# Research news

Science & Engineering
To Power Our Future

*From NETL's Office of Research & Development — October 2014, Issue 1*

FEATURE STORY:

## Revealing Secrets Locked in the Ice

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the ENERGY lab
NATIONAL ENERGY TECHNOLOGY LABORATORY

U.S. DEPARTMENT OF ENERGY

Research news
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# Contents



## Meeting the Energy Challenge

At NETL, we find ourselves on the frontlines of what is quite likely to be the biggest technological challenge of our lifetimes: discovering, developing, and deploying a portfolio of low-cost, environmentally friendly energy sources and energy systems that can meet the nation's, and the world's, growing energy needs for generations to come. It is important work that we do, and I am passionate in my belief that NETL's research and development focus on enabling technologies for sustainable fossil fuel utilization is of critical global importance in a world that will continue to rely on coal, oil, and natural gas to fuel much of its energy needs for the foreseeable future. It is also timely work that we do, because transformative, low-carbon solutions for fossil fuel utilization are needed in the next several decades if we hope to turn the tide on anthropogenic carbon emissions.

To meet this challenge, it is NETL's Office of Research & Development's (ORD) philosophy to create integrated, multi-disciplinary research teams that leverage the capabilities across our three research sites and that are augmented with as-needed added capacity and capability through our site support contract. Over many decades of focus on fossil energy research, NETL, and its predecessor organizations, have built a significant knowledge base and suite of laboratory facilities that are uniquely positioned to address today's sustainable energy challenge. By creating the right research teams with the right research capabilities to address the right research problems, ORD can maximize its effectiveness in advancing sustainable fossil energy technologies.

In this, and future editions of Research News, you will read about ORD's successes in helping to meet the energy challenge, and you will read about the ORD people who dedicate their careers to this research effort. I expect that you will find in these pages that extraordinary research happens at NETL.

***Cynthia A. Powell, Director***
Office of Research & Development
National Energy Technology Laboratory

***Research News*** is a monthly publication from the National Energy Technology Laboratory's Office of Research and Development. We focus on the exciting research done at NETL by our scientists and collaborators.



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**Cover image**
Methane Hydrate, also known as "the ice that burns."

# REVEALING SECRETS LOCKED IN THE ICE

FEATURE

Humans have derived energy from methane ($CH_4$) on a large scale since the 1800s; only in the last few decades have methane hydrates (see Fundamental Fun on page 9) been considered as a possible source. Until recently, it was believed that methane hydrates, fossil fuel trapped within an icy lattice, could only be found at the far reaches of our solar system. As it turns out, the Earth's Arctic permafrost and shallow sediments in the deepwater continental shelves are brimming with methane hydrates. In fact, estimates show that the methane hydrate in our oceans may contain more organic carbon than all of the planet's oil, gas, and coal combined. According to **Yongkoo Seol**, Technical Portfolio Lead for ORD's methane hydrates research effort, the U.S. Department of Energy's (DOE) Methane Hydrates R&D Program is addressing myriad questions about this resource, including how it forms and behaves; its potential as an energy resource; and its role in Earth's carbon cycle.

*NETL researcher Kelly Rose evaluates a natural gas hydrate research core from India's NGHP-01 natural expedition in 2006 aboard the research vessel Joides Resolution.*

This abundant supply of methane hydrate could power the world for years to come, while producing less carbon dioxide ($CO_2$) than burning coal for energy production; however, recovering methane from its icy hydrate form is not simple. Technological and environmental challenges must be addressed before methane hydrate can be safely and economically produced. As part of DOE's mission to achieve energy security and improve domestic supply, safety, and environmental responsibility, NETL's program is studying this energy resource to better understand how to unlock its vast potential for powering the world's future.

NETL researchers have participated in expeditions to the North Sea, the Gulf of Mexico, and other sites potentially rich in hydrates to confirm hydrate reservoirs and obtain core samples for laboratory examination. Back in the lab, the cores undergo testing in specialized facilities (see sidebar on page 4 for details), where researchers unravel the mysteries of how, where, and why hydrates exist. Testing the cores with x-ray computerized tomography (CT) scanners under the high pressures found in the hydrate environment helps to predict how much gas could be produced from specific hydrate reservoirs, enabling researchers to propose site-tailored gas production techniques. In addition, an NETL-developed computer program simulates hydrate behavior during gas production to help predict movement of liquids and solids. These research results will help confirm

**...Continued on page 4**

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the amount of hydrate available, develop technologies to safely and efficiently recover it, and better understand how hydrates link to climate change.

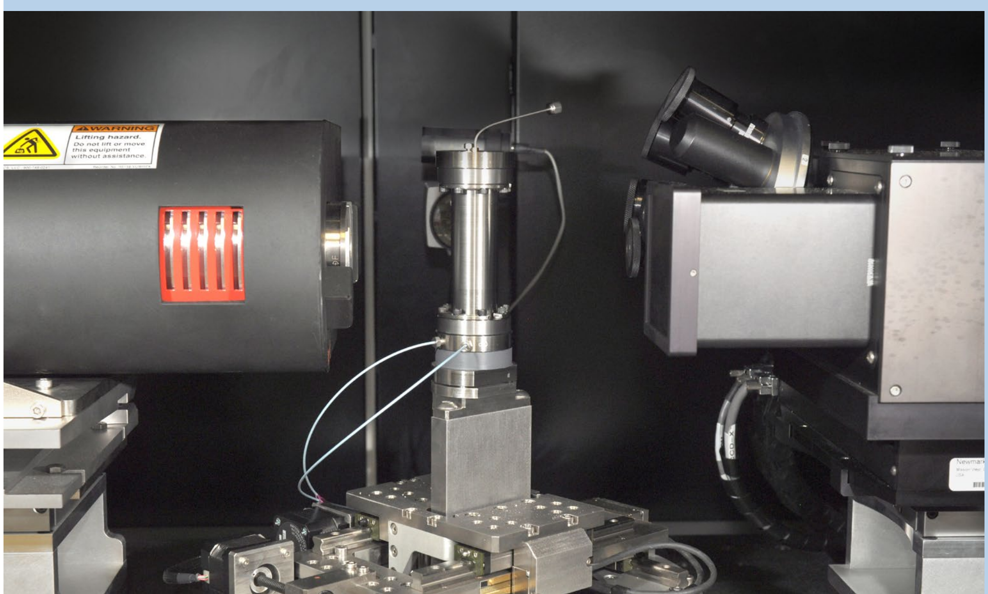
Integrating laboratory experiments with computational models and field research has led NETL scientists to several significant research achievements. "One knowledge gap narrowed by our work is a better understanding of the importance of hydrates' subsurface setting," Geology Team Lead **Kelly Rose** explained. "We already knew that hydrates form under certain pressure, temperature, and salinity, but we recently discovered that additional parameters, such as changes in pore-scale phenomena, influence the concentration, distribution, and presence of subsurface gas hydrate accumulations."

Samples and data from a borehole in the Andaman Sea—part of the Indian Ocean—showed differences in permeability and porosity in sediments beneath the ocean. "Even variations the size of a grain of sand can control how concentrated and where gas hydrate accumulates in marine sediments," Rose explained. Research into the subsurface environment also indicated that these small differences can affect a sediment's ability to sustain gas hydrate formation. These results offer insights into likely controls on the occurrence, distribution, and spatial variability of gas hydrate in other sedimentary settings worldwide. NETL's recently developed pore-scale visualization capability contributed to this breakthrough knowledge by giving scientists a new, close-up view of hydrate sediments. This technology will further promote understanding of hydrate behavior.

NETL's work is also identifying potential hazards that hydrate deposits may represent. Better understanding of the concentration and distribution of methane hydrates leads to greater drilling safety. For example, when drilling for conventional gas deposits in the sea floor, informed producers can better avoid hydrate deposits, reducing the chances of damaging drilling equipment. In addition, Seol said, "We're more informed about natural gas resource distribution and areas where the hydrate could destabilize due to natural or anthropogenic activities." This knowledge can help scientists to better predict the impacts of rising sea temperatures melting ice that encases the methane.

If gas hydrates eventually become a necessary natural gas resource, understanding their distribution, concentration, and behavior can lead to their successful exploration and development, while also protecting the environment. This, in turn, will help ensure the nation's economic and energy security for decades to come.

Contact: Yongkoo Seol



*For visualizing methane hydrate under high pressure, NETL researchers use a micro-CT scanner with a specially designed core holder.*

# Hydrates Facilities

To advance scientific understanding of methane hydrates as a potential future energy resource, scientists use NETL's Geoscience Laboratory; Scanning Electron Microscope Laboratory; and Geoscience Analysis, Interpretation, and Assessments (GAIA) Computational Facilities for experimental and computational research on hydrate samples taken from the field or created in the lab.

Retrieving natural hydrate samples is difficult and expensive, so NETL developed a new technique to create artificial hydrates that act like natural samples. Scientists study these and samples from field sites using specialized equipment, including petrographic microscopes, NETL's custom-built Geotek multi-sensor core logger, and x-ray CT scanners. Using this equipment, researchers can measure permeability, thermal conductivity, and other characteristics, and observe 3-D, real-time hydrate formation, fluid migration, and other aspects that impact hydrate production. The resulting information is used to support and validate computer simulations that predict gas production potential, possible operational hazards, and environmental impacts.

The GAIA Computational Facilities enable real-time collaboration among scientists at NETL's three research sites (Albany, OR; Morgantown, WV; and Pittsburgh, PA). Researchers use the facilities to conduct computer-based analytical work, and access common tools, data, and software in a coordinated environment. Real-time video connectivity allows multiple researchers from the different sites to collaborate remotely.

These facilities help NETL and its partners understand variability among hydrate occurrence sites; the data generated supports computational models, simulations, risk assessments, and experimental studies.

# The Importance of Mentorship

*Kelly Rose (back row, middle) mentors a team of interns on unconventional resources research.*

In any field, the advantages of having a professional mentor can be obvious; what may not always be so apparent are the rewards that accompany being a mentor. **Kelly Rose**, Geology Team Lead for ORD, has mentored 30 early-career scientists, from part-time interns to full-time fellows, and has found embracing the role to be fulfilling. "I've always enjoyed working with others and forming strong collaborative partnerships. At NETL, primarily through the ORISE program, I've had the opportunity to mentor a number of earnest, inspiring, and thought-provoking scientists."

The Oak Ridge Institute for Science and Education (ORISE) program at NETL provides opportunities for undergraduate and graduate students, graduate and postdoctoral researchers, and faculty researchers to work on ORD research projects that support Office of Fossil Energy programs. According to Rose, "ORISE really provides two-way education. These early-career scientists are often coming from academic tracks and have been steeped in data, trends, capabilities, and thinking that are new in the field. ORISE gives the technical staff at NETL the opportunity to be exposed to these new ideas."

**Deborah Glosser**, one of the ORISE scientists currently working with Rose, has been with the program since 2011. "It's not an exaggeration to say that Kelly's mentoring has shaped the entire trajectory of my career as a scientist. . . . Science is very individualized: there's not just one correct way to approach a research task, and Kelly finds that balance between trusting her team members to do their own science while guiding our progress so we don't get lost in the forest.'"

**"ORISE gives the technical staff at NETL the opportunity to be exposed to these new ideas."**

–Kelly Rose, Geology Team Lead for ORD

Rose recently had the opportunity to offer her knowledge and expertise to a greater number of early-career professionals. At the 2014 Incorporated Research Institutions for Seismology (IRIS) meeting, Rose was invited to participate as a panelist in a pre-symposium discussion session, entitled "Jumping on the Employment Express—How to be Part of the Geosciences Employment Boom."

The discussion session was the first event of its type at an IRIS meeting and focused on exploring the multitude of career paths open to those in the geosciences. Rose, with her background in academia, research, and industry, is particularly well suited to participating in such a panel. "The early-career professionals are really looking to understand the range of options that are available. They have mostly been exposed to academic career paths—but they want to know what else is out there. A discussion panel like this helps give them the tools to figure out what career path is right for them."

The panel was attended by more than 35 geoscience students and postgraduates, as well as a handful of geoscience educators and professionals. Based on the success of the panel, IRIS is already planning similar discussions at future meetings.

Contact: Kelly Rose

# New Sensor Technology
## Enables Clean, Efficient Fossil Fuel Power Plants

Innovative process control systems capable of functioning in the high temperatures and harsh environments of fossil-fuel-based power generation systems can play a key role in improving the efficiency of coal conversion while reducing emissions. Such advanced systems will enable continued use of our coal resources to improve U.S. economic competitiveness while providing global environmental benefits through reduced greenhouse gas emissions. A key enabler for innovative process control systems is advanced sensors. These sensors can be used to monitor and control extremely efficient, clean energy systems that employ coal gasification, solid oxide fuel cells (SOFCs), gas turbines, boilers, and oxy-fuel combustion, as well as other industrial or manufacturing processes that operate under extreme conditions.

Currently available sensor technologies have limitations, such as functional temperature ranges, durability, and cost. As a result, there is a pressing need for embedded gas and temperature sensors that can operate at temperatures approaching 1,000 degrees Celsius (˚C), which are typical of power generation systems capable of 90 percent $CO_2$ capture.

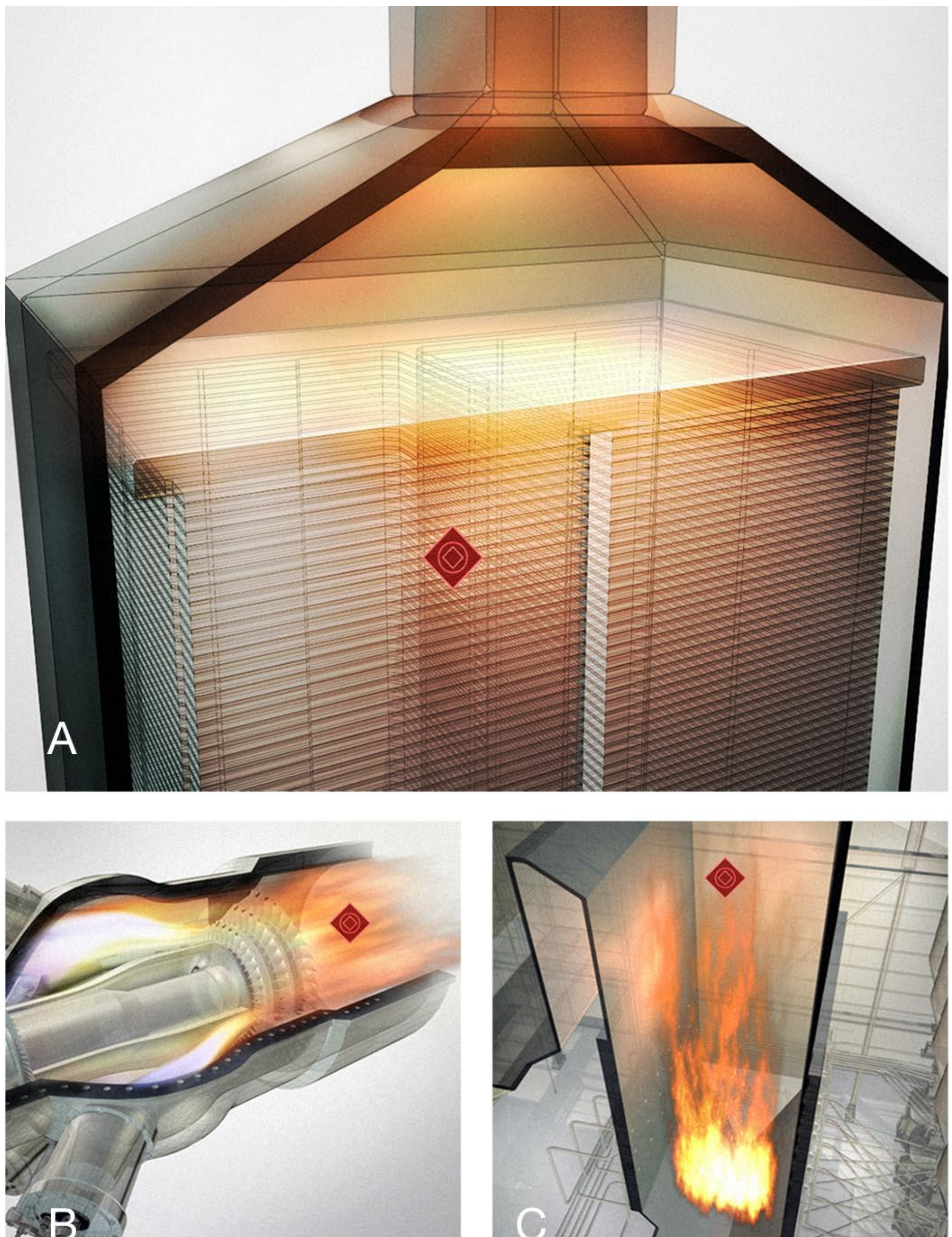
In response to this challenge, NETL and its research partners have developed new sensor materials that demonstrate stability and durability in corrosive environments at temperatures approaching 900 to 1,000 ˚C. The new materials are optical-fiber-based nanocomposites—structures that, due to their small size, high surface area, and combinations of special properties, have greater tolerances of extreme conditions.

Optical-fiber-based sensors can resist electromagnetic interference and do not require electrical wires and contacts that are often the source of sensor failures. This new technology can result in embedded sensors with remote monitoring capability and high durability in the operating environment. The team is currently developing protocols to test prototype sensors in the high-temperature, high-pressure, and highly reducing, oxidizing, or corrosive environments that are typical of advanced power systems.

Ongoing research is focused on identifying optical-fiber core materials that will be stable at even higher temperatures. The team's work has resulted in a portfolio of patented and patent-pending technologies that are available for licensing or further cooperative development.

Additional information about this technology can be found in several of the team's publications, including "Plasmonic Nanocomposite Thin Film Enabled Fiber Optic Sensors for Simultaneous Gas and Temperature Sensing at Extreme Temperatures" and "Optical Gas Sensing Responses in Transparent Conducting Oxides with Large Free Carrier Density."

Contact: Paul Ohodnicki




*Development of functional high-temperature sensor materials will have applications in (a) fuel stacks, (b) gas turbines, and (c) advanced boilers. The red squares illustrate that the team is targeting sensors to be embedded directly in the hot zones for all the different applications.*

# Innovative Laser Technology Gains Attention for Safe $CO_2$ Storage

NETL is attracting private industry attention and winning innovation awards for harnessing the power of lasers to monitor the safe and permanent underground storage of $CO_2$ resulting from fossil fuel combustion in power plants.

Carbon dioxide is a greenhouse gas and byproduct of burning coal, oil, and natural gas. There are increasing calls to isolate $CO_2$ from the atmosphere to reduce its impact on global climate change. Once captured from a power plant, the $CO_2$ can be piped into underground geologic formations for permanent storage. NETL experts are developing a technique, laser induced breakdown spectroscopy (LIBS), that can be used to validate that a storage site is not emitting $CO_2$, or provide early detection of leaks when they do occur. Early leak detection will enable site operators to implement a faster mitigation response to stop the leak. This innovative laser technology is ideal for this application because it can analyze solids, liquids, and gases quickly from a distance at little expense. Other lab-based monitoring techniques require samples to be brought in from the field, delaying analysis and exposing them to temperature and pressure conditions that could alter their chemistry.

The laser in this process emits pulses about five to 10 nanoseconds long. The laser pulses are focused onto a sample, creating a plasma of ions. Atoms in the plasma are excited and then relax, resulting in a spectral emission—a unique fingerprint of light. A fiber optic system delivers the spectral emission to an offsite spectrometer that is used to measure properties of the light and identify the materials it came from. As a result, LIBS can let researchers know within minutes if $CO_2$ is leaking from a storage area by providing spectral data from the site for analysis.

The innovation has received the URS Pyramid Award and the 2013 Third Annual Energy and Innovation Conference Game Changer Award in recognition of its potential for $CO_2$ monitoring. In addition, NETL recently received a patent for "downhole laser sensing technology" that can be used at well sites to detect significant changes in ion concentration in groundwater over the course of $CO_2$ injection or other activities such as hydrofracturing. **Dustin McIntyre,** NETL researcher and developer of LIBS, said several outside organizations have contacted NETL regarding licensing the technology.

Contact: Dustin McIntyre


*NETL researchers **Christian Goueguel** (left) and **Cantwell Carson** align and operate NETL's laser induced breakdown spectroscopy (LIBS) equipment in a lab experiment.*

# Summer Interns Gain—and Give— Insight into Fossil Energy

*In addition to designing and testing his "top hat cyclone" device, Sisler (pictured here with a combustion rig) analyzed surface temperature data taken at gas-turbine conditions. The thermal model he developed to study coupon temperatures will, in his words, "aid in the future setup of experiments for indicating better locations for instrumentation."*

In cartoons, when someone gains sudden insight into a problem, an incandescent light bulb appears overhead. In science, insight is often more gradual. A scientist will experience a series of tiny epiphanies that are more like a string of Christmas lights than a singular shining moment. At least, that was the case with **Andrew Sisler** during his summer internship with NETL.

Sisler's understanding of the energy systems he worked with evolved over the summer. He strove to "achieve many small moments when the light bulb turned on," he explained. One of the outcomes of his research is a novel device that improves the separation of particles from a chemical looping combustion system. The device (called a "top hat cyclone") helps chemical looping reactors maintain normal operation, preventing costly upsets. In this way, Sisler helped to further the Office of Fossil Energy's goal to accelerate the commercialization of advanced energy systems.

***Dominique Williams** and Soheil Razmyar, Mickey Leland Energy Fellows, discuss their presentations during the Mickey Leland Technical Forum that marked the culmination of the internships.*

This year all of NETL's summer interns conducted research that, like Sisler's, helped make fossil energy more affordable and sustainable. The 30 Mickey Leland Energy Fellows, along with four ORISE interns, completed projects that increased the velocity of fuel flow in hybrid energy systems, explored how shale-gas drill pads affect watersheds, and improved catalysts that reduce vehicle emissions, among many other accomplishments.

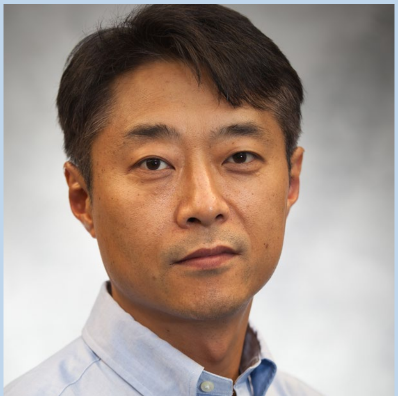
The interns worked alongside ORD scientists and engineers during the course of their projects. Sisler, for instance, was mentored by **Doug Straub**, whom he described as "a great teacher and leader to me." **Laura Dalton**, another intern, investigated foamed cement under the guidance of **Eilis Rosenbaum**. "Laura was tasked with developing a new approach to segmentation where the bubbles [inside foamed cement] are considered separate and discrete," explained Rosenbaum. "She worked very independently. I gave her the project plan, and she ran with it." For her part, Dalton enjoyed that sense of independence. "I was given some freedom in the methods taken for my project and was treated like a professional, which was a valuable experience," she said. She also was able to advance NETL's understanding of how foamed cements can be used in carbon sequestration.

According to Straub, these summer internships can be rewarding for interns, their mentors, and all of NETL. "Although the duration of the assignment is short, significant contributions to the organization's mission can be achieved," he said. "The opportunity to mentor students . . . has been a very positive experience, and I would recommend it for others." The relationships that ORD scientists foster with their interns promise to bring even more energy-related facts to light.

Contact: Nancy Andres

**Students:** To learn more about becoming an intern at NETL, contact Nancy Andres. For more about the MLEF program, click here.

# NETL's In-House Research Program:
## Natural Gas Hydrate R&D



*Yongkoo Seol, Methane Hydrates Technical Portfolio Lead*

Recent discoveries of methane hydrate in Arctic and deepwater marine environments have highlighted the need for a better understanding of this substance as a potential energy resource and a natural storehouse of carbon. Methane hydrate science has advanced steadily over the past decade, resulting in commercial-scale, hydrate production field tests; however, the sustainable, commercially viable production of hydrates still faces a number of scientific uncertainties and technical challenges. For example, depressurizing and removing methane from within the ice-like cage containing it can impact the structural integrity of the hydrate-bearing sediment. NETL researchers are addressing the technical challenges of producing methane hydrate by using numerical modeling codes to simulate methane hydrate's behavior in its natural environment and under production scenarios. The models are continually improved by a complementary research effort to generate new physical property data and understand flow behavior in both lab-synthesized and naturally occurring hydrate-bearing sediments. To accomplish this, the research program includes these key tasks:

- Simulation of long-term production tests at potential Alaska North Slope test sites to assist in locating test sites, to better understand the production process, and to assess the potential for interaction with existing infrastructure.
- Laboratory experimental tests to measure hydrologic and geomechanical properties of hydrate-bearing sediments to improve reservoir-scale production modeling predictions.
- High-resolution, pore-scale visualization and characterization tests of hydrate-bearing sediments to better understand hydrate formation and dissociation behavior and to develop pertinent models that will assist in designing resource recovery strategies.

Contact: Yongkoo Seol

FUNDAMENTAL FUN

# Fundamentals of Methane Hydrate

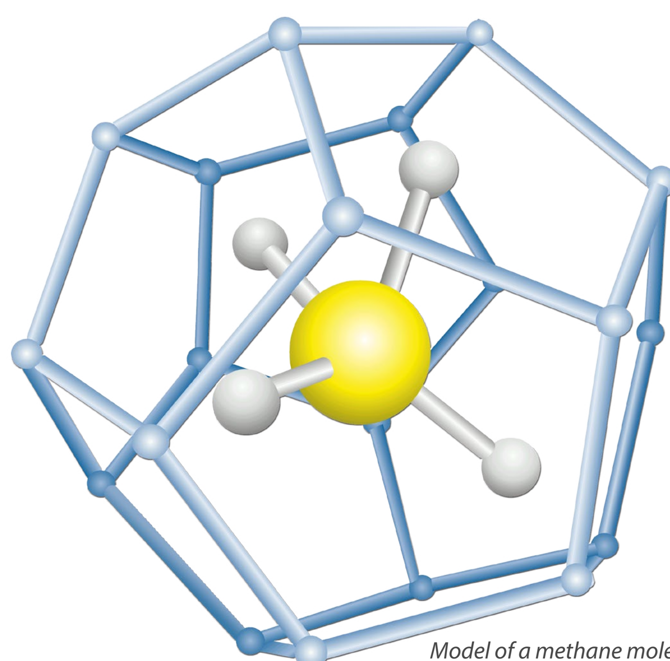
Natural gas hydrate is a special type of clathrate—a crystal structure in which one type of molecule is "caged" inside another. In natural gas hydrate, the "cage" is water ice and the trapped molecules primarily $CH_4$. Natural gas hydrates are a virtually untapped source of natural gas for energy.

Hydrate occurs naturally and stores large volumes of natural gas under the high-pressure and low-temperature conditions found on the continental shelves beneath the oceans. Natural gas is formed—with the help of microbes—as organic material in buried sediments decays. It combines with water in the sediments, which freezes and traps the gas in the clathrate structure.

So why the interest in methane hydrate?

- First of all, it is abundant. Hundreds of thousands of trillion cubic feet (100,000s Tcf) of natural gas may exist in oceanic methane hydrate worldwide (the United States' total natural gas resources are estimated at a fraction of that amount-about 2,000 Tcf). Just 5 Tcf would meet the needs of 5 million households for 15 years.
- Hydrate contains a significant amount of natural gas in a small volume. A cubic meter of hydrate expands more than 150 times as natural gas is released at atmospheric pressure and temperature.

For more information about methane hydrate and how NETL is studying this potentially important energy resource, see the 2011 NETL report, Energy Resource Potential of Methane Hydrate.



*Model of a methane molecule enclosed in a water-molecule cage.*

# APPLAUSE

## Awards

ASM International will present a 2015 ASM Engineering Materials Achievement Award to NETL (**Paul Jablonski**, **Paul Turner**, **Edward Argetsinger** [URS], and **Jeffrey Hansen** [retired]), its partner Boston Scientific, and the other organizations that worked on the development, transfer, and successful commercialization of a novel platinum-chromium alloy used in the manufacture of the next generation of coronary stents.

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## Patents Issued

Apparatus and Process for the Separation of Gases Using Supersonic Expansion and Oblique Wave Compression, **John G. Van Osdol**, 8,771,401, issued July 8, 2014.

A Method and Device for Remotely Monitoring an Area Using a Low Peak Power Optical Pump; **Steven D. Woodruff**, **Dustin McIntyre** (DOE/NETL), and **Jinesh Jain** (URS); 8,786,840, issued July 22, 2014.

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## Kudos!

NETL researchers and collaborators from West Virginia University are cited 13 times in "...a comprehensive literature review on recent state-of-the-art technologies, sensor placement methodologies, dynamic evaluations and control strategies that have been proposed to improve the efficiency of integrated gasification combined cycle (IGCC) power plants." This survey (http://www.sciencedirect.com/science/article/pii/S0016236114007376 ), published by Fuel, is available from Elsevier. Congratulations to **Steve Zitney** and the entire NETL dynamic simulation and control team!"

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## Licenses

Santa Catarina Philanthropic Association/Brazil Coal Association, license for Carbon Capture Simulation Initiative (CCSI) Moving Bed Process Model to develop carbon capture technology, issued July 24, 2014.

# EXTRA! EXTRA!

Read all about ORD's Accomplishments in the
Office of Research & Development Annual Review


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