OFFSHORE RESEARCH PORTFOLIO

Assessing Risk and Mitigating Adverse Events Associated with Drilling and Production

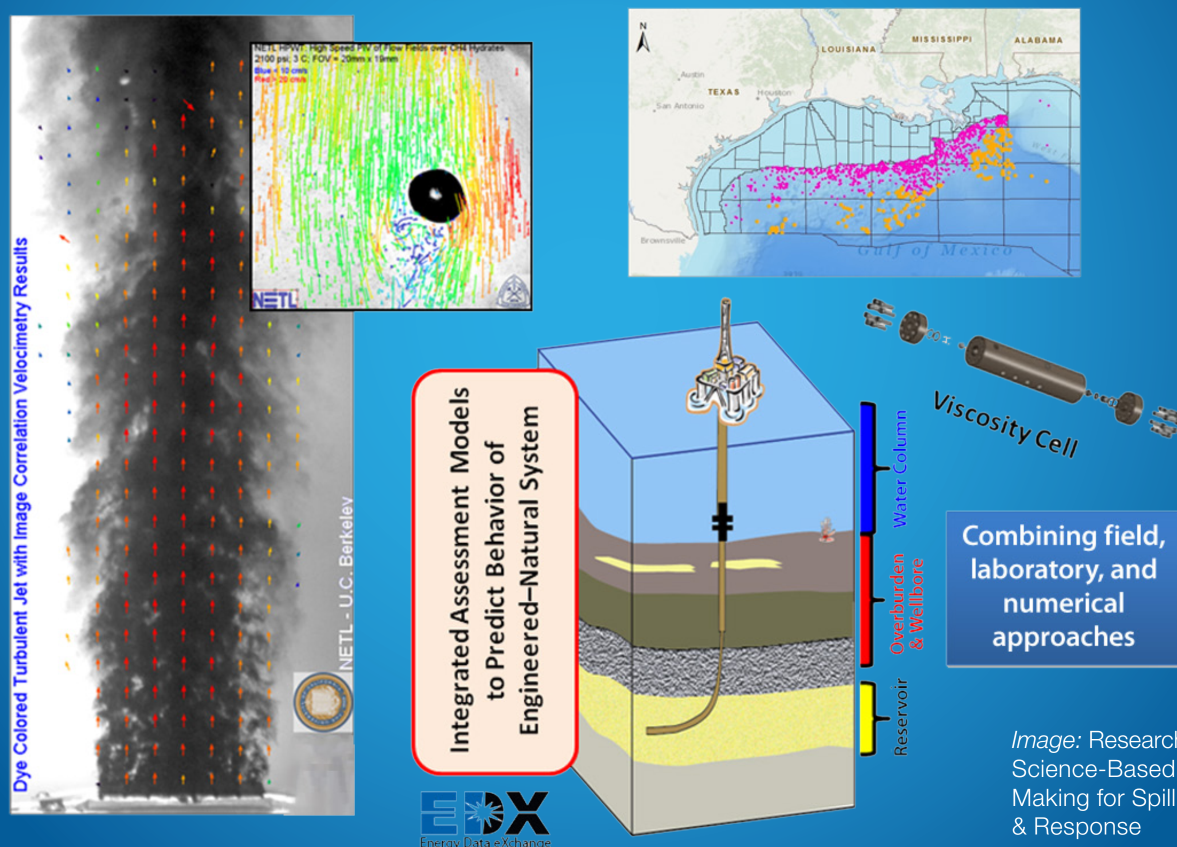

Image: Research to Support Science-Based Decision Making for Spill Prevention & Response

NATIONAL ENERGY TECHNOLOGY LABORATORY

BACKGROUND

Increasingly, offshore domestic oil and natural gas activities are associated with challenging offshore regions such as the ultra-deepwater (> 5,000 feet) Gulf of Mexico and the offshore Arctic. Development in these areas poses unique technical and operational challenges as well as distinct environmental and societal concerns. At present, offshore domestic resources account for approximately 17 percent of United States (U.S.) crude oil production from deep and ultra-deepwater domestic reservoirs and is predicted to increase in coming years. In addition, industry and regulatory agencies have been preparing for increasing future exploration and production activities in the U.S. Arctic offshore waters.

Domestic resources of natural gas and oil will continue to play a critical role in meeting U.S. energy needs provided they can be produced with the confidence that environmental concerns are being addressed effectively. The science base necessary to support stakeholder decisions stems from the ability to understand the behavior of engineered-natural systems over a range of often extreme conditions. The Department of Energy's (DOE) National Energy Technology Laboratory (NETL) has extensive expertise in characterizing engineered natural systems associated with oil and natural gas development. This expertise was leveraged for deepwater and ultra-deepwater hydrocarbon systems through NETL's Complementary Program in support of the Energy Policy Act (EPAct) of 2005 and in coordination with the Research Partnership to Secure Energy for America (RPSEA).

In addition to EPAct, NETL's Offshore portfolio aligns with key federal-scale initiatives including the Ocean Energy Safety Advisory Committee (OESC), chartered February 8, 2011, to advise the Secretary of the Interior on a variety of issues related to offshore energy safety. In particular, the findings and recommendations of the OESC's Spill Prevention Subcommittee, a multi-entity committee that seeks to address safety and potential impacts of offshore hydrocarbon development in the U.S. and adjoining regions. This research is also aligned with some of the goals of the Alaska Interagency Working Group, led by the Department of the Interior (DOI), which brings together state, federal, and tribal government personnel to address energy-related issues and needs in the Alaskan Arctic.

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The objective of the NETL Offshore research portfolio is to build the scientific understanding and assessment tools necessary to develop confidence in the safe and environmentally sustainable development of domestic oil and gas resources. The portfolio consists of six research projects that are working to address quantitative prediction of potential adverse events in extreme offshore drilling and production.

Successful implementation of the portfolio research objectives will ultimately increase America's domestic oil and gas supply, reduce our nation's dependency on foreign imports, and address the environmental and social concerns associated with development:

- **Improve the Science Base for Key Materials**
  Material failures account for nearly two-thirds of all loss of control events, and these almost entirely align with metallic component failures and deepwater cementing issues. Three projects are broadening the Offshore Program's focus on improving the science base for key materials used in extreme drilling environments including where these materials interact in the subsurface.

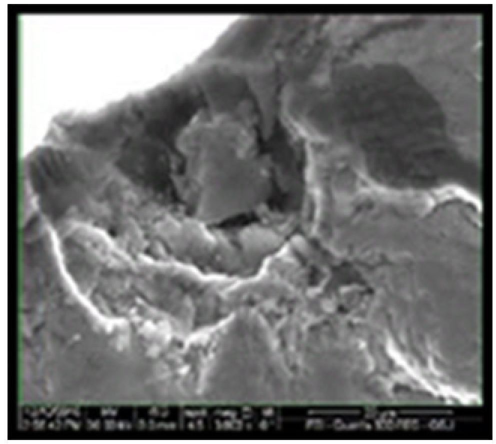

Figure 1. Metal corrosion studies evaluate most commonly used offshore alloys.

- **Characterize Metal-Based Systems Used in Control Devices Subject to Extreme Environmental Conditions**
  NETL is evaluating failure mechanisms and rates for critical components based in part on observed/reported behavior in the field augmented with experimental studies on materials behavior under simulated extreme conditions. Publically available data about the performance of these materials under extreme offshore conditions is limited. To date, this study has successfully evaluated strength and corrosion potential of the most common alloys used in extreme offshore drilling at in situ conditions (pressure, temperature, hydrogen sulfide, etc.). Ongoing work will result in a pit/fatigue modeling tool to allow for the assessment of catastrophic failure potential of these metallic components. NETL is also evaluating new alloys and surface treatments (e.g., hammer peening) for ultra-deep well environments to constrain their behavior under extreme borehole conditions.

- **Determine Physical and Chemical Behavior of Cement Barriers Used in Ultra-deepwater Systems**
  NETL is researching the physical and chemical behavior of typical wellbore cements to better understand how various cement formulations perform, with a particular emphasis on potential failure pathways and remediation technologies. Information is limited on how foam cements commonly used in extreme offshore settings perform and persist under in situ conditions. NETL initiated laboratory characterization studies of commonly used industry standard formulations of foam cements and have obtained the first computed tomography (CT) images of foamed

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cement systems. CT characterization of the samples allows for the quantitative analysis of physical properties and structures within the cement. NETL also developed a reliable methodology to probe the microstructure of foamed cements under in situ conditions. Going forward, researchers will use this methodology to determine stability of foamed cement systems at various "depths" in the subsurface and correlate those properties with the current method of atmospheric testing. Phase 1 findings from this project were released in a Technical Report Series (TRS) publication, *Computed Tomography and Statistical Analysis of Bubble Size Distributions in Atmospheric-Generated Foamed Cement.*

- **Characterize and Analyze the Formation of Cement and Cement Casing Integrity**
  A new project initiated by NETL focuses on determining the physical, chemical, and temporal integrity of the formation of cement and cement casing systems used in extreme offshore settings. The project leverages NETL materials and natural systems expertise to evaluate short- and long-term integrity of the bond between the formation, cement, and casing at in situ conditions representative of the range of subsurface conditions associated with deep offshore drilling. Initially, this project will focus on shallow subsurface conditions (up to 2000 feet below the seafloor) and will incorporate experimental techniques with analysis of field datasets, such as borehole geophysical logs.

- **Improve Hydrocarbon Behavior and Volume Predictions**
  Uncertainties in hydrocarbon properties under in situ conditions (density and viscosity) and behaviors, (hydrate formation and eddies) are key factors impacting the accuracy of predictions of hydrocarbon behavior and volumes in the subsurface and in the water column during a spill event. Two projects in the Offshore portfolio focus on improving the science base for multiphase fluids (e.g., hydrocarbons, CO_2, and brine) at extreme conditions, while another project seeks to predict, assess, and mitigate risks associated with hydrocarbon development in extreme environments in support of spill prevention and response needs.

- **Quantify Complex Fluid-Phase Properties Under High Pressure/High Temperature (HPHT) Conditions**
  NETL is working to improve the accuracy of thermodynamic models under HPHT conditions, allowing for better characterization of reservoir fluids and the dynamics of these fluids during extraction. Improved models will decrease uncertainty associated with fluid quantity and flow at and near the borehole. An accurate understanding of the reservoir and its associated well behavior is an important component of our ability to predict the behavior of wells under both controlled and uncontrolled scenarios. Our lack of understanding of these extreme environments inhibits our ability to predict well behavior and develop methods for safely handling fluids under these conditions. To date, NETL has expanded the density and viscosity databases for hydrocarbon compounds to span HPHT conditions. Researchers have integrated their results with existing lower pressure and temperature data, resulting in a comprehensive database. This work is presented in the Technical Report Series (TRS) publication, *High- Temperature, High-Pressure Equation of State: Solidification of Hydrocarbons and Viscosity Measurement of Krytox Oil Using Rolling-Ball Viscometer.*

  Viscometer and an interactive database and associated application to interface with the database are under development. These will be released through NETL's Energy Data eXchange (EDX), https://edx.netl.doe.gov/

Figure 2. Tubulars used in offshore development.

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- **Improve Flow Assurance, Expediting Well Control, and Reducing Environmental Impacts Resulting from Blow- Outs in High Temperature/ Low Pressure Environments**
  In addition to prevention, spill response research at NETL is addressing major issues related to accurately and rapidly assessing how much hydrocarbon is leaking from a well. NETL researchers are conducting experimental and theoretical studies to obtain fundamental chemical, physical, and hydrodynamic information on the interactions between seawater and fluids that could be released and transported from deep, subsea hydrocarbon reservoirs and inadvertently released into a deepwater environment. This fundamental information will be used in numerical, thermodynamic, and plume models to comprehensively describe potential roles and impacts of gas hydrates. Researchers are working to develop a comprehensive understanding of the formation and stability of simple and complex hydrates under deepwater conditions, stability of hydrates and their interaction with hydrocarbon, and the impact of dispersants, anti-agglomerants, and other chemicals used to mitigate environmental impacts on the fate and interaction of hydrates. Ultimately, the project seeks to develop a remotely-operated-vehicle tool that can be used to rapidly and accurately determine the leak rate, composition, and fate of the hydrocarbons to help guide efficient and effective spill mitigation efforts.

- **Assess Risks and the Potential for Environmental Impacts for Deepwater, Ultra-Deepwater, and Frontier Regions**
  Building on DOE's core competency in simulating and predicting the behavior of engineered-natural systems, NETL is developing a new multi-component model tying the subsurface, wellbore, and water column into a single integrated assessment model (IAM). To effectively evaluate and reduce risks associated with extreme offshore hydrocarbon development, the IAM tool will integrate and synthesize existing subsurface to shore datasets to develop new interpretations for the Gulf of Mexico. The targeted datasets are discussed in the recently released TRS publication, *A Spatio-Temporal Approach to Analyze Broad Risks and Potential Impacts Associated with Uncontrolled Hydrocarbon Release Events in the Offshore Gulf of Mexico.* An interactive database of these data layers will be released through NETL's Energy Data eXchange (EDX). Ultimately, this project will provide a coordinated platform to allow for the independent, rapid, and science- based prediction of ultra-deepwater hydrocarbon risks and potential impacts. With this platform, researchers will be able to conduct predictive assessments of potential social, environmental, and production risk factors and provide recommendations on future data and technology needs to support spill prevention. The tool may also serve as a rapid-response platform in the event of future spills or adverse events.

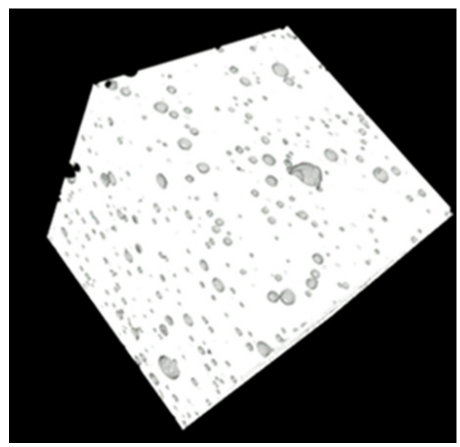

Figure 3. CT image of a foam cement sample generated at NETL for bubble size distribution analysis.

NETL TRS publications associated with this research are available electronically:

http://www.netl.doe.gov/research/on-site-research/publications/featured-technical-reports

Datasets and data-driven products associated with this research are available on the Energy Data eXchange (EDX):

https://edx.netl.doe.gov/

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