Monitoring and Inspection	12/2/2009	12/30/2011
08121-2902-03	GE Global Research	Wireless Subsea Communications	1/22/2010	12/30/2011
08121-2902-04	Phage Biocontrol, LLC	Replacing Chemical Biocides with Targeted Bacteriophages in Deepwater Pipelines and Reservoirs	1/21/2010	2/20/2012
08121-2902-06	Livermore Instruments Inc.	Enumerating Bacteria in Deepwater Pipelines in Real-Time at a Negligible Marginal Cost Per Analysis: A Proof of Concept Study	1/25/2010	3/31/2013
08121-2902-07	The Board of Regents of the University of Oklahoma	Fiber Containing Sweep Fluids for Ultra Deepwater Drilling Applications	1/5/2010	1/4/2012
08122-05	Gas Technology Institute	Barnett and Appalachian Shale Water Management and Reuse Technologies	8/11/2009	3/31/2012
08122-15	California Institute of Technology	Novel Gas Isotope Interpretation Tools to Optimize Gas Shale Production	8/28/2009	2/15/2013

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
08122-35	Houston Advanced Research Center (HARC)	The Environmentally Friendly Drilling Systems Program	7/24/2009	11/24/2012
08122-36	GE Global Research	Pretreatment and Water Management for Frac Water Reuse and Salt Production	8/17/2009	9/16/2011
08122-40	Colorado School of Mines (CSM)	Stratigraphic Controls On Higher-Than-Average Permeability Zones In Tight-Gas Sands, Piceance Basin	7/22/2009	6/1/2012
08122-45	Lawrence Berkeley National Laboratory	Coupled Flow-Geomechanical-Geophysical-Geochemical (F3G) Analysis of Tight Gas Production	4/27/2010	3/31/2014
08122-48	Texas Engineering Experiment Station (TEES)	Sustaining Fracture Area and Conductivity of Gas Shale Reservoirs for Enhancing Long-Term Production and Recovery	9/14/2009	5/16/2013
08122-53	The University of Texas at Austin	Multiazimuth Seismic Diffraction Imaging for Fracture Characterization in Low-Permeability Gas Formations	10/22/2009	11/30/2013

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
08122-55	The University of Texas at Austin	Evaluation of Fracture Systems and Stress Fields Within the Marcellus Shale and Utica Shale and Characterization of Associated Water-Disposal Reservoirs: Appalachian Basin	9/29/2009	1/31/2013
08123-02	Layline Petroleum 1, LLC	Field Demonstration of Alkaline Surfactant Polymer Floods in Mature Oil Reservoirs Brookshire Dome, Texas	12/1/2009	11/1/2012
08123-07	New Mexico Institute of Mining and Technology	Mini-Waterflood: A New Cost Effective Approach to Extend the Economic Life of Small, Mature Oil Reservoirs	8/5/2009	8/4/2011
08123-10	Gulf Coast Green Energy	Electrical Power Generation from Produced Water: Field Demonstration of Ways to Reduce Operating Costs of Small Producers	10/30/2009	4/30/2012
08123-12	Western Michigan University	Evaluation and Modeling of Stratigraphic Control on the Distribution of Hydrothermal Dolomite Reservoir away from Major Fault Planes	10/14/2009	1/31/2013

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
08123-16	The University of Texas at Austin	Development Strategies for Maximizing East Texas Oil Field Production	10/26/2009	7/31/2014
08123-19	The University of Texas of the Permian Basin	Commercial Exploitation and the Origin of Residual Oil Zones: Developing a Case History in the Permian Basin of New Mexico and West Texas	7/8/2009	6/30/2012
09121-3100-01	Fluor Enterprises, Inc.	UDW Seabed Discharge of Produced Water and/or Solids	12/3/2010	6/1/2012
09121-3300-02	The University of Tulsa	Displacement & Mixing in Subsea Jumpers Experimental Data and CFD Simulations	12/14/2010	12/13/2012
09121-3300-05	Lockheed Martin Corporation	Autonomous Inspection of Subsea Facilities	9/10/2010	4/30/2012
09121-3300-06	3D at Depth, LLC	High Resolution 3D Laser Imaging for Inspection, Maintenance, Repair, and Operations	1/19/2011	12/12/2014
09121-3300-08	Blueview Technologies Inc.	Sensors and Processing for Pipe, Riser, Structure, and Equipment Inspection to Provide Detailed Measurements, Corrosion Detection, Leak Detection, and/or Detection of Heat	12/14/2010	11/9/2015

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
		Plumes from Degraded Pipeline Insulation		
09121-3300-10	Los Alamos National Laboratory	Development of Carbon Nanotube Composite cables for Ultra Deepwater Oil and Gas Fields	4/25/2011	5/31/2014
09121-3500-01	Tubel LLC	Intelligent Production System for Ultra Deepwater with Short Hop Wireless Power and Wireless Data Transfer for Lateral Production Control and Optimization	1/28/2011	3/28/2013
09121-3500-02	Subsea Riser Products	Fatigue Testing Of Shrink-Fit Riser Connection For High Pressure Ultra Deepwater Risers	4/3/2011	9/30/2012
09121-3500-07	DTC International, Inc.	Deepwater Subsea Test Tree and Intervention Riser System	1/24/2011	7/31/2014
09121-3500-10	Laserlith Corporation	Gyroscope Guidance Sensor for Ultra-Deepwater Applications	1/24/2011	9/24/2013
09121-3700-02	Paulsson, Inc.	A 1,000 level Drill Pipe Deployed Fiber Optic 3C	2/16/2011	2/14/2014

RPSEA Research Awards (with Period of Performance)				
Proposal Number	**Proposing Entity**	**Proposal Title**	**Period of Performance**	
			Start Date	**End Date**
		Receiver Array for Deep Boreholes		
09122-01	The University of Tulsa	Gas Well Pressure Drop Prediction Under Foam Flow Conditions	12/2/2010	12/1/2014
09122-02	Higgs-Palmer Technologies	Characterizing Stimulation Domains, for Improved Well Completions in Gas Shales	3/17/2011	12/31/2013
09122-04	Gas Technology Institute	Marcellus Gas Shale Project	11/10/2010	6/10/2013
09122-06	West Virginia University Research Corporation	Prediction of Fault Reactivation in Hydraulic Fracturing of Horizontal Wells in Shale Gas Reservoirs	1/19/2011	8/31/2015
09122-07	Utah Geological Survey	Cretaceous Mancos Shale Uinta Basin, Utah: Resource Potential and Best Practices for an Emerging Shale Gas Play	10/20/2010	6/15/2015
09122-11	Board of Regents of the University of Oklahoma	Simulation of Shale Gas Reservoirs Incorporating Appropriate Pore Geometry and the Correct Physics of Capillarity and Fluid Transport	11/4/2010	5/1/2014

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
09122-12	The University of Texas at Arlington	Integrated Experimental and Modeling Approaches to Studying the Fracture-Matrix Interaction in Gas Recovery from Barnett Shale	10/27/2010	2/28/2014
09122-29	The University of Missouri	Using Single-molecule Imaging System Combined with Nano-fluidic Chips to Understand Fluid Flow in Tight and Shale Gas Formation	2/11/2011	8/31/2014
09122-32	Pennsylvania State University	A Geomechanical Model for Gas Shales Based on the Integration of Stress Measurements and Petrophysical Data from the greater Marcellus Gas System	11/4/2011	6/30/2016
09122-41	The University of Texas at Austin	Improved Drilling and Fracturing Fluids for Shale Gas Reservoirs	12/1/2010	6/30/2014
09123-03	New Mexico Institute of Mining and Technology	Field Testing and Diagnostics of Radial-Jet Well-Stimulation for Enhanced Oil Recovery from Marginal Reserves	3/28/2011	12/31/2015
09123-09	University of North Dakota	Enhanced Oil Recovery from the Bakken Shale Using Surfactant Imbibition	3/18/2011	3/17/2014

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
		Coupled with Gravity Drainage		
09123-11	University of Wyoming	Treatment and Beneficial Reuse of Produced Waters Using A Novel Pervaporation-Based Irrigation Technology	3/16/2011	3/15/2014
09123-14	Pioneer Astronautics, Inc.	Green Oil™ Co2-Enhanced Oil Recovery For America's Small Oil Producers	2/11/2011	11/30/2013
09123-18	The University of Kansas Center for Research	Characterization of Potential Sites for Near Miscible CO2 Applications to Improve Oil Recovery in Arbuckle Reservoirs	2/10/2011	9/10/2014
09123-20	DaniMer Scientific, LLC	Creating Fractures Past Damage More Effectively With Less Environmental Damage	3/18/2011	9/30/2012
10121-4202-01	Colorado School of Mines (CSM)	Hydrate Modeling & Flow Loop Experiments for Water Continuous & Dispersed Systems	8/2/2012	9/30/2016
10121-4204-01	Brine Chemistry Solutions, LLC	Corrosion and Scale at Extreme Temperature and Pressure	8/30/2012	8/29/2015
10121-4302-01	NanoRidge Materials, Inc.	Ultra-High Conductivity Umbilical's: Polymer	8/3/2012	2/2/2016

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
		Nanotube Umbilical's (PNU's)		
10121-4304-01	Letton-Hall Group, LLC	More Improvements to Deepwater Subsea Measurement	7/3/2012	9/30/2016
10121-4306-01	GE Global Research	All Electric High Integrity Pressure Protection System (HIPPS) Architecture	12/17/2012	5/31/2016
10121-4402-02	DeepFlex, Inc.	Qualification of Flexible Fiber-Reinforced Pipe for 10,000-Foot Water Depths	10/8/2012	10/7/2016
10121-4401-02	Stress Engineering Services, Inc.	Ultra-Deepwater Riser Concepts for High Motion Vessels	8/21/2012	8/20/2015
10121-4402-01	GE Global Research	Qualification of Flexible Fiber-Reinforced Pipe for 10,000-foot Water Depths	8/6/2012	9/30/2016
10121-4404-03	Doris, Inc.	Low Cost Flexible Production System for Remote Ultra Deepwater Gulf of Mexico (GOM) Field Development	10/29/2012	09/30/2016
10121-4405-02	Det Norske Veritas (USA), Inc.	Ultra-Deepwater Dry Tree System for Drilling and Production in the Gulf of Mexico	9/27/2012	12/31/2014

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
10121-4406-01	Stress Engineering Services, Inc.	Effects of Fiber-Rope/Seabed Contact on Subsequent Rope Integrity	8/21/2012	10/21/2014
10121-4407-01	Remora Technology, Inc.	Deepwater Direct Offloading	8/16/2012	1/16/2014
10121-4501-01	University of Houston	Smart Cementing Materials and Drilling Muds for Real Time Monitoring of Deepwater Wellbore Enhancement	8/17/2012	8/17/2016
10121-4502-01	CSI Technologies, LLC	Deepwater Reverse Circulation Primary Cementing	6/22/2012	9/21/2014
10121-4504-01	The Board of Regents of the University of Oklahoma	Intelligent Casting Intelligent Formation Telemetry (ICIFT) System	7/31/2012	12/31/2014
10121-4505-01	Nautilus International LLC	Coil Tubing Drilling and Intervention System Using Cost-Effective Vessel	7/9/2012	12/22/2014
10121-4801-01	Applied Research Associates, Inc.	Synthetic Hurricane Risk Model for Gulf of Mexico	6/10/2013	9/30/2016
10121-4802-01	University Corporation for Atmospheric	Effect of Climate Variability and Change in Hurricane Activity in the North Atlantic	7/3/2012	9/30/2015

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
	Research-UCAR			
10121-4903-02	Lockheed Martin Corporation	Autonomous Underwater Inspection Using a 3D Laser	7/18/2012	11/18/2014
10122-06	Houston Advanced Research Center (HARC)	The Technology Integration Program: An Extension of the Environmentally Friendly Drilling Systems	7/3/2012	7/2/2016
10122-07	GE Global Research	NORM Mitigation and Clean Water Recovery from Marcellus Frac Water	1/27/2012	3/30/2014
10122-19	CSI Technologies, LLC	Lowering Drilling Cost, Improving Operational Safety and Reducing Environmental Impact	4/25/2012	1/31/2015
10122-20	Colorado School of Mines (CSM)	Development of Non-Contaminating Cryogenic Fracturing Technology for Shale and Tight Gas Reservoirs	7/30/2012	7/1/2016
10122-39	Colorado School of Mines (CSM)	Novel Engineered Osmosis Technology: A Comprehensive Approach to the Treatment and Reuse of Produced Water and Drilling Wastewater	6/26/2012	5/31/2016

RPSEA Research Awards (with Period of Performance)				
Proposal Number	**Proposing Entity**	**Proposal Title**	**Period of Performance**	
			Start Date	**End Date**
10122-42	Texas Engineering Experiment Station (TEES)	A Geomechanical Analysis of Gas Shale Fracturing and Its Containment	1/27/2012	9/30/2016
10122-43	Texas Engineering Experiment Station (TEES)	Diagnosis of Multiple Fracture Stimulation in Horizontal Wells by Downhole Temperature Measurement for Unconventional Oil and Gas Wells	11/7/2011	3/1/2015
10122-47	Colorado School of Mines (CSM)	Predicting Higher-Than-Average Permeability Zones in Tight-Gas Sands, Piceance Basin: An Integrated Structural and Stratigraphic Analysis	4/24/2012	7/31/2016
10123-03	Power Environmental Energy Research Institute (PEER)	Game Changing Technology of Polymeric-surfactants for Tertiary Oil Recovery in the Illinois Basin	4/1/2012	10/1/2014
10123-17	The University of Texas of the Permian Basin	Identifying and Developing Technology for Enabling Small Producers to Pursue the Residual Oil Zone (ROZ) Fairways of the Permian Basin, San Andres	6/25/2012	12/31/2015

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
11121-5101-01	Pacific Science & Engineering Group, Inc.	Trident: A Human Factors Decision Aid Integrating Deepwater Drilling Tasks, Incidents, And Literature	8/22/2013	9/22/2016
11121-5302-01	Safer Marine Transfer, LLC	Deepwater Permanent Subsea Pressure Compensated Chemical Reservoir Construction and Testing	5/19/2014	9/18/2016
11121-5402-01	GE Global Research	Integrity Management of Risers to Support Deepwater Drilling and Production Operations	11/22/2013	9/30/2016
11121-5404-03	Houston Offshore Engineering	Vortex Induced Vibration Study for Deep Draft Column Stabilized Floaters	12/4/2013	9/30/2016
11121-5503-01	GE Global Research	Intelligent BOP RAM Actuation Sensor Systems	10/4/2013	7/4/2016
11121-5801-01	Fugro Global Environmental and Ocean Sciences, Inc.	Hi-Res Environmental Data for Enhanced UDW Operations Safety	2/18/2014	9/30/2016
11122-07	Texas A&M Engineering Experiment Station (TEES)	Conductivity of Complex Fracturing in Unconventional Shale Reservoirs	6/26/2013	9/30/2016

RPSEA Research Awards (with Period of Performance)				
Proposal Number	**Proposing Entity**	**Proposal Title**	**Period of Performance**	
			Start Date	**End Date**
11122-20	Gas Technology Institute	Advanced Hydraulic Fracturing	12/27/2012	8/31/2016
11122-27	The University of Texas at Austin	Relationships between Induced Seismicity and Fluid Injection: Development of Strategies to Manage Fluid Disposal in Shale Hydrocarbon Plays	3/11/2013	3/10/2015
11122-31	Drexel University	Development of Plasma Technology for Water Management of Frac/Produced Water	4/9/2013	10/8/2015
11122-42	CSI Technologies, LLC	Prevention and Remediation of Sustained Casing Pressure and other Isolation Breaches	5/29/2013	09/30/2016
11122-45	GSI Environmental Inc.	Reducing the Environmental Impact of Gas Shale Development: Advanced Analytical Methods for Air and Stray Gas Emissions and Produced Brine Characterization	6/25/2013	8/31/2016
11122-53	Colorado School of Mines (CSM)	Advancing a Web based Tool for Unconventional Natural Gas Development with Focus on Flowback and Produced Water Characterization,	5/31/2013	8/30/2016

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
		Treatment and Beneficial Use		
11122-55	Colorado State University	Development of Geographic Information System-Based Tool for Optimized Fluid Management in Shale Gas Operations	3/8/2013	9/30/2016
11122-56	The University of Texas at Austin	Understanding and Managing Environmental Roadblocks to Shale Gas Development: An Analysis of Shallow Gas, NORMs, and Trace Metals (Texas)	6/14/2013	9/30/2015
11122-57	Southern Research Institute	Advanced Treatment of Shale Gas Frac Water to Produce NPDES Quality Water	4/30/2013	10/30/2015
11122-60	The University of Ohio	Cost-Effective Treatment of Flowback and Produced Waters via an Integrated Precipitative Supercritical (IPSC) Process	6/12/2013	4/16/2016
11122-63	Oklahoma State University	Petrophysics and Tight Rock Characterization for the Application of Improved Stimulation and Production Technology in Shale	6/27/2013	6/26/2016

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
11122-71	University of Southern California	Water Handling and Enhanced Productivity from Gas Shales	8/21/2013	5/20/2016
11122-73	Battelle Memorial Institute	Development of Subsurface Brine Disposal Framework in the Northern Appalachian Basin	4/1/2013	11/1/2015
11123-03	New Mexico Institute of Mining and Technology	Cost-Effective Treatment of Produced Water Using Co-Produced Energy Sources Phase II: Field Scale Demonstration and Commercialization	11/5/2012	10/31/2015
11123-08	Utah Geological Survey	Basin-Scale Produced Water Management Tools and Options – GIS based models and statistical analysis of shale gas/tight sand reservoirs and their produced water streams, Uinta Basin, Utah	10/10/2012	8/5/2015
11123-09	Battelle Memorial Institute, Pacific Northwest Division	Maintenance for Paraffin Management in Production Tubing Using Non-Invasive Ultrasonic Technology	10/25/2013	9/30/2016
11123-14	The University of Missouri	Study and Pilot Test of Preformed Particle Gel Conformance Control Combined With Surfactant	11/6/2012	8/31/2015

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
11123-15	OsComp Systems, Inc.	Hybrid Rotor Compression for Multiphase and Liquids-Rich Wellhead Production Applications	1/15/2013	9/30/2014
11123-23	DaniMer Scientific, LLC	Field Demo of Eco-Friendly Creation of Propped Hydraulic Fractures	2/22/2013	10/31/2014
11123-24	The Board of Regents of the University of Oklahoma	Reduction of Uncertainty in Surfactant-Flooding Pilot Design using Multiple Single Well Tests, Fingerprinting and Modeling	1/15/2013	5/15/2015
11123-28	The University of Kansas Center for Research	Field Demonstration of Chemical Flooding of the Trembley Oilfield, Reno County, Kansas	11/1/2012	9/30/2016
11123-32	The University of Texas at Austin	Water Management in Mature Oil Fields using Advanced Particle Gels	1/21/2013	1/20/2015
12121-6001-01 (this project was awarded but a contract was never executed)	Texas A&M Engineering Experiment Station (TEES)	Defined Effort to provide "Marine Vibrator Prototype	9/26/2014	4/9/2015
12121-6002-02	SEG Advanced Modeling Corporation (SEAM)	Pressure Prediction and Hazard Avoidance through Improved Seismic Imaging	9/18/2014	9/30/2016

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
12121-6301-03	Clearview Subsea-Merged	Subsea Produced Water Sensor Development	9/11/2014	9/30/2016
12121-6302-01	GE Global Research	Subsea High Voltage Direct Current Connectors for Environmentally Safe and Reliable Powering of UDW Subsea Processing	6/20/2014	9/30/2016
12121-6403-01	GexCon US, Inc.	Development of Advanced CFD Tools for the Enhanced Prediction of Explosion Pressure Development and Deflagration Risk on Drilling and Production Facilities	8/23/2014	9/30/2016
12121-6502-01	Blade Energy Partners, Ltd	Reliability of Annular Pressure Buildup (APB) Mitigation Technologies	7/28/2014	12/15/2015
12121-6503-01	CSI Technologies, LLC	Analysis of Best Practices for Deepwater Cementing in Oil Based Mud (OBM) and Synthetic Based Mud (SBM	6/25/2014	9/30/2016
12122-15	Utah State University	Measurement of Hydrocarbon and Greenhouse Gas Emissions from Uncharacterized Area Sources	5/19/2014	8/31/2016

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
12122-52	The University of Texas at Austin	Connectivity between fractures and pores in hydrocarbon-rich mudrocks	6/25/2014	6/24/2016
12122-91	The Board of Regents of the University of Oklahoma	4D Integrated Study Using Geology, Geophysics, Reservoir Modeling & Rock Mechanics to Develop Assessment Models for Potential Induced Seismicity Risk	6/16/2014	9/30/2016
12122-95	Colorado School of Mines	Reconciling top-down and bottom-up greenhouse gas and air pollutant emission estimates from unconventional gas development in the Denver-Julesburg Basin	8/28/2014	9/30/2016
12123-16	New Mexico Institute of Mining and Technology	A Portable, Two Stage, Antifouling Hollow Fiber Membrane Nanofiltration Process for the Cost-Effective Treatment of Produced Water	6/5/2014	9/5/2016
12123-18	PPG Industries (DBA Monroeville Chemicals Center)	Water Treatment System for Effective Acid Mine Drainage Water Use in Hydraulic Fracturing	7/11/2014	8/31/2016

RPSEA Research Awards (with Period of Performance)				
Proposal Number	Proposing Entity	Proposal Title	Period of Performance	
			Start Date	End Date
12123-42	Rice University	Reducing the Impacts of Deterioration of Cement Integrity on Small Producers	6/18/2014	9/17/2016

C. APPENDIX C – LIST OF PUBLIC DOCUMENTS

Due to the size, the documents are posted on the RPSEA website, www.rpsea.org

D. APPENDIX D – LIST OF CURRENT AND PRIOR RPSEA BOARD MEMBERS

Each Annual Plan identifies Board members during that year. Members of the Board at Program's end (9/30/16) are highlighted in the list.

RPSEA CURRENT AND PRIOR BOARD MEMBERS		
Ahmed Abou-Sayed	Craig Howard	Gene Ratterman
John Allen	David Hyland	Richard Riordan
Roger Anderson	Edward Johnston	Van Romero
Richard Bajura	Fred Julander	Donald Russell
Eric Barron	Brooks Keel	Hani Sadek
Wafik Beydoun	Melanie Kenderdine	Robello Samuel
Don Birx	Caslen Moore Kennedy	Colin Scanes
Stanley Borys	Roger King	Jim Schroeder
Robert Boswell	Thomas Klei	Robert Siegfried
Doris Carver	Vello Kuuskraa	Harold Silverman
Brian Cebull	Dan LeFevers	Matt Simmons
Brian Clark	Guy Lewis	C. Michael Smith
Herve Coutrix	Jeff Lindner	Kevin Smith
Richard Deans	Jerry Logan	Steve Smith
Paul Doucette	Dan Lopez	Jay Still
Christine Economides	Bill Maddock	Scott Tinker
Iraj Ershaghi	Charles McConnell	Tim Tipton
Wayne Esser	Dirk McDermott	Lori Traweek
Roger Fincher	Chris McGill	Ken Tubman
Bill Fisher	Steven McKetta	Arthur Vailis
Jeff Fisher	C. Michael Ming	Kalliat Valsaraj
David Fleischaker	Todd Mitchell	Tony Vaughn
Paul Gardner	Fersheed Mody	Kaushik Vyas
Traci Gholson, CFO	Kishore Mohanty	T.J. Wainerdi
Dan Gleitman	Ernest Moniz	Mike Wallen
Michael Grecco	B. N. Murali	John Warren
Sean Hanrahan	Mark Murphy	John Weete
Kenneth Hall	Maxine Natchees	Art Weglein
Christine Hansen	Dag Nummedal	Kevin Weller

Jeff Harvard	John O'Brien	Tom Williams, President
Richard Haut	James Pappas	Mark Zoback
Chris Haver	Thadeus Patzek	Van Romero
Lynn Helms	Rob Perry	
A. Daniel Hill	Brook Phifer	
Steven Holditch	James Raney	

E. APPENDIX E – LIST OF RPSEA PROGRAM ADVISORY COMMITTEE MEMBERS

ULTRA-DEEPWATER PROGRAM ADVISORY COMMITTEE	
Greg Kusinski	Chevron Corporation
Terry Lechinger	Stress Engineering Services
Khalid Mateen	Total E&P Research & Technology, LLC
Robert Pilko	Blade Energy Partners, Ltd
Anish Simon	Statoil
Trevor Smith	BP America, Inc.
John Vozniak	Archer Oil Tools
Flora Yiu	Anadarko Petroleum Corporation
Jane Zhang	Shell International Exploration & Production
Gary Covatch *(Ex-Officio)*	National Energy Technology Laboratory
Roy Long *(Ex-Officio)*	National Energy Technology Laboratory

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Brook Phifer	NiCo Resources
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Kevin Weller	Mesa Energy Partners, LLC
Eric Smistad *(Ex-Officio)*	National Energy Technology Laboratory

F. APPENDIX F – LIST OF RPSEA TECHNICAL ADVISORY COMMITTEE MEMBERS

DRILLING, COMPLETIONS AND INTERVENTIONS TECHNICAL ADVISORY COMMITTEE

Frank Cummings (Chair)	DOFERO Consultancy, LLC
Torrance Haggerty (Chair)	T&H Consultants
Torrance Haggerty (Chair)	Battelle Memorial Institute
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Juan Albeniz	GE Oil & Gas
Eric Allen	DNV GL Group
John Allen	Allen Energy Consultants
John Allen	WorleyParsons Group
Emad Andarawis	GE Oil & Gas
Robert Archer	RPS Group Plc
Andrew Aubrey	Jet Propulsion Laboratory
Hank Bakker	Devon Energy Corporation
Scott Ball	Weatherford International Ltd.
Hugh Banon	BP America, Inc.
Benton Baugh	Radoil, Inc.
Steve Beach	RPSEA
David Beardmore	ConocoPhillips Company
Glen Benge	Baker Hughes
Henry Bergeron	Chevron Corporation
Neil Bergstrom	Devon Energy Corporation
Eric Bickel	Texas A&M University
John Bickham	Battelle Memorial Institute
Michael Bittar	Halliburton
Douglas Blankenship	Sandia National Laboratories
Pauline Boeira	BG Group
Paul Bommer	The University of Texas at Austin
Brett Borland	ConocoPhillips Company
Dwayne A. Bourgoyne	Colorado School of Mines
Hans Bratfos	DNV GL Group
Brian Braun	Chevron Corporation
Susan Brockway	Los Alamos National Laboratory
Brandon Broom	Lockheed Martin Corporation
Lloyd Brown	ConocoPhillips Company
Lloyd Brown	Science Deployed, LLC
Robert Brown	Consultate L.L.C.
Robert Brown	HIMA Americas, Inc.
David Bump	Anadarko Petroleum Corporation
Martial BURGUIERES	Weatherford International Ltd.
John Byeseda	Cameron
Bill Capdevielle	Hess Corporation
Kay Cawiezel	BP America, Inc.
Cassindy Chao	Laserlith Corporation
Carl Chapman	Offshore Marine Consultants
Diana Charles	BG Group
Curtis Cheatham	Weatherford International Ltd.
Kevin Chell	GE Oil & Gas
T.O. Cheung	Keppel Offshore and Marine
Wilson Chin	Stratamagnetic Software, LLC
Jim Chitwood	Chevron Corporation
Mark Chustz	Shell International E&P
Chip Claiborne	Chevron Corporation
Phil Clark	Chevron Corporation

Frank Close	Chevron Corporation
Martin Cobern	APS Technology, Inc.
Jason Colbert	Devon Energy Corporation
Gary Collins	ConocoPhillips Company
Cindy Conroy	Ziebel
Gary Covatch	National Energy Technology Laboratory
Alex Crabtree	Hess Corporation
Charles Crawley	Chevron Corporation
Joseph Crouch	Southwest Research Institute
Jorge Cubelos	Total E&P Research & Technology USA, Inc.
JC Cunha	Petrobras America, Inc.
Herve de Naurois	Total E&P Research & Technology USA, Inc.
Sarah Delille	Statoil
Bernard Dems	The Dow Chemical Company
Paul Deutch	Foro Energy, Inc.
Herb Dhuet	Baker Hughes
Michel Dib	WorleyParsons Group
Raymond Dishaw	Global Systems Inc.
Paula Dittrick	Oil & Gas Journal
Mahammed Dooply	Schlumberger Limited
Paul Doucette	GE Oil & Gas
Andy Duncan	Weatherford International Ltd.
Chris J. Durrand	Novatek International Inc.
James Dwyer	Baker Hughes
Mitchell Dziekonski	Titanium Engineers, Inc.
Luke Eaton	ConocoPhillips Company
Donna Elwood	Ziff Energy Group
Sonny Enrique	ConocoPhillips Company
Robert Estes	Baker Hughes
Michael Fehler	SEG Advanced Modeling Corporation
Andrew Feltham	Total E&P Research & Technology USA, Inc.
Darryl Fett	Total E&P Research & Technology
Bill Fincham	National Energy Technology Laboratory
Roger W. Fincher	Baker Hughes
Michael Freeman	Schlumberger Limited
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Tom Gay	BG Group
Matt George	The University of Oklahoma
Rupak Ghosh	BP America, Inc.
Greg Gillette	GE Oil & Gas
Alexa Gonzalez Luis	Blade Energy Partners, Ltd.
Ken Gray	The University of Texas at Austin
Ivica Grgas	ConocoPhillips Company
Fabio Guimaraes	BG Group
Anamika Gupta	Blade Energy Partners, Ltd.
Himanshu Gupta	BP America, Inc.
James Hall	Letton-Hall Group
Henning Hansen	Ziebel
Mike Harris	HTK Companies
Alan He	Statoil
Bill Head	RPSEA
Ryan Herbel	GE Oil & Gas
Michael Hughes	GE Oil & Gas

Imdad Imam	GE Oil & Gas
Odd Indrehaug	Statoil
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Jay Jikich	National Energy Technology Laboratory
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Mark Johnson	Chevron Corporation
Norman Kamanga	Statoil
Bill Kinney	Fluor Corporation
Glen Koster	GE Oil & Gas
Greg Kusinski	Chevron Corporation
Christy Lan	Bureau of Safety and Environmental Enforcement
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Young-Woong Lee	Shell International Exploration & Production
Joe Levine	Bureau of Safety and Environmental Enforcement
Yile Li	Shell International Exploration & Production
Zhen Li	ExxonMobil
Cesar Lima	Petrobras America, Inc.
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Alisha McClellan	Chevron Corporation
Hamish McCracken	BG Group
Brad McFarland	Weatherford International Ltd.
Dan McLeod	Lockheed Martin Corporation
Bob Meize	Anadarko Petroleum Corporation
Weihong Meng	Fluor Corporation
Ben Mezak	C-Ray Media, Inc.
Farouk Mian	Universal Technologies Corporation
Keith Millheim	Nautilus International LLC
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Richard Mitchell	Devon Energy Corporation
Randy Monson	Nautronix, Inc.
Cory Moore	Chevron Corporation
John Moore	Halliburton
Charles Mowrey	Cubility
Danette Mozisek	RPSEA
Zafar Munshi	Titanium Engineers, Inc.
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Lee Nirider	Marathon Oil Corporation
David Norman	Chevron Corporation
Lewis Norman	Halliburton
Charles Ohaeri	Anadarko Petroleum Corporation
Shola Okewunmi	Chevron Corporation

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Alexander Parlos	Texas A&M University
Bjorn Paulsson	Paulsson, Inc.
Mike Payne	BP America, Inc.
Rob Perry	BP America, Inc.
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Mateusz Podskarbi	Schlumberger Limited
Ron Powell	Weatherford International Ltd.
Thomas Power	Stress Engineering Services
Robert Radtke	Technology International, Inc.
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Viola Rawn-Schatzinger	Petroleum Technology Transfer Council
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Don Richardson	RPSEA
Oriol Rijken	SBM Offshore N.V.
Erin Ring	Noble Corporation
Mayela Rivero	Total E&P Research & Technology USA, Inc.
Francois Rodot	Total E&P Research & Technology USA, Inc.
John D Rogers	Houston Advanced Research Center
Brian Rovelli	Total E&P Research & Technology USA, Inc.
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Steve Szymczak	Baker Hughes
Wallace Tang	Laserlith Corporation

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Paula Turner	Novatek International Inc.
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Michael VanDerwerken	GE Oil & Gas
Daan Veeningen	National Oilwell Varco, Inc.
John Vicic	Shell International Exploration & Production
John Victor	Oil States International, Inc.
Cumaraswamy Vipulanandan	University of Houston
Martha Viteri	DNV GL Group

John Vozniak	Individual
Kevin Walsh	Lockheed Martin Corporation
Jeff Watters	CSI Technologies, LLC
Don Whitfill	Halliburton
Alan Whooley	MCS Kenny
Dean Wiberg	Jet Propulsion Laboratory
Morten Wiencke	GE Oil & Gas
Thomas E. Williams	Environmentally Friendly Drilling Systems Program
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Dana Witt	Chevron Corporation
Pieter Wybro	WorleyParsons Group
Glenda Wylie	Halliburton
Takwe Yango	Texas A&M University
Charles Yemington	Nautilus International LLC
Xiaolei Yin	ExxonMobil
Flora Yiu	Anadarko Petroleum Corporation
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Ding Zhu	Texas A&M University
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Frank Close	Chevron Corporation
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Sarah Delille	Statoil
Herb Dhuet	Baker Hughes
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Dave Driver	BP America, Inc.
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Michael Tognarelli	BP America, Inc.
Mason Tomson	Rice University
Ed Tovar	InTechSys, LLC
George Tovar	Ocean Power Technologies, Inc.
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Jenifer Tule-Gaulden	Anadarko Petroleum Corp.
Azra Tutuncu	Colorado School of Mines
Randy Valencia	Apache Corporation
Daan Veeningen	National Oilwell Varco, Inc.
John Vicic	Shell International Exploration & Production
Peter Vickery	Applied Research Associates, Inc.
Michael Vogel	Shell International Exploration & Production
John Vozniak	Individual
T.J. Wainerdi	University of Houston
Alan Whooley	MCS Kenny
Dean Wiberg	Jet Propulsion Laboratory
Morten Wiencke	GE Oil & Gas
Thomas E. Williams	Environmentally Friendly Drilling Systems Program
Devin Witt	Chevron Corporation
Renee Wright	Marathon Oil Corporation
Pei Xu	Colorado School of Mines
Xinfeng Yang	Chevron Corporation
Charles Yemington	Nautilus International LLC
Chris Yetsko	ConocoPhillips Company
Flora Yiu	Anadarko Petroleum Corporation
Franz Zdravistch	BMT Scientific Marine Services

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Ming-Yao Lee (Chair)	Chevron Corporation
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Juan Albeniz	GE Oil & Gas
Chris Alexander	Stress Engineering Services
Eric Allen	DNV GL Group
John Allen	Allen Energy Consultants
John Allen	WorleyParsons Group
Todd Anderson	GE Oil & Gas
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Benton Baugh	Radoil, Inc.
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Yildiz Bayazitoglu	Rice University
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Henry Bergeron	Chevron Corporation
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Greg Biggerstaff	Anadarko Petroleum Corporation
Pauline Boeira	BG Group
Charles A. Bollfrass	Texas A&M University
Patrick Boster	RTI Energy Systems
Hans Bratfos	DNV GL Group
Susan Brockway	Los Alamos National Laboratory
Douglas Brown	T-REX Engineering & Construction
Jason Brown	Chevron Corporation
Lloyd Brown	ConocoPhillips Company
Lloyd Brown	Science Deployed, LLC
Robert Brown	Consultate L.L.C.
Robert Brown	HIMA Americas, Inc.
Steve Bryant	The University of Texas at Austin
Chris Buckingham	Southwest Research Institute
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Christopher Caldwell	RTI Energy Systems
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Dave Cercone	National Energy Technology Laboratory
Carl Chapman	Offshore Marine Consultants
Walter Chapman	Rice University
Diana Charles	BG Group
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Curtis Cheatham	Weatherford International Ltd.
Lea-Der Chen	Texas A&M University Corpus Christi
Xiaohong Chen	American Bureau of Shipping
T.O. Cheung	Keppel Offshore and Marine
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Chip Claiborne	Chevron Corporation

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Martin Cobern	APS Technology, Inc.
Art Cohen	University of South Carolina
Jason Colbert	Devon Energy Corporation
Craig Colby	DNV GL Group
Phil Collins	KBR, Inc.
Stan Cone	Fluor Corporation
Yiannis Constantinides	Chevron Corporation
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Charles Crawley	Chevron Corporation
Duncan Crichton	BP America, Inc.
Joseph Crouch	Southwest Research Institute
Christopher Curran	BP America, Inc.
Jim E. Dailey	Technip USA
Philippe Darcis	Tenaris
Heather Davis	DNV GL Group
Scott Davis	GexCon US
Chet Dawes	Lincoln Composites, Inc.
Herve de Naurois	Total E&P Research & Technology USA, Inc.
Sarah Delille	Statoil
Bernard Dems	The Dow Chemical Company
Paul Deutch	Foro Energy, Inc.
Paul Devlin	Chevron Corporation
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Paula Dittrick	Oil & Gas Journal
Paul Doucette	GE Oil & Gas
Christopher Dyke	NanoRidge Materials
Mitchell Dziekonski	Titanium Engineers, Inc.
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Bjorn-Andre Egerdahl	Statoil
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Turgay Ertekin	The Pennsylvania State University
Gioia Falcone	Texas A&M University
Biao Fang	GE Oil & Gas
Bill Fincham	National Energy Technology Laboratory
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Vily Frenk	Technip USA
Ravi Gadangi	GE Oil & Gas
Mike Gann	Anadarko Petroleum Corporation
Tony Garzione	RPSEA
Tom Gay	BG Group
Joseph Gebara	Technip USA
Fathi Ghorbel	Rice University
Rupak Ghosh	BP America, Inc.
Greg Gillette	GE Oil & Gas
Ed Gilson	BP America, Inc.
Bob Gordon	Stress Engineering Services
Sande Gorm	GE Oil & Gas
John Greeves	VersaMarine Engineering LLC
Bill Greiner	WorleyParsons Group
Ivica Grgas	ConocoPhillips Company
Max Grobe	AMOG Consulting, Inc.
Philip Grossweiler	M&H Energy Services
George Gu	ConocoPhillips Company
Fabio Guimaraes	BG Group
Himanshu Gupta	BP America, Inc.

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Torrance Haggerty	Battelle Memorial Institute
Guillermo Hahn	RiserTec Limited
John Halkyard	Deep Reach Technology, Inc.
John Halkyard	John Halkyard & Associates
James Hall	Letton-Hall Group
Jeff Hall	Jet Propulsion Laboratory
David Harris	Anadarko Petroleum Corporation
Richard Haut	Houston Advanced Research Center
Bill Head	RPSEA
Krista Heidersbach	Chevron Corporation
Leon Holloway	ConocoPhillips Company
Chuck Horn	Genesis
Chaojun Huang	Rice University
Stephen Hudak, Jr.	Southwest Research Institute
Jerry Hudson	Marathon Oil Corporation
Michael Hughes	GE Oil & Gas
Jon Husby	Aker Solutions
Imdad Imam	GE Oil & Gas
Julie Ingram	Technip USA
Mehernosh Irani	BP America, Inc.
Ahmad Jamili	The University of Oklahoma
Vineet Jha	GE Oil & Gas
Jay Jikich	National Energy Technology Laboratory
Antonio Jimenez	Quest Integrity Group, LLC
Steven Johnson	Chevron Corporation
T. Alan Johnson	Technip USA
Moussa Kane	Total E&P Research & Technology USA, Inc.
Heon Yong Kang	Texas A&M University
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Sandeep Khurana	Devon Energy Corporation
Andrew Kilner	AMOG Consulting, Inc.
Moo-Hyun Kim	Texas A&M University
Bill Kinney	Wood Group Kenny
Bill Kinney	Fluor Corporation
Kerry Kirkland	Stress Engineering Services
Gary Koctar	Nexen Energy ULC
Eivind Koren	Statoil
Vasanth Kothnur	GE Oil & Gas
Gene Kouba	Chevron Corporation
Nishu Kurup	Offshore Dynamics, Inc.
Nishu Kurup	Houston Offshore Engineering, LLC
Greg Kusinski	Chevron Corporation
Jonathan T. Kwan	Quanelle, LLC
Ngok Lai	Houston Offshore Engineering
Christy Lan	Bureau of Safety and Environmental Enforcement
Reza Langari	Texas A&M University
Jim Latto	GE Oil & Gas
Terry Lechinger	Stress Engineering Services
Cedric LeCunff	Principia R.D.
Young-Woong Lee	Shell International Exploration & Production
Jean-Luc Legras	Acergy US Inc.
Chip Letton	Letton-Hall Group

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Yile Li	Shell International Exploration & Production
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Juan Albeniz	GE Oil & Gas
Mike Alford	Chevron Corporation
Eric Allen	DNV GL Group
Dag Almar Hansen	Techni Holding
Sam Almerico	Oceaneering International, Inc.
Amin	Letton-Hall Group
Robert Archer	RPS Group Plc
Kjell Magne Ashvik	Statoil
Andrew Aubrey	Jet Propulsion Laboratory
Carlos Avila	Chevron Corporation
Joseph Ayyoubi	Petrobras America, Inc.
Donald Balch	Aker Solutions
Hugh Banon	BP America, Inc.
Steve Beach	RPSEA
Ken Bebak	Baker Hughes
Henry Bergeron	Chevron Corporation
John Bickham	Battelle Memorial Institute
Pauline Boeira	BG Group
Julie Boles	BP America, Inc.
Patrick Boster	RTI Energy Systems
Lyndon Bowen	Chevron Corporation
Jep Bracy	BHP Billiton Petroleum
Barry Brasher	Anadarko Petroleum Corporation
Hans Bratfos	DNV GL Group
Brian Braun	Chevron Corporation
Susan Brockway	Los Alamos National Laboratory
Robert Brown	Consultate L.L.C.
Jason Brown	Chevron Corporation
Lloyd Brown	Science Deployed, LLC

Eric Browne	GE Oil & Gas
Chris Buckingham	Southwest Research Institute
Richard Cain	Anadarko Petroleum Corporation
Christopher Caldwell	RTI Energy Systems
Chris Calebrese	GE Oil & Gas
Massimo Camatti	GE Oil & Gas
Brandon Cassimere	ExxonMobil
Diana Charles	BG Group
Manasi Chaubal	NanoRidge Materials
Qin Chen	GE Oil & Gas
Lea-Der Chen	Texas A&M University Corpus Christi
Jim Chitwood	Safe Marine Transfer, LLC
Rahul Chokhawala	GE Oil & Gas
Phil Cioffi	GE Oil & Gas
Chip Claiborne	Chevron Corporation
Frank Close	Chevron Corporation
Francesco Conte	PetrolValves LLC
Kevin Corbett	Individual
Gary Covatch	National Energy Technology Laboratory
Charles Crawley	Chevron Corporation
Joseph Crouch	Southwest Research Institute
Doug Crouch	NanoRidge Materials
Mike Cunningham	Oceaneering International, Inc.
Christopher Curran	BP America, Inc.
Tim Daigle	Fluor Corporation
Jim E. Dailey	Technip USA
Rod Dalgetty	GE Oil & Gas
Stevenson Dansby	Siemens Corporation
Tim Dean	Anadarko Petroleum Corporation
Rick De Leeuw	Shell International Exploration & Production
Sarah Delille	Statoil

Herve de Naurois	Total E&P Research & Technology USA, Inc.
Paul Deutch	Foro Energy, Inc.
Richard Dodd	Bel Valves Limited
Paul Doucette	GE Oil & Gas
Christopher Dyke	NanoRidge Materials
Mitchell Dziekonski	Titanium Engineers, Inc.
Kristin Elgsaas	GE Oil & Gas
Hani Elshahawi	Shell International Exploration & Production
Carl Embry	3D at Depth, LLC
Sonny Enrique	ConocoPhillips Company
Bill Fincham	National Energy Technology Laboratory
Viana Flavia	Southwest Research Institute
Angela Floyd	BP America, Inc.
Matthew Franchek	University of Houston
Vily Frenk	Technip USA
Ted Furlong	GE Oil & Gas
Ravi Gadangi	GE Oil & Gas
Shawn Gao	Shell International Exploration & Production
Tom Gay	BG Group
Ray Glidewell	Devon Energy Corporation
Keat-Choon Goh	Shell International Exploration & Production
Sande Gorm	GE Oil & Gas
Weston Griffin	GE Oil & Gas
Torstein Grostad	Statoil
Himanshu Gupta	BP America, Inc.
Torrance Haggerty	T&H Consultants
Torrance Haggerty	AMSYS Innovative Solutions
Masoud Haji	Chevron Corporation
James Hall	Letton-Hall Group
Liwei Hao	GE Oil & Gas
Maja Harfman Todorovic	GE Oil & Gas
David Harold	Statoil
Gary Harrison	BP America, Inc.
Greg Hatton	Shell International Exploration & Production
Richard Haut	Houston Advanced Research Center
Bill Head	RPSEA
Krista Heidersbach	Chevron Corporation
Terry Holesinger	Los Alamos National Laboratory
Chuck Horn	Genesis
Michael Hughes	GE Oil & Gas
Imdad Imam	GE Oil & Gas
Julie Ingram	Technip USA
Spiridon Ionescu	WorleyParsons Group
Pat Irwin	GE Oil & Gas
Will Ishmael	Oceaneering International, Inc.
Shahin Islmayilov	Statoil
Joe Jackens	Concurrent Technologies Corporation
John Jacobson	Lockheed Martin Corporation
Ahmad Jamili	The University of Oklahoma
Jay Jikich	National Energy Technology Laboratory
Bob Johansen	BP America, Inc.
Alec Johnson	Petrobras America, Inc.
T. Alan Johnson	Technip USA

Steven Johnson	Chevron Corporation
Jeffrey Jones	ExxonMobil
Jeswin Joseph	Statoil
Moussa Kane	Total E&P Research & Technology USA, Inc.
Yogesh Kapoor	Petrobras America, Inc.
Sandor Karpathy	Stress Engineering Services
Anurag Kasyap	GE Oil & Gas
David Keffer	PetrolValves LLC
Eric Kelner	Letton-Hall Group
Kerry Kirkland	Stress Engineering Services
Jan Erik Elnan Knutsen	GE Oil & Gas
Eivind Koren	Statoil
Vasanth Kothnur	GE Oil & Gas
Gene Kouba	Chevron Corporation
Greg Kusinski	Chevron Corporation
C. E. Lacy	Shell International Exploration & Production
Christy Lan	Bureau of Safety and Environmental Enforcement
Peter Lawson	Baker Hughes
Chip Letton	Letton-Hall Group
Zhen Li	ExxonMobil
Yile Li	Shell International Exploration & Production
Cesar Lima	Petrobras America, Inc.
Roy Long	National Energy Technology Laboratory
Chris Lundberg	NanoRidge Materials
John Lyons	ConocoPhillips Company
Glenn MacDonald	Granherne, Inc.
Bryan Marlborough	Operability Consulting, LLC
Emanuel Marsis	Baker Hughes
Ana Martin	BP America, Inc.
Mike Mason	Apache Corporation
Andreas Matzakos	Shell International Exploration & Production
Alisha McClellan	Chevron Corporation
Hamish McCracken	BG Group
Brad McFarland	Weatherford International Ltd.
Dan McLeod	Lockheed Martin Corporation
Norm McMullen	Individual
Kevin McNamee	Nalco Company
Christopher McPherson	Emerson Process Management
Bjorn Meland	Statoil
Aslaug Melbo	GE Oil & Gas
Ben Mezak	C-Ray Media, Inc.
Farouk Mian	Universal Technologies Corp.
Peter Moles	Oceaneering International, Inc.
Randy Monson	Nautronix, Inc.
Mike Mooney	ConocoPhillips Company
Jeffrey Mueller	ConocoPhillips Company
Zafar Munshi	Titanium Engineers, Inc.
Pramod Naik	MCS Kenny
Ibrahima Ndiaye	GE Oil & Gas
Cornelia Noel	Shell International E&P
Thomas O'Donnell	Chevron Corporation
Thomas O'Donnell	Siemens Corporation
Akin Oke	Chevron Corporation
Shola Okewunmi	Chevron Corporation
Tim Ong	Chevron Corporation
James Pappas	RPSEA
Charlene Paulus	ENI Petroleum

Julian Pham	Bureau of Safety and Environmental Enforcement
Jose Piedras	Total E&P Research & Technology USA, Inc.
Bill Pike	National Energy Technology Laboratory
Robert Pilko	Blade Energy Partners, Ltd.
Mateusz Podskarbi	Schlumberger Limited
Jim Poole	NanoRidge Materials
Erin Potrzebowski	Chevron Corporation
Thomas Power	Stress Engineering Services
Neal Prescott	Fluor Corporation
Jesse Ramon	Southwest Research Institute
Dan Rascoe	Jet Propulsion Laboratory
Viola Rawn-Schatzinger	Petroleum Technology Transfer Council
Tony Ray	ConocoPhillips Company
Alexander Ray	Anadarko Petroleum Corporation
Philippe Remacle	Total E&P Research & Technology USA, Inc.
Oriol Rijken	SBM Offshore N.V.
Paul Robinson	University of Houston
Svend Rocke	GE Oil & Gas
Debora Rodrigues	University of Houston
Chris Roper	Saab North America, Inc.
Hani Sadek	Chevron Corporation
Farah Saidi	BP America, Inc.
Brian Salinas	Oceaneering International, Inc.
Gorm Sande	GE Oil & Gas
Andrea Sbordone	Schlumberger Limited
Art Schroeder	Energy Valley, Inc.
Art Schroeder	Safe Marine Transfer, LLC
Eric Schultz	BP America, Inc.
Michael Scroggins	BP America, Inc.
Stephen Sears	Louisiana State University
Dennis Serig	Serig Consulting
Dan Sexton	GE Oil & Gas
Vikrant Shah	BP America, Inc.
Xu She	GE Oil & Gas
Joe Shen	Chevron Corporation
Jim Sheridan	Baker Hughes
George Shoup	Statoil
George Siappas	Chevron Corporation
Christof Sihler	GE Oil & Gas
Mike Sillett	BMT Scientific Marine Services Inc.
Anish Simon	Statoil
Oyvind Snefjella	Statoil
Paul Sommerfield	ExxonMobil
Luiz Souza	Petrobras America, Inc.

Keith Sperling	Chevron Corporation
Hariprasad Subramani	Chevron Corporation
Jeff Sullivan	GE Oil & Gas
Joseph Swenson	Fluor Corporation
Edouard Thibaut	Total E&P Research & Technology USA, Inc.
Dave Thomas	Xodus Group Inc.
Terry Thompson	Shell International Exploration & Production
R. Lee Thompson	Teledyne Blueview, Inc.
Eric Toskey	Letton-Hall Group
Ed Tovar	InTechSys, LLC
Steve Triggs	BP America, Inc.
Jenifer Tule-Gaulden	Anadarko Petroleum Corporation
Charlie Tyrrell	Shell International Exploration & Production
Ingar Tyssen	Emerson Process Management
Jagadeesh Unnam	OneSubSea
Shahnawaz Vahora	OTM Consulting Inc.
Randy Valencia	Apache Corporation
Michael VanDerwerken	GE Oil & Gas
Kim Vandiver	Massachusetts Institute of Technology
Daan Veeningen	National Oilwell Varco, Inc.
Francisco Vera	OneSubSea
Thomas P. Walsh	Petrotechnical Resources Alaska
Robert Webb	BP America, Inc.
Peter Webber	Nalco Company
Konrad Weeber	GE Oil & Gas
Alan Whooley	MCS Kenny
Dean Wiberg	Jet Propulsion Laboratory
Morten Wiencke	GE Oil & Gas
Chris Wolfe	GE Oil & Gas
Suyu Ye	Statoil
Gary Yeager	GE Oil & Gas
Xiaolei Yin	ExxonMobil
Weijun Yin	GE Oil & Gas
Flora Yiu	Anadarko Petroleum Corporation
Klaus Zanker	Letton-Hall Group
Franz Zdravistch	BMT Scientific Marine Services
Di Zhang	GE Oil & Gas
Jeff Zhang	Clearview Subsea
Rui Zhou	GE Oil & Gas
Matt Zimmerman	BP America, Inc.
Jun Zou	Houston Offshore Engineering, LLC

G. APPENDIX G – LIST OF TECHNOLOGY TRANSFER EVENTS – FORUMS, WORKSHOPS, AND CONFERENCES

(These are conferences where RPSEA was a primary sponsor. Forums and workshops were utilized for technology transfer activities, as well as in the development of annual plans). (Sorted by Date)

Event Name	Location	Date
Seismic E&P Forum	Houston, TX	2006-Oct-10
Autonomous Intervention for Deepwater Oil & Gas Operations Forum	Boston, MA	2006-Oct-31
Tight Gas, Shale Gas & Coalbed Methane Forum	Golden, CO	2006-Nov-14
Problem Identification Forum	Los Angeles, CA	2006-Nov-29
Shale Gas Forum	Norman, OK	2006-Dec-5
Produced Water Forum	Albuquerque, NM	2006-Dec-14
Small Producer Forum	Albuquerque, NM	2006-Dec-15
Vortex Induced Vibrations Forum	Houston, TX	2007-Jan-11
Flow Assurance Forum	Tulsa, OK	2007-Feb-8
Unconventional Plays & Research Needs for Appalachian Small Producers Forum	Morgantown, WV	2007-Feb-15
Seafloor Engineering Forum	College Station, TX	2007-Mar-9
The Bakken Shale Forum	Grand Forks, ND	2007-Nov-6
Shale Plays, Technology & Permian Basin Trends Forum	Midland, TX	2007-Nov-29
Fracture in Devonian Black Shale of the Appalachian Basin Workshop	Morgantown, WV	2008-Jan-8
Alaskan Unconventional Gas Resource Forum	Anchorage, AK	2008-Apr-7
CO2 EOR with Carbon Sequestration Forum	Austin, TX	2008-Apr-23
Technologies for Mitigation of Environmental Input of Rocky Mountain Unconventional Oil & Gas Operations Forum	Golden, CO	2008-May-12
Coalbed & Shale Gas Symposium	Tuscaloosa, AL	2008-May-21
Low Impact Oil & Gas Operations in Environmentally Sensitive Areas Forum	College Station, TX	2008-May-30
An Integrated Framework for Treatment & Management of Produced Water	Golden, CO	2008-Sep-25
UDW Technology Conference	Houston, TX	2008-Nov-6
Long Term Environmental Vision for Ultra-Deepwater Exploration & Production Research	The Woodlands, TX	2008-Nov-20
CO2 Operations and Opportunities to Advance Technology for Mature Fields Forum	Austin, TX	2009-Feb-2
Mid-Continent Small Producer Forum	Wichita, KS	2009-Apr-30
Unconventional Gas Development in the Western Energy Corridor Forum	Idaho Falls, ID	2009-May-12

Event Name	Location	Date
Coalbed & Shale Gas Forum	Tuscaloosa, AL	2009-May-20
Mid-Continent Gas Shales Forum	Rosemont, IL	2009-Jun-4
NanoUmbilical Workshop	Houston, TX	2009-Dec-10
NCAR workshop	Boulder, CO	2010
Piceance Basin, Mamm Creek Field Project Review	Denver, CO	2010-Jan-26
Small Producers Program Showcase - Permian Basin Focus	Midland, TX	2010-Feb-3
DNV Technology Qualification Process Workshop	Katy, TX	2010-Feb-23
Effect of Climate Variability and Change in Hurricane Activity in the North Atlantic	Boulder, CO	2010-Mar-8
Unconventional Resource Conference	Golden, CO	2010-Apr-6
Piceance Basin Tight Gas Seminar	Denver, CO	2010-Apr-8
Coalbed & Shale Gas Symposium	Tuscaloosa, AL	2010-May-19
UDW Technology Conference	Houston, TX	2010-Jun-22
Research & Technology Needs for Deepwater Development-Addressing Oil Recovery And Effective Cleanup of Oil Spills Forum	The Woodlands, TX	2010-Jul-22
Natural Gas - The Path to Clean Energy Forum	College Station, TX	2010-Nov-18
Environmentally Friendly Drilling Workshop - Managing the Eagle Ford Development	San Antonio, TX	2011-Mar-15
Unconventional Resource Conference	Denver, CO	2011-Apr-19
Piceance Basin, Mamm Creek Field Project Review	Denver, CO	2011-Apr-21
Composite Reinforced Ultra-Deep Drilling Riser Technology Transfer	Houston, TX	2011-May-5
Environmentally Friendly Drilling Workshop - Best Management Practices	Boulder, CO	2011-May-26
Improvements to Deepwater Measurement	Houston, TX	2011-Jun-20
Accessible Software Developed for Application to Unconventional Resources	Houston, TX	2011-Jun-30
Shales-Gas and Tight-Gas-Sand Reservoirs of Utah Core Workshop	Salt Lake City, UT	2011-Jul-13
Lowering the Environmental Footprint of Marcellus Shale Development	Morgantown, WV	2011-Jul-26
UDW Technology Conference	The Woodlands, TX	2011-Jul-26
Focusing on Environmental Issues Associated with Unconventional Natural Gas Operations	The Woodlands, TX	2011-Aug-18
Onshore Production Conference: Technological Keys to Enhance Production Operations - California	Bakersfield, CA	2011-Oct-11
Onshore Production Conference: Technological Keys to Enhance Production Operations - Kansas	Lawrence, KS	2011-Nov-8
Onshore Production Conference: Technological Keys to Enhance Production Operations - Colorado	Golden, CO	2011-Nov-30
Environmentally Friendly Drilling Technology Workshop	Kingsville, TX	2012-Feb-28

Event Name	Location	Date
Onshore Production Conference: Technological Keys to Enhance Production Operations - Midland	Midland, TX	2012-Apr-10
Unconventional Gas Conference	Canonsburg, PA	2012-Apr-17
Subsea Water Quality Management Sensors Forum	Houston, TX	2012-May-21
Evaluation of Fracture Systems and Stress Fields within the Marcellus Shale and Utica Shale	Pittsburgh, PA	2012-Jul-1
UDW Technology Conference	The Woodlands, TX	2012-Sep-19
Onshore Production Conference: Technological Keys to Enhance Production Operations - Houston	Houston, TX	2012-Nov-29
Summary of Results from Completed GTI Marcellus Shale R&D Project Workshop	Canonsburg, PA	2013-May-7
Environmentally Friendly Drilling Workshop - Natural Gas Power for Shale Development	San Antonio, TX	2013-May-14
Onshore Production Conference: Technological Keys to Enhance Production Operations - Kansas	Wichita, KS	2013-Jun-27
Environmentally Friendly Drilling Workshop	Canonsburg, PA	2013-Sep-4
Onshore Production Conference: Technological Keys to Enhance Production Operations - California	Long Beach, CA	2013-Oct-17
UDW Technology Conference	The Woodlands, TX	2013-Oct-29
Onshore Production Conference: Technological Keys to Enhance Production Operations - Illinois	Evansville, IN	2014-Apr-30
Advanced Borehole Seismic Array for Deep or Horizontal Wells Forum	Houston, TX	2014-May-20
Onshore Production Conference: Technological Keys to Enhance Production Operations - Houston	Houston, TX	2014-Jun-17
UDW Technology Conference	Houston, TX	2014-Sep-3
Onshore Production Conference: Technological Keys to Enhance Production Operations - Salt Lake City	Salt Lake City, UT	2014-Sep-10
Subsea Produced Water Sensor Development	Houston, TX	2014-Dec-16
Subsea Produced Water Sensor Development	Houston, TX	2015-Feb-23
Water Sensor Development workshop	Houston, TX	2015-Feb-23
Denver Environmental Issues workshop	Denver, CO	2015-Aug-11
Onshore Technology Workshop - Focusing on Environmental Issues Facing Shale Gas Developers in the US Rocky Mountain Region - Workshop	Denver, CO	2015-Aug-11
Onshore Technology Workshop - Focusing on Environmental Issues Facing Shale Gas Developers in the US Rocky Mountain Region - Field Trip	Denver, CO	2015-Aug-11
Corrosion and Scale at Extreme Temperature and Pressure	Houston, TX	2015-Aug-13
UDW Technology Conference	Houston, TX	2015-Sep-9
Canonsburg Hydraulic Fracturing/Water Treatment/Chemical Flooding workshop	Canonsburg, PA	2015-Oct-27

Event Name	Location	Date
Onshore Technology Workshop - Focusing on Hydraulic Fracturing, Water Treatment, Chemical Flooding and Environmental Impact Issues in the Northern Appalachian Basin - Workshop	Canonsburg, PA	2015-Oct-27
Onshore Technology Workshop - Focusing on Hydraulic Fracturing, Water Treatment, Chemical Flooding and Environmental Impact Issues in the Northern Appalachian Basin - Field Trip	Canonsburg, PA	2015-Oct-27
Houston Induced Seismicity workshop	Houston, TX	2015-Nov-4
Onshore Technology Workshop - Focusing on Induced Seismicity	Houston, TX	2015-Nov-4
Onshore Technology Workshop - Focusing on Emissions from Unconventional Resources Development Activity	Denver, CO	2016-May-26
Onshore Technology Workshop - Focusing on Appalachian Basin Technology	Canonsburg, PA	2016-Jul-20
Best of RPSEA - 10 years of Research	Galveston, TX	2016-Aug-30

H. APPENDIX H – LIST OF R&D PARTICIPATING ENTITIES

Alphabetical – Total 550 Organizations		
212 Resources Corporation	Aurora Oil and Gas	CD-adapco
2H Offshore Inc.	Austin Powder Company	CDL Inc.
3D at Depth, LLC	AVI Consultants LLC (Rice University)	Center for Petroleum Asset Risk Management
3DGeo Development Inc	Awwa Research Foundation	CGGV Veritas Services
ABB, Inc.	Axept	Champion Technologies
ABS Consulting	Babcock & Wilcox	ChemEOR
Accutest Laboratories	Baker Hughes Incorporated	Chesapeake Energy Corporation
Advanced Hydro Inc	Barnett Shale Water Conservation and Management Committee	Chevron Corporation
Advanced Resources International	Battelle Memorial Institute	Ciris Energy, Inc.
Advanced Seismic Research Corporation	Bear Creek Services	Clearview Subsea-Merged
Aerodyne	BenneTerra	Clemson University
Aerotek	Bereskin and Associates	Cline Energy
Aetman Engineering	Berexco LLC	CNX Gas Company LLC
Aker Solutions	Berkeley GeoImaging Resources	Coastal Chemicals Company
Alamo Area Council of Governments	BG Group	Coleman Oil and Gas
Alan C. McClure & Associates	BHP Billiton Petroleum	Colorado School of Mines
Altier Bros. Inc.	Bill Barrett Corporation	Colorado State University
AltraRock Energy, Inc.	BJ Services Company	Colt Energy, LLC
American Energies Corporation	BKT United	Computer Modelling Group, Inc.
American Energy Reserves	Black Brush Oil and Gas, LLP	Conoco Phillips Company
American Power Ventures	Blade Energy Partners	Consultant – Steve Boggs
Ames Energy Advisors	Blue Top Energy, LLC	Consultant – Nick Blackman
Amherst College	Blueview Technologies Inc.	Consultant – Ed Cheeseman
Ampak Oil Company	BP America, Inc.	Consultant – James McAdams
Anadarko Petroleum Corporation	Brine Chemistry Solutions, LLC	Consultant – Rick Smith
AOA Geophysics	Burleson Cooke, LLP	Consumer Energy Alliance
Apex HiPoint LLC	Cabot Oil & Gas Corporation	Cooperative Institute for Research in Environmental Science
Appalachian Shale Water Conservation and Management Committee	California Institute of Technology	Core Laboratories
Appalachian, LLC	CALSEP International Consultants	CrownCrest Operation LLC
Applied Petroleum Technology Academy	Cambridge University	CSI Technologies, LLC
Applied Physical Sciences	Cameron	CTES
Applied Research Associates, Inc.	Campbell Applied Physics Inc.	Curtis-Wright
Aquionics Inc.	CARBO Ceramics, Inc.	CurTran
ARCADIS US	Carmen Schmitt, Inc.	Daneshy Consultants
Argonne National Laboratory	Carrizo Oil and Gas, Inc	DaniMer Scientific, LLC
Armstrong Energy Corporation	Carter Technologies Co.	Danmark Energy L.P.
Ascend Geo, LLC	CASE-EJIP/SAC	DeepFlex Inc.
ATK Technologies	C-Crete Technologies	Deepwater Research Inc. (Mark V System)
Deepwater Technical Solutions	Epic Software	GSI Environmental Inc.

Delmar Systems, Inc	ER Operating	Guadalupe-Blanco River Authority
Denbury Resources	Exco Resources	Gulf Coast Green Energy
Design, Technology & Irrigation Group	Expro Group	GX Technologies (ION Geophysical)
Det Norske Veritas	ExxonMobil	Hach Company
Devon Energy Corporation	Falcon Exploration	Halliburton
Diversified Operating Corporation	Filtration & Separation Technologies	Harvard Petroleum Company, LLC
DNV	FloaTEC, LLC	HC Itasca Consulting Group
DORIS Engineering	Florida Atlantic University	Helix Canyon Offshore
DORIS Inc.	Fluid Inclusion Technology, Inc.	HESS Corporation
Dow Chemical Company	Fluor Enterprises, Inc.	Higgs-Palmer Technologies
Downhole Surveys	FMC Technologies	Highland Fluid Technologies
Drexel University	Fort Lewis College	Hilcorp Energy Company
DrillRight Technology	Fountain Quail Water Management, LLC	HOLT CAT
Dry Coolers, Inc.	Framo Engineering	Houston Advanced Research Center
DTC International, Inc.	Fugro Global Environmental and Ocean Sciences, Inc.	Houston Offshore Engineering
DUCO, Inc.	Fulcrum Resources	H-Tech Petroleum Consulting, Inc.
East Management LLC	G4 Resources	Huisman Equipment
Eby Petrography & Consulting	Gas Technology Institute	Huisman/Innodrill
Echelon Applied Geoscience Consulting	GE Analytical Instruments	Huntsman Petrochemical Inc.
Echelon Exploration & Production	GE Aviation	Hydration Technologies, Inc.
Ecology & Environment, Inc.	GE Energy	Hydration Technology Innovations, LLC
EFD Advanced Analytical Services Roundtable	GE Global Research Center	Ideal Aerosmith Inc
El Paso Exploration & Production Compnay	GE Nuclear	Imperial Collage London
ElectraTherm, Inc.	GE Oil & Gas	Independent Petroleum Association of New Mexico
Eltron Research and Development	GE Water & Process Technologies	INTECSEA, WorleyParsons Group
Emerging Products Technical Consulting, LLC	General Marine Contractors, LLC	Intertek Group
EMGS ASA	GeoIsoChem Inc.	Iowa State University
Encana Corporation	Geological Survey of Alabama	IsoTech (Weatherford)
Endicott Interconnect Technologies, Inc.	Geopure Water Technologies	itRobotics
Energy Corporation of America	Georgia Institute of Technology	J & L Allen, Inc.
Energy Onvector LLC	Geotrace Technologies	J. Ray McDermott Engineering
EnerPol	GeoX Consulting	Jacarilla Apache Nation
Engineering Testing and Analysis International	GexCon US	Jeter Field Service
Eni S.p.A.	Global Water Technologies	John Halkyard and Associates
Environ	Golder Associates	John Linder Operating Company, LLC
Environmental Process Dynamics Inc	Goodrich Petroleum Corporation	Jones Energy
EOG Resources, Inc.	Groundwater Protection Council	Kansas Geological Survey
KatchKan U.S.A.	Maritima de Ecologia (MARECSA)	Natures Composites/Wyocomp

KC Harvey Environmental	MATADOR Resources Company	Nautilus International, LLC
Keltic Well Services	MCS Kenny Ltd	Naval Facilities Engineering Service Center
Kemlon Products	Media and Process Technology, Inc.	New Dominion
Kennedy/Jenks Consultants	Melzer Consulting	New Mexico Institute of Mining and Technology
Keppel Fels	Mertz Energy	New Mexico Oil Conservation Division
Keppel Offshore & Marine	Mesa State University	New Mexico State University
Kiewit Offshore Services	M-I SWACO	New York State Department of Environmental Conservation
Kilbarger Drilling Inc.	Micro Assembly Technologies	New York State Energy Research Development Authority
KinderMorgan	Mid-Con Energy III, LLC	Newfield Exploration Company
Knowledge Reservoir, LLC	Mid-Con Energy Operating,	Newpark Mats and Integrated Services, LLC
Kvaerner Field Development, Inc.	Midland College	Nexen Petroleum
Lake Charles Instruments/Neftemer	Midland Energy Library	NGAS Production Company
Land Steward Consultants Ltd (Maywald)	Missouri University of Science and Technology	NOAA National Weather Service
Landmark Graphics Corporation	Montana State University	Noble Energy, Inc.
Laserlith Corporation	Moody & Associates	NORSAR
Latitude Geographics Group, Ltd.	Multi-Chem Corporation	Nortech/Nexans
Lawrence Berkeley National Laboratory	Multiphase Systems Integration	North Carolina State University
Lawrence Livermore National Laboratory	NALCO	North Dakota Industrial Commission
Layline Petroleum 1, LLC	NanoRidge Materials, Inc.	Northeastern University
Layne Christensen/Intevras Technologies	NATCO Group	NOV/CTES
Legacy Reserves	National Center for Atmospheric Research	NREL
Legado Resources	National Centers for Environmental Prediction	NSI Technologies, LLC
Letton-Hall Group	Missouri University of Science and Technology	Oak Ridge National Laboratory
Lincoln Composites Inc.	Montana State University	Oceaneering International
Livermore Instruments Inc.	Moody & Associates	Oceanweather, Inc.
Lockheed Martin	Multi-Chem Corporation	Octave Reservoir Technologies
Los Alamos National Laboratory	Multiphase Systems Integration	ODS-Petrodata
Louisiana State University	NALCO	Offshore Dynamics
M&B Engineering	NanoRidge Materials, Inc.	Offshore Technology Research
M2 Water Treatment, Inc.	NATCO Group	Ohio Department of Natural Resources
Maersk Oil America	National Center for Atmospheric Research	Ohio State University
Marathon Oil Corporation	National Centers for Environmental Prediction	Ohio University
MARIN USA	Natural Resources Defense Council	OHM
Oil Chem Technologies	Quantitative Clastics Laboratory	Southwest Research Institute

Oklahoma Corporation Commission	Quicksilver Resources, Inc.	Southwestern Energy Company
Oklahoma State University	Radoil	SRI International
Omega Project Solutions Inc.	Railroad Commission of Texas	Sripps Institute of Oceanography
Optiphase, Inc.	Rancho San Pedro, LLC	SSP Inc.
OsComp Systems Inc.	Range Resources Corporation	Stanford University
Pacific Northwest National Laboratory	Rare Technology	StatoilHydro
Pacific Science & Engineering Group	Red River Compression	Stewart Environmental Consultants
Paramedia Research Group, Inc.	Red Wing Engineering	Stim-Lab
Parker Hannifin Corporation	Remora Technology, Inc	Strassberg Consulting
Paula Moon & Associates	Rensselaer Polytechnic Institute	Stratamagnetic Software, LLC
Paulsson, Inc.	Repsol Services Inc	Stratus Consulting
PCM Technical	Restech	Stress Engineering Services
PENN Virginia Oil and Gas, L.P.	Rolls Royce	STW Resources, Inc.
Pennsylvania Department of Conservation and Natural Resources	Roosevelt Resources	Subsea Riser Products
Pennsylvania Department of Environmental Protection	Roxar Inc.	Subsea7
Pennsylvania General Energy Company LLC	Safe Marine Transfer, Inc.	Superior Energy Services
Peter M Lovie LLC	Saitama University	Swiss Federal Laboratories for Materials Science and Technology
Petrobras	Sam Houston State University	T.D. Williamson, Inc.
Petrodin LTDA	Schlumberger Limited	Tabula Rosa
Petroglyph Operating Company	Scott Environmental Services	Technip, USA
Petrohawk Energy Corporation	Seadrill Americas Inc.	Teledyne Webb Research
Petroleum Technology Transfer Council	SEAM Corporation	TerraPlatforms, LLC
PGS Americas	Seanic Ocean Systems	Tertiary Oil Recovery Project - University of Kansas
Phage Biocontrol, LLC	SeaTrepid International, LLC	Tetra Tech, Inc.
Pinnacle Gas Resources	SEG Advanced Modeling Corporation	Texas A&M University
Pinnacle Operating Company, Inc.	Segovia Solutions	Texas A&M University – Kingsville
Pinnacle Technologies	Seismic Source Company	Texas A&M University Agri-Life Extension Service
Pioneer Astronautics, Inc.	Shell Chemicals (North Dakota)	
Pioneer Natural Resources Company	Shell Exploration & Production	Texas Oil and Gas Association
Pitts Oil Company	Sigma3	Texerra LLC
Polaris Energy Company	Sinclair Oil & Gas Company	The Enhanced Oil Recovery Institute
Portland State University	SINTEF Petroleum Research	The Measurement Group LLC
Power, Environmental, Energy Research Institute	SM Energy Company	The Nature Conservancy
PPG Industries (DBA Monroeville Chemicals Center)	Smart Chemical Services	The Pennsylvania State University
Premier Drill Pipe, LTD	SNF Holding Co.	The University of Nottingham
Princeton University	Southern Methodist University	The University of Oklahoma
Produced Water Absorbents	Southern Nevada Water Authority	The University of Texas at Arlington
QEP Resources	Southern Research Institute	The University of Texas at Austin
The University of TX, Permian Basin	University of California Davis	Waaders Consultant

The University of Tulsa	University of California, Los Angeles/Jet Propulsion Laboratory	Walden Consulting
The University of Vermont	University of Colorado	Water Resources Company
Tidewater Marine, LLC	University of Hannover	Weatherford
Timberline Oil and Gas	University of Houston	Welker Engineering Company
TIORCO LLC	University of Kansas	Well Enhancement Services LLC
Titanium Company	University of Kentucky	WellTec
TMD Energy	University of Manchester, UK	West Virginia Geological and Economic Survey
Tom Williams	University of Massachusetts	West Virginia University
Total E&P Research & Technology, LLC	University of Michigan	Western Michigan University
Trendwell Energy Corporation	University of New Mexico	WesternGeco LLC
Triangle Petroleum Corporation	University of North Dakota	WFS
Trout Unlimited	University of Pittsburgh	Whiting Petroleum Corporation
Tubel LLC	University of Southern California	Wildcat Development
U.S. Geological Survey	University of Texas Department of Petroleum and Geosystems Engineering	Williams Exploration and Production Company
U.S. Naval Research Laboratory	University of Utah	Willis Re
U.S. Oil & Gas Corporation	University of Wyoming	Wind River Resources Corporation
Unconventional Gas Resources, Inc.	US Sensor Systems, Inc.	WyoTex Ventures LLC
Universal Geoscience Consulting Inc.	Utah Department of Natural Resources	X-FAB Silicon Foundries Group
University Corporation for Atmospheric Research	Utah Geological Survey	XTO Energy
University of Alabama at Birmingham	Utah State University	Yardney Lithion
University of Alaska Fairbanks	UTEC Survey Inc.	Yates Petroleum
University of Arizona	Veolia Water Solutions & Technologies	Zaetric
University of Arkansas	Viking International Resources	Z-Seis Corp
University of California Berkeley	Virco	

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