# Natural Gas Hydrate Research at NETL RIC


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# Presentation Outline

- NETL R&IC Hydrate Portfolio Overview
- Major Accomplishments
- Lesson Learned
- Synergy Opportunities
- Project Summary

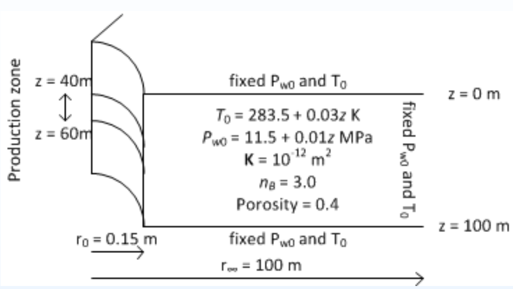
# NETL R&IC Hydrate Portfolio

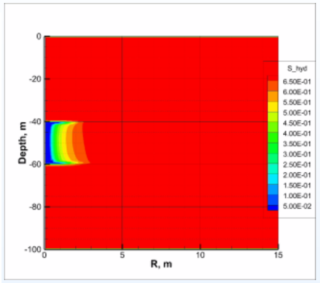
| Project Area | Tasks | Goals |
|---|---|---|
| **Numerical Simulation Supports** | • Gas Production Prediction/Code Comparison<br>• Hydrate Accumulation Genesis in ANS<br>• 3D Model based on ML and new data framework | • Economical recoverability for long-term gas production and recommendations on planning, execution, and analysis of field production tests |
| **Coupled Processing Modeling** | • THCM Code development and Modeling<br>• Sand Production Modeling<br>• Code Parallelization | • NETL's THCM simulator for methane hydrate reservoir modeling |
| **Laboratory Experimental Supports** | • Hydrological/Geomechanical Property<br>• Pressure Core Analysis and Tool Development<br>• Multiscale (Core/Pore) Testing and Imaging<br>• Fundamental thermophysical properties of HBS | • Relevant input for numerical simulations<br>• Fundamental knowledge on gas hydrate and its responses |
| **Field Production Test Supports** | • Shut In Procedure/Well Completion Method<br>• Engineering Support for field test design and operation | • Engineering support needed for the planning and operation of the ANS production well test |
| **Machine Learning Application** | • Well log data analysis for key parameter estimation and lithofacies/hydrate morphology recognition | • Efficient and accurate parameter estimations using new ML technique for large data analysis and model development |
| **Life Cycle Assessment** | • to refine the previous assessment of the total CO2 emissions associated with the gas production and consumption from ANS | • Evaluate key contributors to the GHG emissions and the environmental impact of gas hydrate production |
| **Interagency and International Collaboration** | • Code comparisons, Pressure Core Working Group | • Supporting success of domestic and international exploration and expedition |

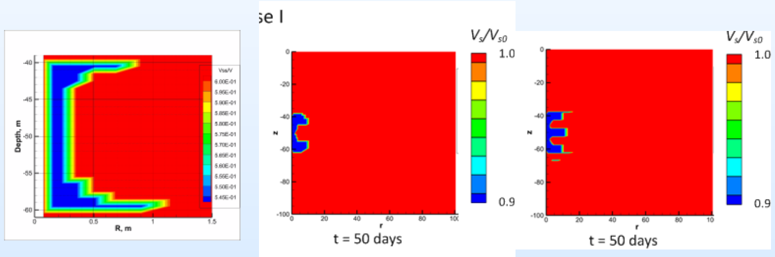
# Major Accomplishment

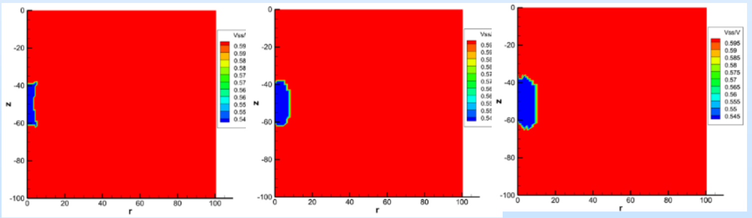
## NETL's THCM simulator, Mix3HRS-GM to incorporate Sand Migration Modeling

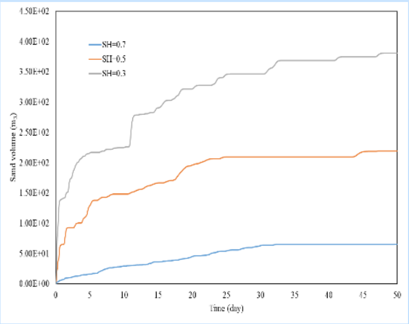
- **Goal**: NETL's own state-of-the-art simulator for reliable prediction of gas production and sand production from hydrate reservoir and establishment of early warning system for excessive sand production.
- **Challenges:** Coupling reservoir deformation, hydrate dissociation and sand mobilization/migration. Progressive evolution of the coupled phenomena.
- **Approach:** NETL's THCM simulator, Mix3HRS-GM, extended its capability to model sand migration through incorporating sand-water mixture flow and sand mobilization model.
- **Outcome**:
  - 2D axisymmetric reservoir simulations examining the impact of heterogeneity (permeability anisotropy, hydrate saturation, hydrate dissociation, mechanical deformation) and production scenarios (depressurization rate, sand screen shut-ins).
  - Identifying key parameters determining the sand production (critical gradient, particle sizes, dry density) to be determined by experiments
- **Implication:** For successful long-term gas production without being interrupted by sand production, the results suggested optimal reservoir conditions and parameters.

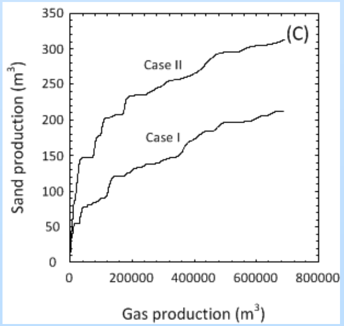


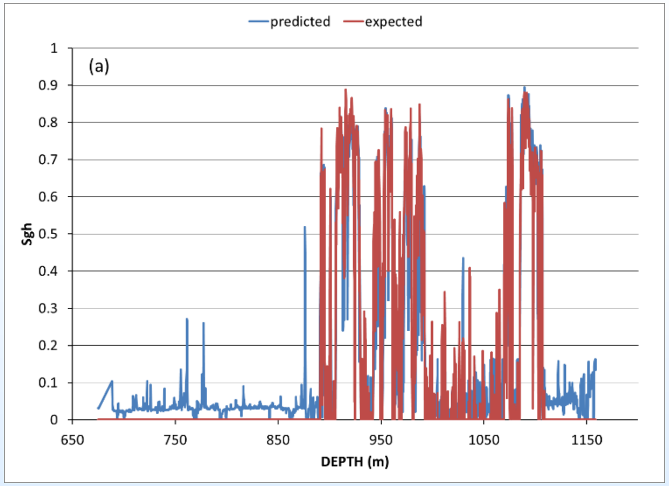


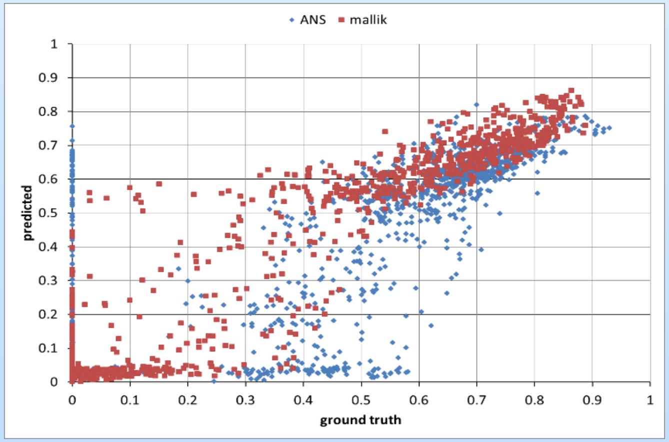
# Major Accomplishment

## Machine Leaning Applied to Gas Hydrate Reservoir and Basin Characterization

- **Machine Learning (ML) Approaches**: Provide the ability to identify and exploit underlying dependencies between input well log data and target variables that are not readily available through physics-driven models
- **Application of ML techniques in Gas Hydrate Research**:
  - Characterize gas hydrate reservoir and basin regions using well logs, seismic and other geologic and geophysical (G&G) data,
  - Spatial variability of hydrological and geophysical properties from a wellbore to develop reservoir models capturing 3D spatial heterogeneity of reservoir
- **Results**:
  - ML gas hydrate saturation prediction at one basin using information learnt at another basin (accuracy up to 92%)
  - ML recognition of pore-filling and fracture-filling gas hydrate in marine sediments (accuracy up to 85%)
  - ML lithofacies recognition in reservoir and non-reservoir sections (accuracy up to 90%)
- **Implication to DOE Natural Gas Hydrates Program** to obtain high precision data on gas hydrates in their natural environment and under production scenarios that secures future exploration of gas hydrate as future U.S. energy source




Mallik 5-38 Sgh predicted using $V_p$ $\phi$ *GR* Well Log Combination




“Ground truth” versus predicted Sgh at the Mallik (red squares) and ANS wells (blue squares)

# Major Accomplishment

## Pressure Core Characterization and Visualization Tools in NETL Gas Hydrate Laboratory

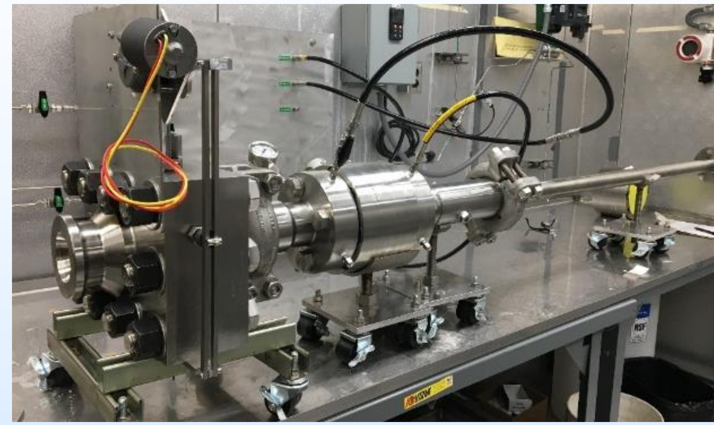
- **Goal**: Characterizing HBS at core scale in the form of pressure cores retrieved from the natural hydrate-bearing sediments to understand interactions between hydrate and its hosting geologic matrix.

- **Challenges**: Experimental complexity associated with hydrate stable pressure and temperature condition, and the sample heterogeneity which should be carefully reviewed before testing.

- **Approach:** A suite of tool set manipulates and characterizes natural hydrate bearing cores, as well as visualize methane hydrate in natural sediment pores with high resolution at its *in-situ* condition.

- **Results:** The PCXT (pressure core characterization and x-ray CT visualization tools) is built, and the pressure cores retrieved from Gulf of Mexico was tested. The capability of PCXT is expanded to be able to use multi-sized pressure cores.

- **Implications**: The tool set will be utilized to analyze pressure cores from Alaska (2022-2023) and Gulf of Mexico (2021-2022), which will be the key input for numerical reservoir simulation of gas production potential.



Anisotropic Permeability Cell

Triaxial Stress Chamber

# Major Accomplishment

## High Resolution Visualization of Methane Hydrate In Natural Sediments

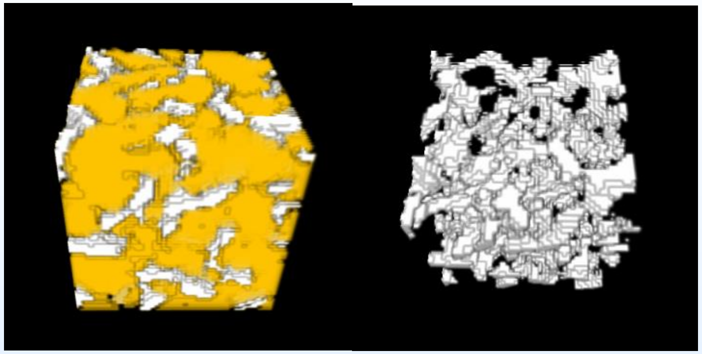
- **Goal**: Describing the pore habit of methane hydrate in sediment matrix for understanding natural distribution of methane hydrate, methane trace (transport and solidification) in the hydrate stability zone, and physical properties gas production

- **Challenges**: Core degradation due to hydrate dissolution, salt diffusion, mechanical disturbance which could disturbe the hydrate saturation/hydrate pore habits of natural HBS

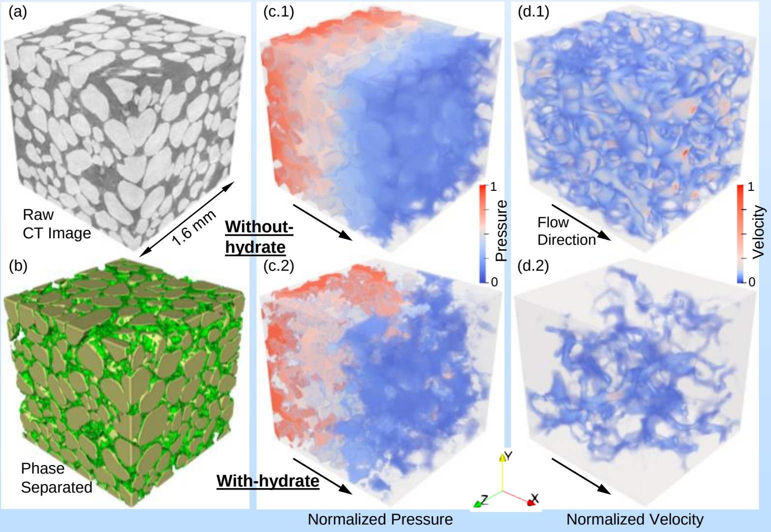
- **Approach:** Pressure-core Characterization and X-ray visualization Tools (PCXT) and the phase-contrast micro-CT technique: develop 3D pore structures of hydrate bearing sediments and develop numerical simulation methods for flow simulation of HBS.

- **Outcome:** Observation of non-cementing and pore-invasive hydrate in silty sediment acquired from Gulf of Mexico. And the pore network modeling results to investigate the effect of hydrate distribution on fluids flow through a porous media acquired from a CT images.

- **Implication:** help understand natural distribution of methane hydrate, methane migration in the hydrate stability zone, physical properties, and the associated impact of fluid migration dominating potential gas production from pore scale



Hydrates in pore space of natural sediment subcored from the undisturbed fine-grained silty sediment.



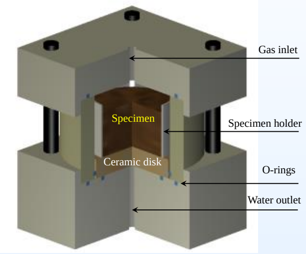

Numerical simulation of fluid migration through pore space based on CT images

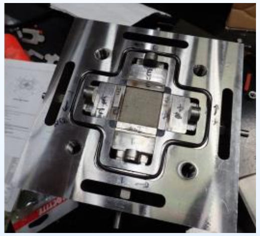
# Major Accomplishment

## Permeability Anisotropy in Natural Hydrate-Bearing Sediments

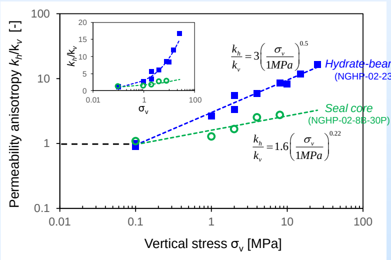
- **Goal**: Quantify vertical and horizontal permeability in natural sediments and provide new models for reservoir modeling
- **Challenges**: No existing standard testing protocols/equipment; sediments layering and heterogeneity
- **Approach:** Customize unique testing devices; develop novel pore network modeling schemes
- **Results:** Permeability anisotropy measurements; water retention curve; relative permeability curves; elegant permeability models for natural hydrate-bearing sediments; flow in layered sediments. Salient results are summarized in 9 journal publications during FY20.
- **Implications**: The experimental and numerical methodologies developed through this task provide novel solutions to quantify permeability anisotropy in natural sediments, and provide direct measurements for sediments from NGHP02, GOM2, and Alaska testing sites.

Customized setup: Permeability anisotropy cell for (Left) reconstituted core with synthesized hydrate; and (right) natural core sediments.

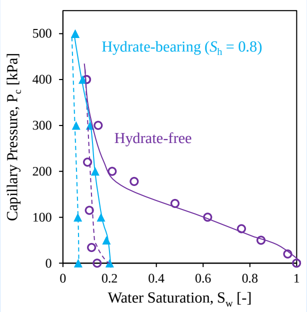


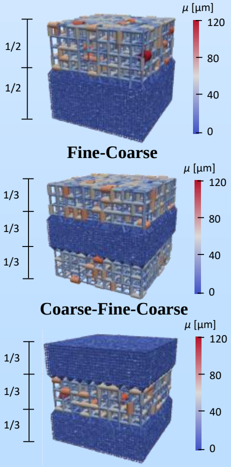



Permeability anisotropy

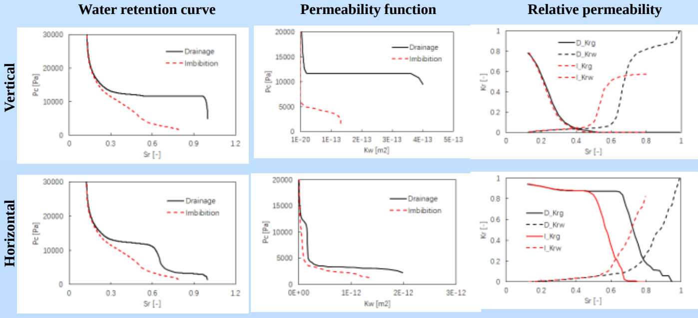



Water retention curves




Modeling of flow in layered systems



# Lessons Learned

- 3D reservoir modeling is critical to include complicated geologic features and to refine practical 2D models.
- Characterization of pressure core is challenging as well as collecting cores, transporting and storing, and manipulating. Sophisticated tools for characterization, visualization, and analysis is essential.
- Collaborations on both reservoir modeling and laboratory characterization is the key to the success.
- Continuing efforts to identify new research areas and technology in gas hydrate is necessary to support carbon-neutral energy development and environmental impact awareness.

# Synergy Opportunities

- Collaborations:
  - Reservoir modeling for coupled processes: JOGMEC, LBNL, TAMU
  - Laboratory test and comparison : AIST, LBNL, UTA, GT
  - Pressure core working group: AIST, USGS, UTA, GT
  - Life cycle analysis; WVU, UGSG
  - Machine learning application: USGS, India
- Information sharing for advanced comprehensive analysis and improved test design and execution: Code comparison studies, inter-laboratory comparison study, discussion groups, well log data analysis
- New Research Area: global climate change impacts, carbon-neutral methane production, industrial applications

# Project Summary

| Project Area | Key Outcomes | Future Work |
|---|---|---|
| **Numerical Simulation Supports** | • 2D/3D Geological Models for Kuparuk Site<br>• Production simulations for fixed/staged production scenarios with TOUGH+/CMG-STARS<br>• Sensitivity analysis for key parameters | • 3D Modeling for Kuparuk with updated input (geologic features and laboratory data)<br>• Model validation with field acquired data from production test |
| **Coupled Processing Modeling** | • Fully coupled reservoir simulator<br>• Sensitivity studies to identify major parameters for sand production<br>• Parallelized reservoir simulator for flow | • Fully coupled THCM simulations for Kuparuk site with both geomechanical deformation and sand migration |
| **Laboratory Experimental Supports** | • Pressure Core Analysis and Tool Development<br>• Multiscale (Core/Pore) Testing and Imaging<br>• Hydrological/Geomechanical Property | • Relevant input for numerical simulations<br>• Fundamental knowledge on gas hydrate and its responses |
| **Field Production Test Supports** | • Shut In Procedure/Well Completion Method<br>• Engineering Support | • Engineering support needed for the planning and operation of the ANS production well test |
| **Machine Learning Application** | • Well log data analysis and parameter estimations | • Resources potential estimation with efficiency and accuracy |
| **Life Cycle Assessment** | | • Refine the previous assessment of total $CO_2$ emissions associated with ANS |
| **Interagency and International Collaboration** | • Code comparisons, Core Analysis Working Group | • Supporting success of domestic and international exploration and expedition |

# Appendix

– Benefit to the Program
– Project Overview
– Organization Chart
– Gantt Chart
– Bibliography

# Benefit to the Program

- Program Goals supported:
  - Comprehensive evaluations of gas hydrate accumulations at permafrost and marine sites for the purpose of assessing technical and economical recoverability for short- and long-term gas production
  - Development of NETL's THCM simulator for methane hydrate reservoir simulator
  - Fundamental characterization of hydrate bearing sediments for petrophysical properties
  - Characterization of field-retrieved pressure cores to develop relevant input for numerical simulations
  - Direct engineering solutions and recommendations for the ANS production test
  - Characterization of potential environmental impacts of gas hydrate exploration, development, and use through life cycle analysis
- Project benefit:
  - Assessing productivity of gas hydrate reservoirs by means of numerical simulations to support the design and operations of field programs and to assess the overall viability of gas hydrate resource development.
  - Synthesizing existing data and knowledge of gas hydrates systems to create a cohesive knowledge-data framework that allows for data-driven evaluation of the gas hydrate system
  - predict long-term reservoir responses during gas production including not only gas production prediction but also sediment deformation and sand migration
  - Obtained petrophysical properties to provide critical input reservoir models for predicting geomechanical stability, gas production efficiency.
  - High resolution pore-scale images help to establish linkages between core-scale physical properties and pore-scale hydrate habits characterization, therefore building the bridge between pore-scale and core-scale sediment behaviors.

# Project Overview

**Project Goals:**

- Provide the state-of-the-art experimental, modeling, and economic analysis to support planning and execution of long-term field gas production tests, predicting environmental implications and developing long-term projection of US energy asset.
- Provide pertinent, high-quality information that benefit the development of geological and numerical models and methods for predicting the behavior of gas hydrates in natural and production conditions.

**EY20 Funding:** $3.05 M ($2.75 M + $0.3 M Carryover)

**Overall Project Performance Dates:** 04/01/2021 – 03/31/2022

**Project Participants:**

- FE HQ Division Director; Timothy Reinhardt
- FE HQ Project Manager: Gabby Intihar
- NETL Technology Manager: Joseph Stoffa
- NETL Senior Fellow: Grant Bromhal
- NETL Program Manager: Sandra Borek
- NETL R&IC TPL: Yongkoo Seol
- NETL R&IC Researchers
- LRST Site Support Researchers
- ORISE Fellows
- Universities: West Virginia Univ., RPI, Georgia Tech, Pitt, Stanford, TAMU

# Organization Chart

- NETL Technology Manager: Joseph Stoffa
- Senior Fellow(s): Grant Bromhal
- R&IC TPL(s): Yongkoo Seol
- R&IC PI(s): Yongkoo Seol, Don Remson, Tim Grant,
- FE HQ Division Director: Timothy Reinhardt
- FE HQ Project Manager: Gabby Intihar
- Program Manager: Sandra Borek

| Task # | Task Leads | Team Members |
|---|---|---|
| Z | Sandra Borek | Jeff Ilconich (LRST) |
| 2 | Yongkoo Seol | Evgeniy Myshakin (LRST), Gabe Creason (LRST), Nagasree Garapati (WVU), Allegra Scheirer (Stanford), Laura Dafov (Stanford), Zach Burton (Stanford) |
| 3 | Yongkoo Seol | Evgeniy Myshakin (LRST), Xuerui Gai (LRST) Shun Uchida (RPI), Jeen-Shang Lin (Pitt) |
| 4 | Yongkoo Seol | Jeong Choi (LRST), Karl Jarvis (LRST), Sheng Dai (GT) |
| 5 | Yongkoo Seol | Taehyung Park (ORISE), Karl Jarvis (LRST), Bryan Tennent (LRST) |
| 6 | Don Remson<br>Tim Grant | Ray Boswell, Jim Kirksey (MESA), Alana Sheriff (MESA) |
| 7 | Don Remson<br>Tim Grant | Ray Boswell, Jim Kirksey (MESA), Alana Sheriff (MESA) |
| 8 | Yongkoo Seol | Ray Boswell, Jeff Ilconich (LRST)<br>Ryder Scott Subcontractors |
| 9 | Yongkoo Seol | Evgeniy Myshakin (LRST), Leebyn Chong (LRST) |
| 10 | Yongkoo Seol | Evgeniy Myshakin (LRST), Xuerui Gai (LRST) |

# Gantt Chart

| Task | Task Title for Current Execution Year | 2020 | 2021 | 2022 | 2023 |
|---|---|---|---|---|---|
| 2 | Numerical Simulations Supports for Reservoir Characterization and Performance Prediction | | | | |
| 3 | Development of Thermal-Hydro-Chemo-Mechanical Simulator for Methane Hydrate Reservoir Modeling | | | | |
| 4 | Fundamental Property Characterization of Hydrate-Bearing Sediments | | | | |
| 5 | Pressure Core Characterization and Analysis | | | | |
| 7 | Methane Hydrate Well Research | | | | |
| 8 | Alaskan North Slope Engineering Support | | | | |
| 9 | Machine Learning Application to Gas Hydrate Systems | | | | |
| 10 | Permafrost-Gas Hydrate System in Arctic | | | | |
| 11 | Sand Migration Lab Testing | | | | |
| 12 | Life Cycle Assessment | | | | |

Go/No-Go TimeFrame
Project Completion

Current Progress as of Aug. 2021

On Schedule
Delayed
Completed
Planned

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