METHANE HYDRATE NEWS

FIRE IN THE ICE

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NATIONAL ENERGY TECHNOLOGY LABORATORY

Japan's Phase Four Methane Hydrate Research Program

Koji Yamamoto[1], Norio Tenma[2], and Masanori Abe[3]

[1]Japan Oil, Gas and Metals National Corporation (JOGMEC)
[2]National Institute of Advanced Industrial Science and Technology (AIST)
[3]Japan Methane Hydrate Operating Co., Ltd. (JMH)

Japan's MH21 research program, initiated in 2001, has yielded many valuable outcomes. These include the discovery of highly concentrated methane hydrate zones in sandy layers of turbidite sediments, verification of depressurization as an energy-efficient gas production technique through laboratory and empirical experiments, and completion of onshore and offshore production tests that resulted in a wealth of valuable field data. However, there is still a long way to go to achieve the project's goal of introducing marine methane hydrates into the Japanese domestic resource portfolio.

After a review of past accomplishments and remaining challenges, the Japanese Ministry of Economy, Trade, and Industry (METI) decided to continue methane hydrate R&D with the launch of a new phase, Phase Four. Phase Four of the program covers Japanese fiscal years 2019–2022, which spans April 2019 through March 2023. The new R&D program was designed in accordance with Japan's revised national marine resource development plan (link to METI 2019 plan). The newly formed MH21-S consortium is tasked with executing the part of the plan that targets resources that occur in sedimentary pores, known as pore-filling type hydrate.

Project Targets in 2023

To realize the long-term goal of the project, namely commercialization of Japan's offshore gas hydrate resources, a new offshore production test in Japanese water is being planned for 2023 or later. This is essential to demonstrate that methane hydrate offshore Japan can be a viable energy resource. Before starting detailed design of this new test, the Phase Four program team has been analyzing economic conditions that must be satisfied to justify the additional expense.

The conditions for the new test were defined through an economic analysis of assumed offshore production systems, under realistic future gas prices and deepwater technology scenarios. Results of this analysis revealed that

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CONTACT

Joseph Stoffa
Technology Manager
Methane Hydrate R&D Program
(304) 285-0285
joseph.stoffa@netl.doe.gov

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two dominant factors determine the economic viability of the resource: (1) the scale of resource, measured as gas volume in place; and (2) the gas production rate for a given well. Economic criteria associated with these factors were evaluated quantitatively.

An appropriate candidate test site must have sufficient resource volume to supply future gas production fields, and it must undergo a preliminary environmental impact analysis. To qualify as an appropriate site, the minimum gas volume in place at the site must be 10 billion m^3 (0.35 Tcf). Another major condition is that the expected gas production rate per well, as determined from improved and verified reservoir models, must be above a lower threshold rate of 50,000 m^3/day (1.8 mmscf/day) (Figure 1). With these economic conditions satisfied, improved production technologies should yield several months of continuous gas production under existing offshore conditions, at a candidate test site.

Problems to Address

The last two production tests in the Eastern Nankai Trough managed to achieve pressure drawdown and maintain stable production of gas and water for several days. Along with operational problems, such as sand control and flow assurance issues, the most critical challenge to be addressed for the future of commercially viable gas production from the hydrate reservoir was the gas production rate. The maximum gas production rate achieved was around 20,000 m^3 in the AT1-P well (2013), which is below the economic threshold rate, noted above, of 50,000 m^3/day. Some numerical models had predicted that the gas rate could be increased with time; however, such behavior was not observed in any of the prior tests. (link to article).

The analyses of monitoring data in producer and observer wells, as well as history matching between numerical model results and actual production behavior, indicate two factors that likely inhibited stable and increasing gas production rates. One was the excess water supply from the reservoir, which mainly arose from the heterogeneous occurrence of methane hydrates and the existence of adjacent water-bearing zones. Another factor was a pressure drop across the wellbore surface and sand control device (skin), which prevented the drawdown of the formation pressure, even when the bottom-hole pressure was drawn down. The unconsolidated nature of the reservoir may have contributed to the latter factor.

A risk analysis of the above factors was conducted to gain insights into prevention and mitigation measures. The development of these measures is considered to be the most important part of the Phase Four study. Several ideal and actual methane hydrate dissociation scenarios, along with examples of preliminary risk analysis results related to the excess water supply problem, are shown in Figure 2.

National Energy Technology Laboratory

1450 Queen Avenue SW
Albany, OR 97321-2198
541-967-5892

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880
304-285-4764

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940
412-386-4687

Program staff are also located in Houston, TX and Anchorage, AK.

Visit the NETL website at:
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Fire in the Ice is published by the National Energy Technology Laboratory to promote the exchange of information among those involved in gas hydrates research and development.

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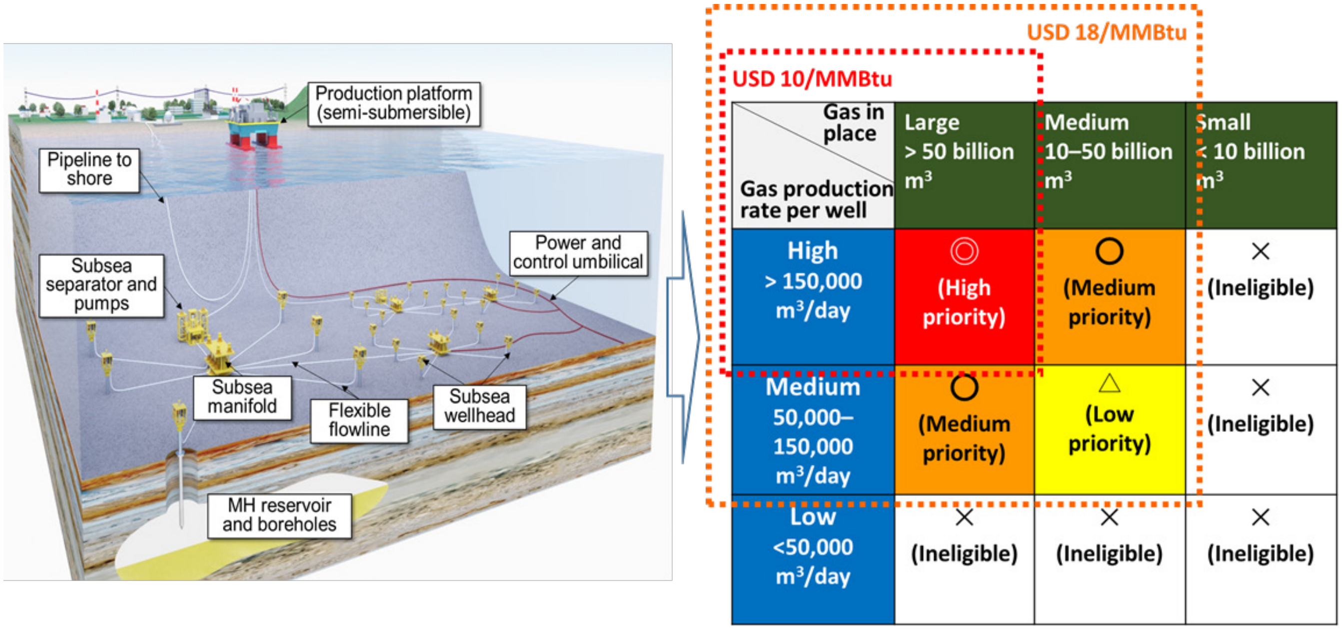
Interested in contributing an article to *Fire in the Ice*?

This methane hydrate newsletter now reaches 1600 individuals, representing 20 countries. If you would like to submit an article on research results likely to be of interest to the methane hydrate R&D community, please contact Fran Toro at frances.toro@netl.doe.gov or Karl Lang at klang@keylogic.com. We look forward to hearing from you.



Gas production rate per well / Gas in place	Large > 50 billion m^3	Medium 10–50 billion m^3	Small < 10 billion m^3
High > 150,000 m^3/day	◎ (High priority)	○ (Medium priority)	× (Ineligible)
Medium 50,000–150,000 m^3/day	○ (Medium priority)	△ (Low priority)	× (Ineligible)
Low <50,000 m^3/day	× (Ineligible)	× (Ineligible)	× (Ineligible)

Figure 1. (LEFT) Schematic diagram showing an assumed gas production system. (RIGHT) Table showing evaluated economic criteria of gas volume in place (volumes shown in green) and gas production rate per well (rates shown in blue). Gas prices of 10 U.S. dollars per million btu's shown in dashed red square, 18 U.S. dollars per million btu's in dashed orange square.

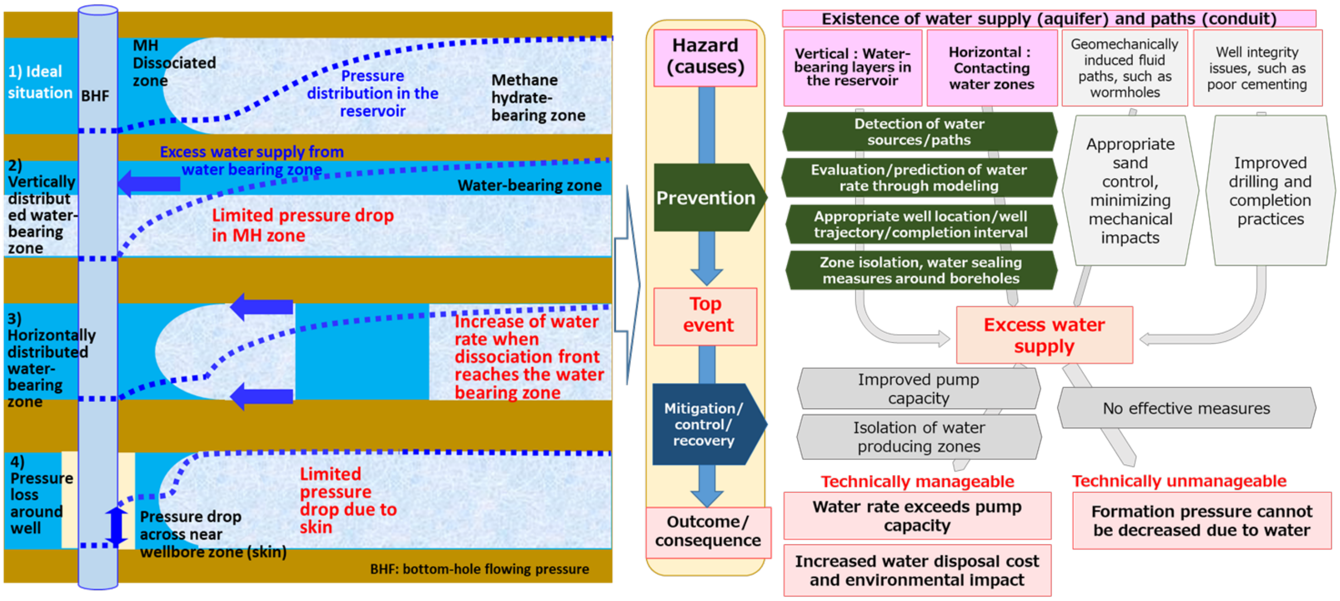


Figure 2. (LEFT) Well diagram showing methane hydrate (MH) dissociation scenarios behind the borehole. Top panel shows ideal situation, and three lower panels illustrate problem situations due to excess water supply and limited pressure drop. (RIGHT) Chart illustrating an example of risk and prevention/mitigation analysis, for the excess water supply scenario.

R&D Plan for Phase Four

The Phase Four R&D Plan is focused on identification and verification of the best solutions to these production problems. The Phase Four approach has two key items, as shown in Figure 3: (1) development of improved production technologies, including improved reservoir modeling; and (2) execution of a marine survey to identify appropriate future test sites.

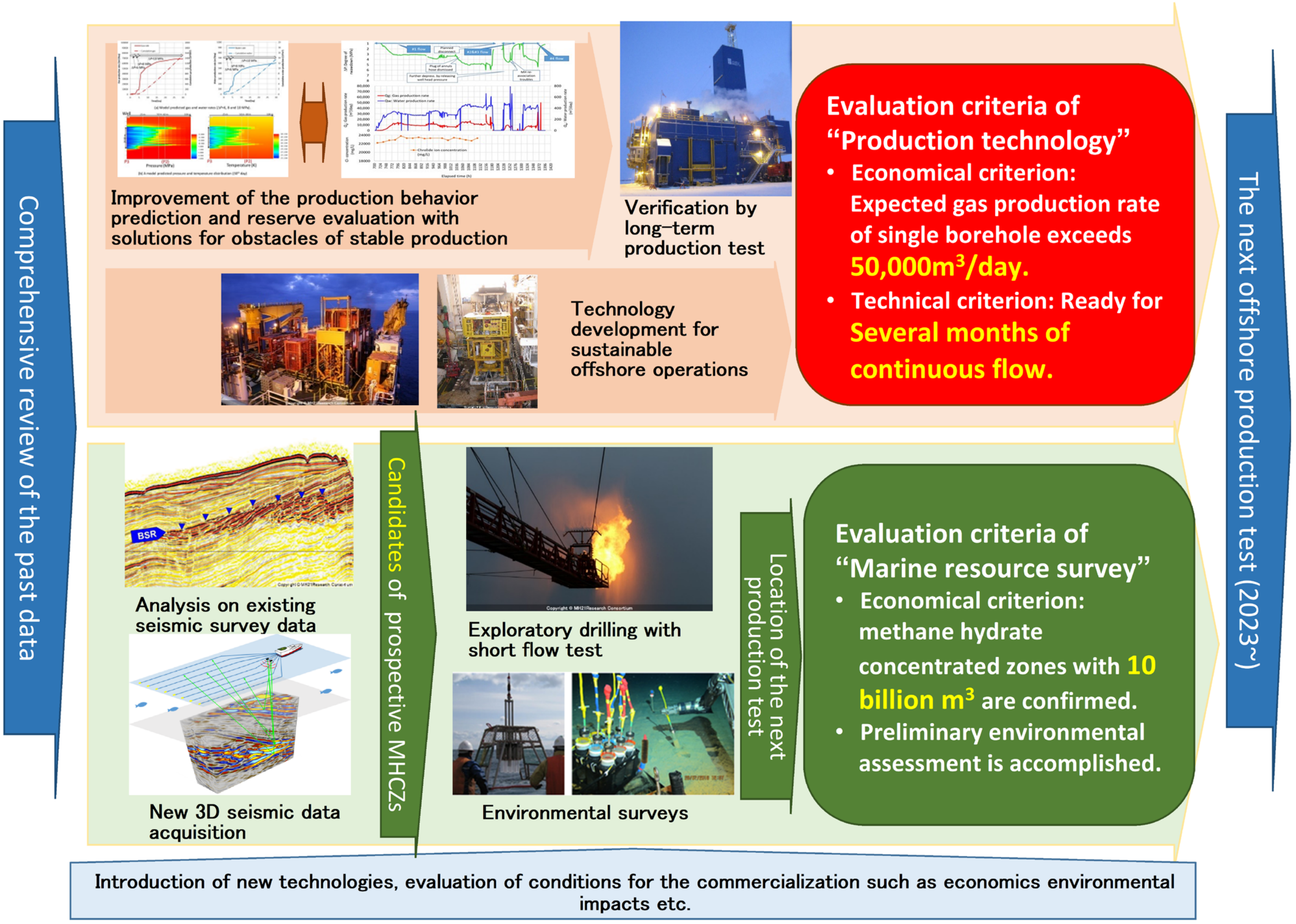


Figure 3. MH21-S study plan for the Phase Four program, for Japanese fiscal years 2019–2022.

The production technology study contains analyses of past production test data, the development of countermeasures for potential problems, and the refinement of reservoir models and physical models. To verify these technologies over an extended timescale, a long-term onshore production test will be conducted, via collaboration between Japan and the United States. The first step of the effort, the drilling of a stratigraphic test well on the Alaska North Slope, was completed in December 2018 (see Fire in the Ice, Vol. 19, Iss. 1). This has been followed by careful planning of a one-year continuous flow test, based on the depressurization method.

To determine an appropriate site for a future production test, the first step is detailed analysis of existing and newly acquired three-dimensional (3D) seismic survey data. Such data will be used to select a list of candidate sites, and these candidate sites will be tested via an exploratory drilling campaign. This will include short-term flow tests for reservoir characterization of selected candidate sites.

In addition to these major activities, environmental impact studies, economic analyses, and integration of new technologies into mainstream studies will continue throughout the project. The R&D activities will be conducted by the MH21-S consortium, which includes the original participants – the Japan Oil, Gas, and Metals National Corporation (JOGMEC) and the National Institute of Advanced Industrial Science and Technology (AIST) – as well as new consortium member Japan Methane Hydrate Operating Co., Ltd. (JMH), a private company established with funding from major energy and engineering firms. In addition to the R&D studies of pore-filling-type methane hydrate by the MH21-S consortium, AIST will continue to conduct surveys and technological studies of seafloor methane hydrate production and recovery as a separate program.

Conclusions and Future Directions

Japan's methane hydrate R&D program is entering a new phase, Phase Four, aimed at establishing the economic viability of its methane hydrate resource. There are many unresolved questions about the nature of methane hydrate in geological formations, rendering science a crucial component of the program. In the coming years, the MH21-S consortium, organized by industry and academia, will pull together all necessary knowledge and expertise to bring Japan closer to commercialization of its offshore methane hydrate resource.

Suggested Reading

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SECOND INTERNATIONAL GAS HYDRATE CODE COMPARISON STUDY—SUCCESSES AND LESSONS LEARNED

Mark D. White

Pacific Northwest National Laboratory

The second International Gas Hydrate Code Comparison Study (IGHCCS2) was completed, in July, 2020. Results and lessons learned are now available in a public-access article in the Journal of Marine and Petroleum Geology (see JMPG, Vol. 120, 104566).

The IGHCCS2 was a 3-year effort launched in November, 2017 and sponsored by the U.S. Department of Energy National Energy Technology Laboratory (DOE/NETL). It brought together gas hydrate experts from diverse nations to compare and improve numerical modeling tools used for gas hydrate reservoir simulation.

The journal article serves as the study's final report and includes some background on the impetus for the study; a complete list of partners who participated in the study; simulators used in the study; benchmark problem descriptions and solutions; and overall successes and lessons learned from the study.

The study was a follow-on to IGHCCS1, the first international gas hydrate code comparison study, conducted in the early 2000s and also funded by the DOE/NETL. That effort focused on coupled thermal and hydrologic processes in hydrate-bearing reservoirs, during production by depressurization and thermal stimulation. Since then, gas hydrate reservoir models have grown more sophisticated, and several newer codes incorporate geomechanical processes into the mix.

Modeling teams from all over the world, representing 21 institutions, participated in IGHCCS2. These included the University of Cambridge, GEOMAR, Jilin University, Japan Oil, Gas and Metals National Corporation, Korea Advanced Institute of Science and Technology, Korea Institute of Geoscience and Mineral Resources, Kyoto University, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, NETL, University of Pittsburgh, Pacific Northwest National Laboratory, Rensselaer Polytechnic Institute, Sandia National Laboratories, University of Southampton, Texas A&M University, University of California Berkeley, University of Ulsan, Universitat Politecnica de Catalunya, and University of Texas at Austin.

For the IGHCCS2, participants developed five new benchmark problems, which served as the basis for testing and comparing hydrate reservoir simulators. The benchmark problems were carefully configured to represent a range of hydrate reservoir production scenarios. They range from simple geometries to more complex cases. Figures 1 and 2 illustrate the conceptual frameworks for Benchmark Problems 1 and 2. One benchmark problem was specifically designed to represent the first offshore production test, off the coast of Japan.

To identify strengths and limitations of the different simulators, participants ran simulations of the benchmark problems and compared results. Each benchmark problem was given a problem champion, whose role it was to field questions and oversee discussions and results related to their particular problem. Participants submitted solutions for the benchmark problems and discussed differing results via teleconferences. The simulators evolved over the course of the IGHCCS2, as researchers made modifications to reflect new insights and lessons learned. The five benchmark problems and sample solutions are provided in the JMPG journal article

The IGHCCS2's strategy, comparing hydrate reservoir simulators using carefully designed benchmark problems, was effective for identifying areas of agreement and disagreement between the modeling codes. The solutions to the benchmark problems indicate that it is indeed critical to account for geomechanical effects of hydrate production, along with coupled thermal and hydrologic processes.

Overall, the IGHCCS2 was very successful in achieving its goals. From a procedural standpoint, it brought together modeling teams from around the world to focus on a common goal of optimizing hydrate reservoir simulation. From a technical, it succeeded in validating the conceptual basis of existing simulation codes.

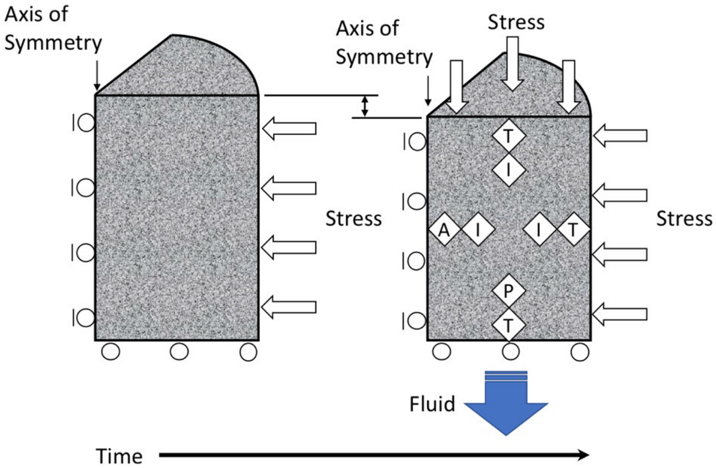


Figure 1. Conceptual schematic of Benchmark Problem 1, with white arrows indicating a stress boundary, circles indicating a roller boundary, T indicating a temperature boundary, P indicating a pressure boundary, I indicating an impermeable boundary, and A indicating an adiabatic boundary. Fluid exits sample base in response to consolidation (blue arrow).

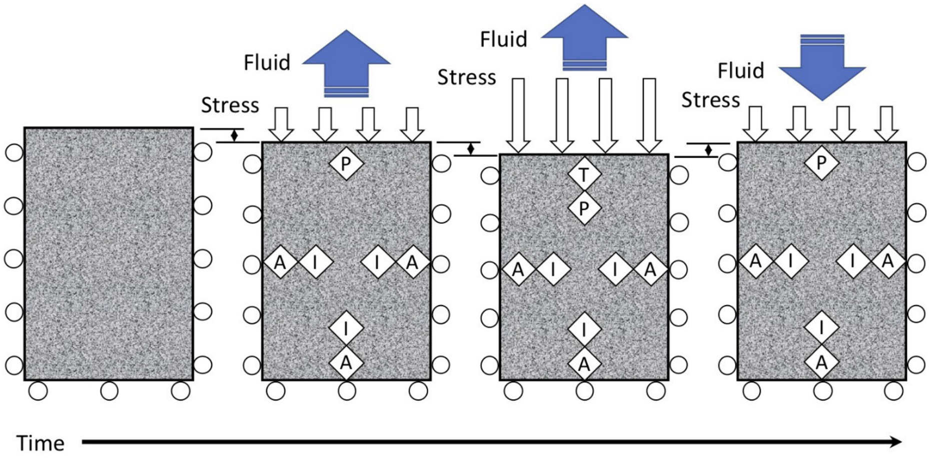


Figure 2. Conceptual schematic of Benchmark Problem 2, with white arrows indicating a stress boundary, circles indicating a roller boundary, T indicating a temperature boundary, P indicating a pressure boundary, I indicating an impermeable boundary, and A indicating an adiabatic boundary. Fluid moves out and into the model domain across the top surface (blue arrows) in response to the evolving stress state.

Overarching technical outcomes include:

1. Successful validation of the computational framework of gas hydrate reservoir simulators; and
2. Demonstration of the importance of including geomechanical effects in modeling gas hydrate reservoirs.

The IGHCCS2 benchmark problem solutions can be found at: https://edx.netl.doe.gov/group/ighccs2

The full journal article, which serves as the study's final report, is available at: https://doi.org/10.1016/j.marpetgeo.2020.104566

The complete citation is:

M.D. White, T.J. Kneafsey, Y. Seol, W.F. Waite, S. Uchida, J.S. Lin, E.M. Myshakin, X. Gai, S. Gupta, M.T. Reagan, A.F. Queiruga, S. Kimoto, R.C. Baker, R. Boswell, J. Ciferno, T. Collett, J. Choi, S. Dai, M. De La Fuente, P. Fu, T. Fujii, C.G. Intihar, J. Jang, X. Ju, J. Kang, J.H. Kim, J.T. Kim, S.J. Kim, C. Koh, Y. Konno, K. Kumagai, J.Y. Lee, W.S. Lee, L. Lei, F. Liu, H. Luo, G.J. Moridis, J. Morris, M. Nole, S. Otsuki, M. Sanchez, S. Shang, C. Shin, H.S. Shin, K. Soga, X. Sun, S. Suzuki, N. Tenma, T. Xu, K. Yamamoto, J. Yoneda, C.M. Yonkofski, H.C. Yoon, K. You, Y. Yuan, L. Zerpa, M. Zyrianova, 2020. An international code comparison study on coupled thermal, hydrologic and geomechanical processes of natural gas hydrate-bearing sediments. Marine and Petroleum Geology, Volume 120, 104566, ISSN 0264-8172.

IGHCCS2

2ND
INTERNATIONAL
GAS
HYDRATE
CODE
COMPARISON
STUDY

ELECTRICAL CONDUCTIVITY OF PURE CO_2 HYDRATE AND CH_4 HYDRATE: ROLE OF THE GUEST MOLECULE

Laura Stern[1], Steven Constable[2], Ryan Lu[3], Wyatt Du Frane[3], Jeffery Roberts[2,3]

[1]U.S. Geological Survey, Menlo Park, CA
[2]Scripps Institution of Oceanography, University of California, La Jolla, CA
[3]Lawrence Livermore National Laboratory, Livermore, CA

To conclude a series of DOE-sponsored laboratory experiments in which our team measured electrical conductivity of methane hydrate-bearing samples, we investigated the electrical conductivity of CO_2 hydrate for direct comparison with methane hydrate. Their surprisingly distinct signatures could aid in the monitoring of CO_2 in certain deep marine environments. To the best of our knowledge, these are the first reported conductivity measurements on pure, polycrystalline CO_2 hydrate.

Background

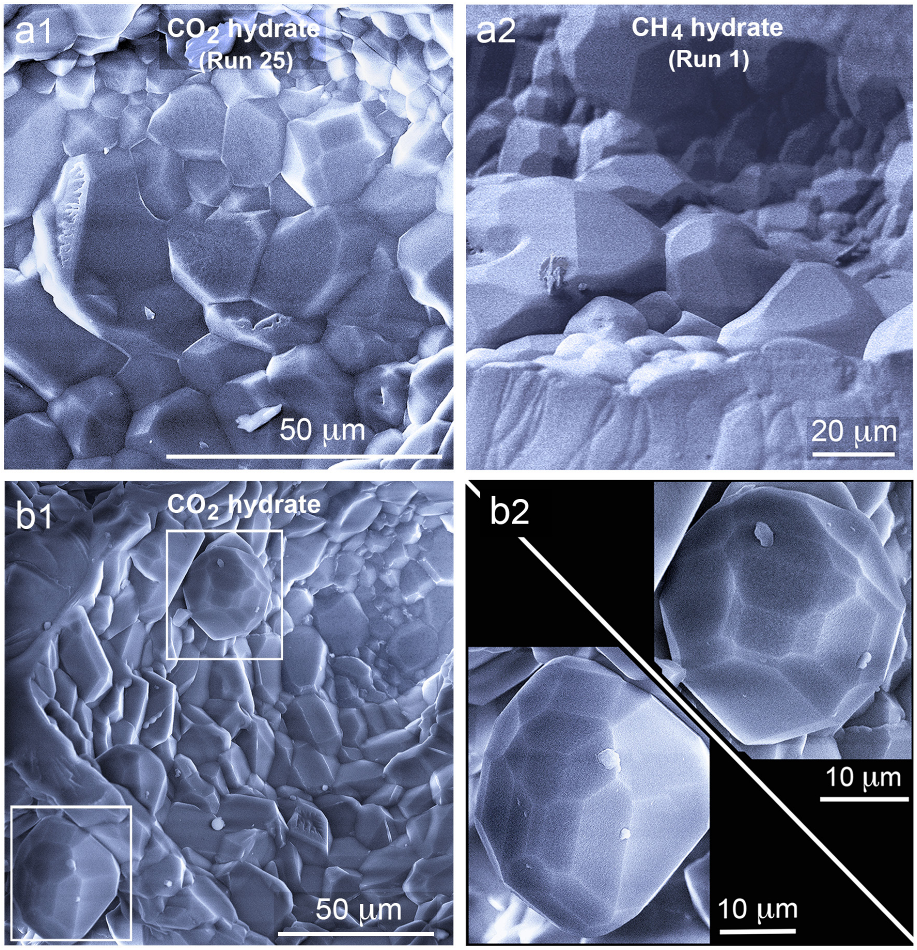
Energy considerations and global carbon concerns continue to spur research efforts examining methane (CH_4) hydrate, carbon dioxide (CO_2) hydrate, and mixed CH_4/CO_2 gas hydrates. These efforts commonly target physical processes involved during CH_4-CO_2 replacement and issues surrounding possible sequestration of CO_2 by injection into deep methane hydrate-forming deposits. In our previous work aimed at characterizing gas hydrate by marine electromagnetic (EM) methods, we formed pure structure I CH_4 hydrate as well as increasingly complex CH_4 hydrate + sediment + fluid/brine mixtures, while simultaneously measuring electrical impedance. Results highlighted the important contribution of minor ionic impurities derived from sediment surfaces or the initial ice grains themselves.

An outstanding question remained: can guest-molecule composition itself influence electrical conductivity (σ) of structure I hydrate? We chose CO_2 hydrate for comparison given its analogous structure, near-ideal cage filling (by our methods), and previous in-house experience in forming well-characterized samples of CO_2 hydrate for other material property comparisons with CH_4 hydrate. Here we compare σ of pure CO_2 hydrate with CH_4 hydrate prepared from the same H_2O (ice) source. This eliminates variation in ionic impurities imparted by the ice reactant itself.

Methods

Procedures followed those of our previous tests on CH_4 hydrate *(Fire in the Ice, Vol. 11, Iss. 2 and Vol. 18, Iss. 1)*, modified here for the CO_2-H_2O system. Granular "seed" ice, formed from distilled-deionized water, was packed between two electrodes in the pre-chilled conductivity chamber. The chamber was flooded with CO_2 to pressure-temperature conditions within the CO_2 hydrate + CO_2 liquid field and subjected to 6 thermal cycles of 12-50 hours each to ensure complete reaction of ice to hydrate. Electrical impedance (Z) was measured throughout all cycles over the frequency range 0.5 to 300 kHz using an LCR (Inductance-Capacitance-Resistance) meter to form complex Z spectra. Final measurement of Z was collected on fully-reacted CO_2 hydrate, in both the CO_2 liquid and gas fields, to verify no apparent changes caused by the CO_2 state itself. Sample texture was then assessed by cryogenic scanning electron microscopy (Cryo-SEM). When made by comparable methods, CO_2 hydrate is virtually indistinguishable from CH_4 hydrate in appearance, grain size, and grain connectivity (Figure 1).

*Figure 1. What do samples look like? Cryo-SEM images of CO_2 and CH_4 hydrate. Upper left image of pure CO_2 hydrate test material (**a1**) confirms dense, polycrystalline material with grainsize typically 5-80 µm, similar to pure CH_4 hydrate test material (**a2**). Lower images show CO_2 hydrate formed previously by* Circone et al. *methods (**b1**, **b2**), on which the current study is based. Final porosity (~25%) occurs primarily as isolated cavities. Along exposed cavity walls, crystals often exhibit highly faceted development where they grow unimpeded. Note, the sample in **b1** was synthesized and first imaged in 2001, then wrapped and stored in liquid nitrogen for nearly 20 years prior to re-imaging during the current study. Single crystals outlined in **b1**, expanded in **b2**, display no adverse effects from long-term storage and retain well-developed isometric crystalline forms and at least most of their carbon content. Imaging conducted at -180±5 °C, 10-15 kV.*



Electrical conductivity

Impedance spectra were analyzed to calculate σ of the sample material, while excluding external systemic (such as electrode) contributions. Conductivity that exhibits an exponential temperature dependence can be fit using an Arrhenius relation:

$$\sigma(T) = \sigma_0 * e^{-E_a/RT}$$

where σ_0 is a pre-exponential constant, E_a is activation energy, R is the gas constant, and T is temperature. Plotting log(σ) vs. inverse T provides slopes proportional to E_a and that characterize T dependence. An Arrhenius plot of σ of CO_2 hydrate, CH_4 hydrate, and other select samples is shown in Figure 2.

The key take-away of Figure 2 is that σ of pure CO_2 hydrate is ~ 1.5 orders of magnitude greater than for pure CH_4 hydrate across the geologically-relevant temperature range -15 to +8°C. Activation energy E_a is ~ 33% higher than for CH_4 hydrate (46.5 kJ/mol vs. 34.8 kJ/mol) and almost identical to that of H_2O ice used to synthesize our samples (45.3 kJ/mol). CO_2 hydrate is also more conductive than CH_4 hydrate containing at least 50 vol. % of (lab-standard) SiO_2 sediments. Conductivity of CO_2 hydrate is also higher than that of ice, although we note this measurement is on ice from distilled-deionized H_2O and not necessarily representative of ice in nature. Interestingly, CO_2 hydrate is more conductive than CH_4 hydrate doped with 0.25 wt.% NaCl, which we have previously shown is the near-maximum NaCl impurity content in CH_4 hydrate without formation of a discrete liquid/brine phase.

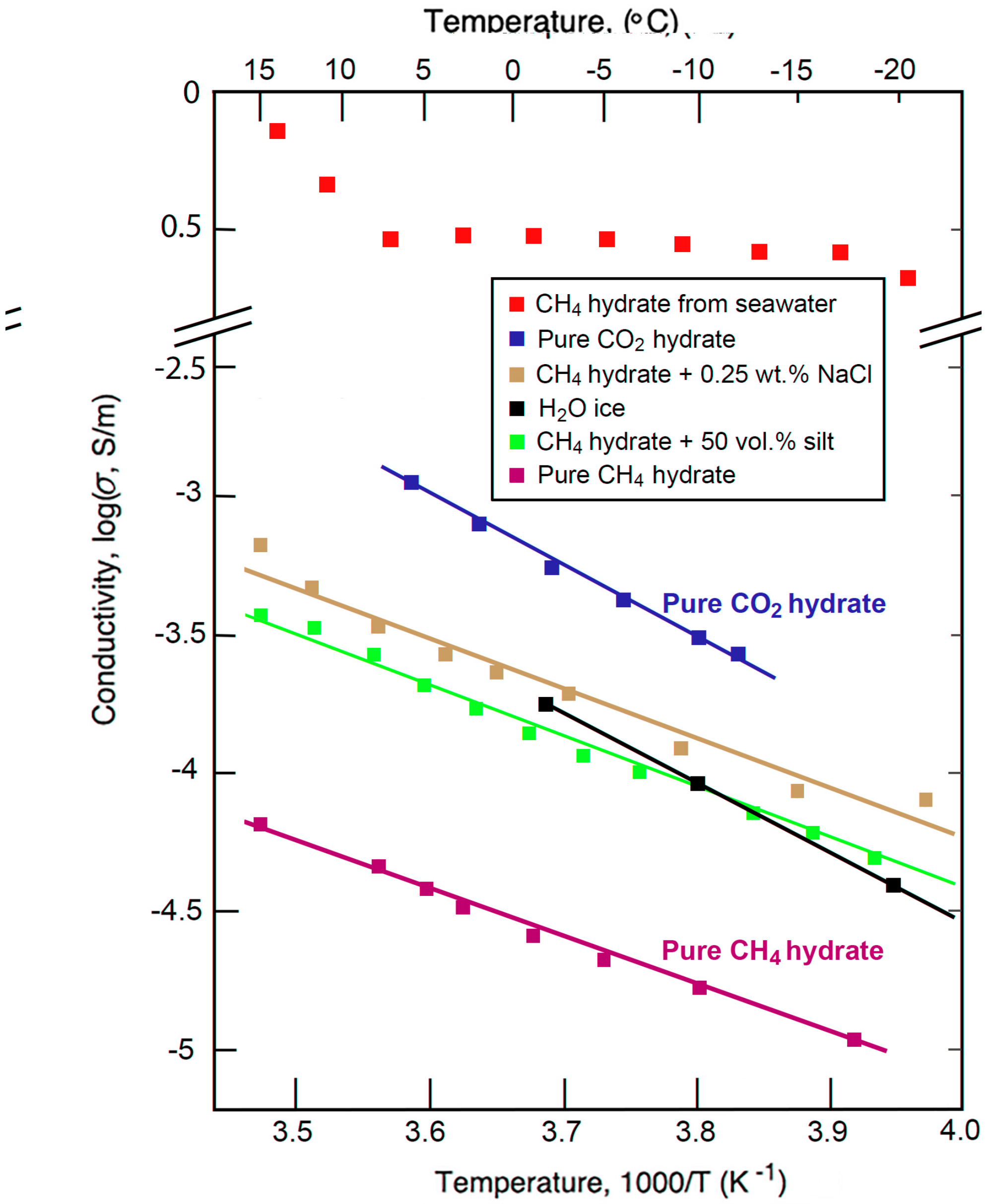


Figure 2. Electrical conductivity (σ) versus reciprocal temperature (Arrhenius) plot for pure CO_2 hydrate compared with our previous tests on ice, pure CH_4 hydrate, CH_4 hydrate with SiO_2 sediments (50 vol% silt shown here), CH_4 hydrate with 0.25 wt% NaCl, and CH_4 hydrate formed from flash-frozen seawater. CO_2 hydrate and all CH_4 hydrate samples other than the seawater sample were formed from the identical batch of seed ice. Amongst this group, CO_2 hydrate exhibits the highest conductivity. CH_4 hydrate prepared from seawater, however, is significantly more conductive than all other samples plotted here due to a coexisting brine component that formed and remained within that sample throughout testing. (Note break in vertical axis.)

Electrical conductivity of crystalline materials is the product of defect concentration and defect mobility. In ice, σ is governed by intrinsic Bjerrum defects (L and D) and (possibly) extrinsic protonic defects caused by ionic impurities. Based on the similar activation energies of pure CH_4 hydrate and CH_4 hydrate with either 0.25% NaCl or SiO_2 sediments, our previous studies concluded that σ of methane hydrate is dominated by ionic impurities.

We now see that the guest molecule itself, at least in the case of CO_2, can elicit an increase in σ larger than that from ionic-impurity doping in CH_4 hydrate, even though no impurities were added other than from the seed ice. CO_2 hydrate formation results in greater expansivity from either liquid water or ice than CH_4 hydrate formation, and extreme fit of the CO_2 molecule into the small cage of the structure I hydrate, and related cage distortion and host–guest interactions, may also augment defect formation. The nearly identical E_a of CO_2 hydrate and ice, both higher than for CH_4 hydrate with impurities, suggests that the charge carrier is the same as for ice– presumably, Bjerrum defects. In general, our results are consistent with prior findings and suggest that distorted cage structure may lead to the formation of additional charge carriers.

Possible applications

Previously, we discussed how EM remote-sensing studies in the field can benefit from salinity-conductivity insights gained from lab measurement of σ on CH_4 hydrate with variable amounts of sediments, ionic impurities, and brines. Here we show that the guest molecule itself can also affect σ, even within the same-structure hydrate. For CO_2 *vs* CH_4 hydrate, measurable differences in σ show promise for use of EM methods in monitoring CO_2 hydrate formation (or sequestration) in certain natural, remote settings where high-conductivity seawater or brines do not dominate the system.

Acknowledgments

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AAPG Annual Convention & Exhibition in May to Include Gas Hydrates Session

ACE 2021
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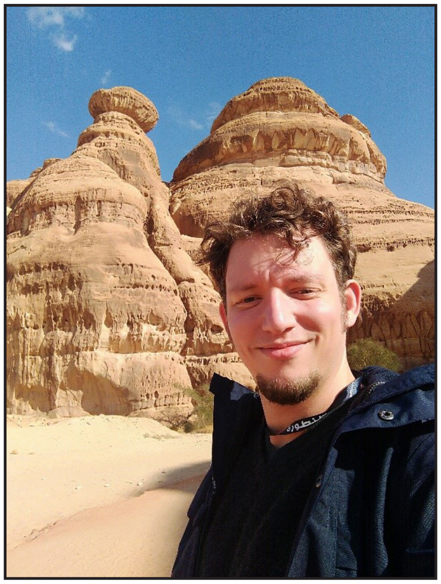
The American Association of Petroleum Geologists (AAPG) – Annual Convention & Exhibition this coming May will include a technical session on *"Gas Hydrates and Hydrocarbons of the Future."* This session will focus on gas hydrate deposits as hydrocarbon resources of the future; and the science and technology required to bring these emerging resources to market. This includes detection and identification of these hydrocarbon resources; as well petrophysical and basin-scale characterization. The gas hydrate session falls under Theme 9: New Energy Frontiers, Critical Minerals, and Planetary Geology.

The AAPG 2021 Annual Convention and Exhibition is scheduled to be convened in Denver, Colorado, May 23-26, 2021. It is currently planned as a hybrid meeting.

To stay updated on meeting plans, please visit: https://ace.aapg.org/2021.

For information on the gas hydrate session, please email Tim Collett (tcollett@usgs.gov) or Ann Cook (cook.1129@osu.edu), the session conveners.

Dr. Adrian Garcia Newest Recipient of Methane Hydrate Research Fellowship



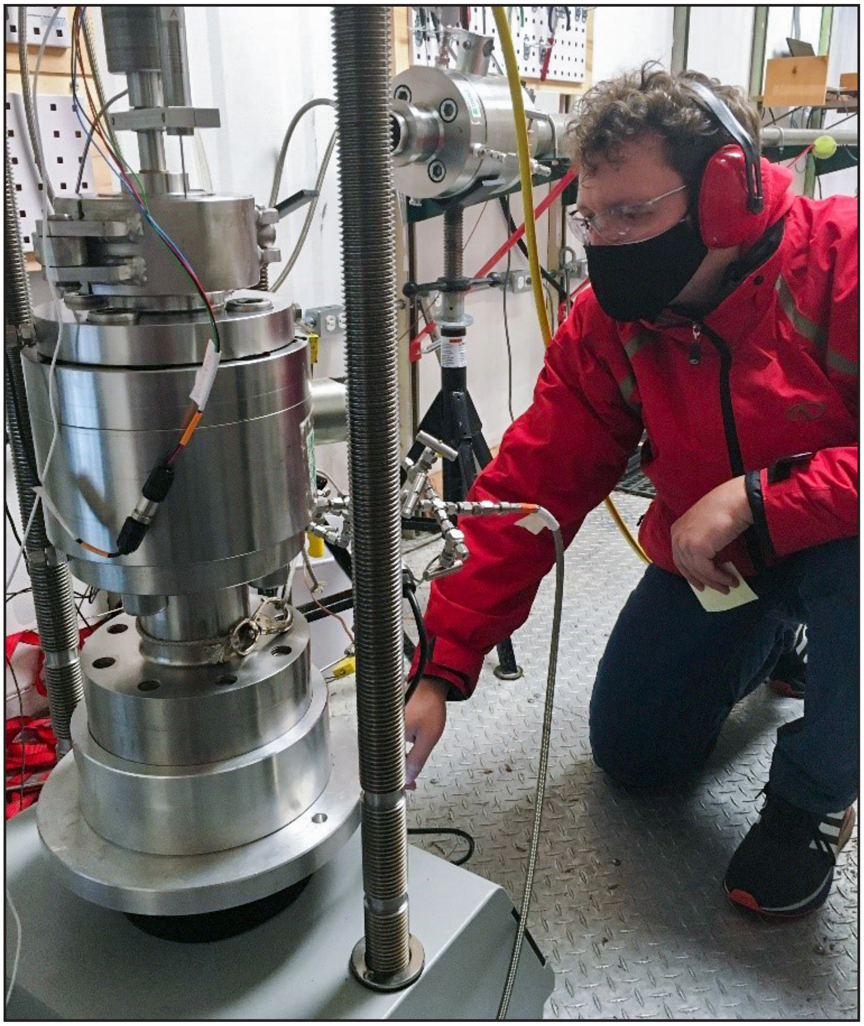
Adrian near the Al-Hijr (Madâin Sâlih) World Heritage site in Saudi Arabia in January 2020, during the final months of his Ph.D. program at KAUST.

Dr. Adrian Garcia has been awarded the NETL-NAS Methane Hydrate Research Fellowship to support his work developing specialized tools for measuring physical properties of hydrate-bearing sediments in pressure cores. Adrian is conducting this research as a postdoctoral fellow at the U.S. Geological Survey's (USGS's) Gas Hydrates Project in Woods Hole, Massachusetts.

Adrian's specific research is focused on design, fabrication, and use of the High Stress Triaxial Permeameter (HSTP)—a tool that complements existing Pressure Core Characterization Tools at the USGS. The HSTP will allow measurement of vertical permeability, relative permeability, and compressibility in hydrate-bearing sediments stored in pressurized core chambers. Adrian's engineering skills have quickly become indispensable to the USGS Gas Hydrates Project. He is collaborating with his USGS postdoctoral adviser, Bill Waite, as well as Steve Phillips, who recently joined the USGS Gas Hydrates Project as a Research Geologist.

Adrian completed his Ph.D. in energy resources and petroleum engineering with J. Carlos Santamarina at the King Abdullah University of Science and Technology (KAUST) in Saudi Arabia. His Ph.D. research focused on experiments and numerical modeling to elucidate three-dimensional rock fracturing, and studies of the thermal properties of fractured rock. Adrian completed his undergraduate and Master's degrees in geotechnical engineering with Professor Santamarina in the Department of Civil and Environmental Engineering at the Georgia Institute of Technology.

Congratulations to Dr. Garcia on receiving the latest Methane Hydrate Research Fellowship!



Adrian Garcia with the effective stress cell in the USGS Hydrate Pressure Core Analysis Laboratory in Woods Hole in October 2020. Photo by W. Waite.

NATIONAL
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NETL-NAS METHANE HYDRATE FELLOWSHIP SUMMER APPLICATION PERIOD APPROACHES JUNE 1 – AUGUST 1, 2021

The National Energy Technology Laboratory-National Academy of Sciences, Engineering, and Medicine (NETL-NAS) Research Fellowship Program is designed to support the development of methane hydrate science and technology and enable highly qualified graduate and post-graduate students to pursue advanced degrees and training in hydrate research.

Applications for this NETL-NAS fellowship are accepted and reviewed during two open periods: 1) December 1 – February 1; and 2) June 1 – August 1.

M.S., Ph.D., and Postdoctoral applicants, who are U.S. citizens and are affiliated with a federal laboratory or accredited university in the U.S., are eligible for these fellowships and encouraged to apply. The fellowships are two to three years in duration and include stipends ranging from $30,000 – $60,000 per year, with adjustments for experience. There are also supplements for research equipment and travel.

The 2021 summer application period is approaching, and potential fellows are encouraged to apply, through the NAS website, at: https://sites.nationalacademies.org/pga/rap/pga_050408

The National Academies of SCIENCES ENGINEERING MEDICINE

Spotlight on Research

MARK WHITE

Pacific Northwest National Laboratory

Mark White is a mechanical engineer and modeling guru at the Pacific Northwest National Laboratory (PNNL). He has played a crucial role in advancing PNNL's capabilities for numerical modeling of multi-phase, coupled-process fluid flow regimes in subsurface geologic reservoirs. In recent years, he has worked to enhance PNNL's STOMP software to accommodate the complexities of hydrate-bearing reservoir systems. He is perhaps best known in the gas hydrate R&D community for providing oversight and coordination of the Second International Gas Hydrate Code Comparison Study (IGHCCS-2; see article, this issue, p. 6).

Mark's path to computational modeling was a circuitous one, with several detours for downhill skiing. He was born in Colorado and grew up in Pennsylvania, where his father was a professor at Penn State. Mark learned to ski at the local Happy Valley community ski areas, Black Moshannon and Skimont. Even on those modest hills, he was fast—so his parents sent him off to a ski racing camp in the mountains of British Columbia. "They wanted to see how I stood up to the big boys of ski racing," Mark recalls. He found he was not destined to be an Olympic skier, but he loved racing and dreamed of making a living as a ski instructor.

Mark was also drawn to academics, especially anything in the sciences. As an undergraduate at Penn State, he chose to major in biophysics because it allowed him to take courses in four different scientific disciplines—physics, chemistry, biochemistry and biophysics. During college, he was also introduced to writing computer code, and he recalls using card punch machines to test his first Fortran codes in the 1970s—inserting fresh cards into the clattering punch mechanism and returning hours later, with eagerness and suspense, to retrieve programming results.

It was while working a summer job in the Agricultural Engineering department at Penn State that Mark discovered his affinity for mechanical problems and the fundamental ethos of engineering.

"Scientists tend to observe their world, and engineers tend to modify it. I seem to be of the latter mold," he remarks. Eventually, he dove into mechanical engineering at Colorado State University, where he completed M.S. and Ph.D. programs—and was given opportunities to do hands-on internships at L'Ecole de Mines, in France, and Los Alamos National Laboratory, in New Mexico, along the way. He was even able to work a side job as a ski instructor at Pajarito, while interning at Los Alamos.

Mark's experimental and numerical simulation skills led him to his research position at PNNL. During the early 1990s, he was tasked with developing a subsurface flow and transport simulator for the proposed Yucca Mountain nuclear waste repository, and the STOMP lineage of simulators was born. Soon, hydrate researchers were requesting a STOMP spin-off for hydrates. Mark said "sure," bought a copy of Dendy Sloan's book, read it cover to cover, and developed STOMP-HYDT-KE.

If you or someone you know would like to be the subject of the newsletter's next "Spotlight on Research," please contact Karl Lang (klang@keylogic.com) or Fran Toro (frances.toro@netl.doe.gov). Thank you!