CSEM for Geohazard Identification

Offshore Research NETL FWP #1022409

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U.S. Department of Energy

National Energy Technology Laboratory

2021 Carbon Management and Oil and Gas Research Project Review Meeting

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Presentation Outline

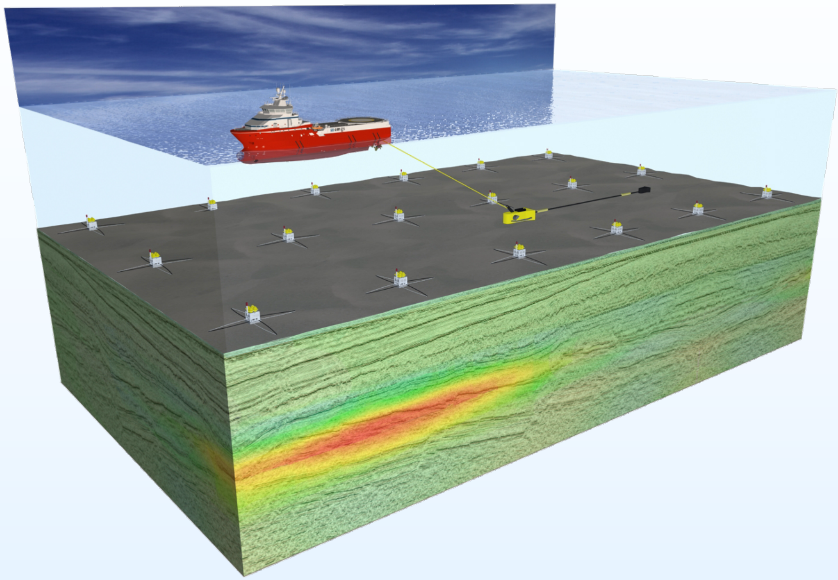
Goal: Develop a technological leap in Controlled Source Electromagnetic (CSEM) imaging resolution for geohazard ID (>10 × improvement)

- Technical Status
- Accomplishments to Date
- Lessons Learned
- Synergies
- Summary

Technical Status

CSEM for Geohazard ID

- Used to de-risk exploratory drilling; exploration of thin (sub)horizontal oil/gas bearing formations; groundwater studies
- Square-wave power source (0.1 Hz < *f* < 10 Hz)
- State-of-art: 10k Amps, 300 m-long transmitter, 3000 kAm dipole moment
- Seafloor electric and magnetic field sensors
- Data inverted for subsurface resistivity structure
- CSEM can distinguish between electrically conductive fluids (e.g. brine) and resistive fluids (e.g. oil/natural gas)
- Works well in salt and basalt settings
- MT + CSEM with same equipment
- CSEM better for resistive, MT for conductive



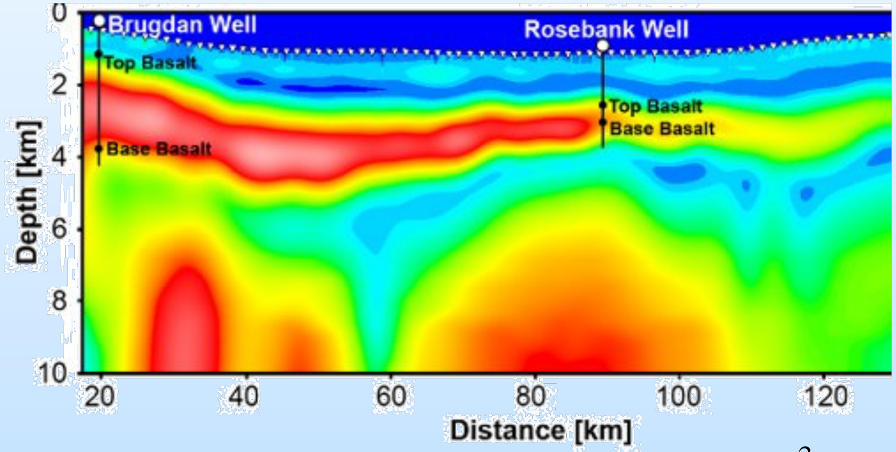


Image Source (top and bottom): EMGS

Technical Status

- Improve SNR for each received transmitter pulse
  - Improve feature detection, particularly for small aspect ratio, (sub)vertical targets that can be invisible to conventional CSEM
  - Demonstrate much wider applicability to offshore geohazard targets
  - CSEM can also be an alternative to 3-D seismic where marine mammal impacts on permitting are an issue

- Eliminating Signal Stacking to Improve Resolving Power
  - Traditional CSEM produces weak signal levels at receivers
  - Signal stacking of continuous square-wave signal (averaging multiple received waveforms) is required to improve SNR
  - Transmitter antenna is towed behind ship, so source location is constantly moving
  - Stacking blurs target resolving power since signal is composite of many source-receiver geometries

Technical Status

- Project Approach
  - Can we improve ability to resolve geohazard targets by using alternative transmitter configurations, a more powerful source and eliminating signal stacking?
  - Review, analyze and assess current CSEM S/N and performance
  - Scope and design new MHD + supercapacitor-based power supply approach for CSEM
  - Quantify improved S/N performance benefits to CSEM and geohazard ID
  - Develop new CSEM analysis codes for quasi-real-time target identification/discrimination

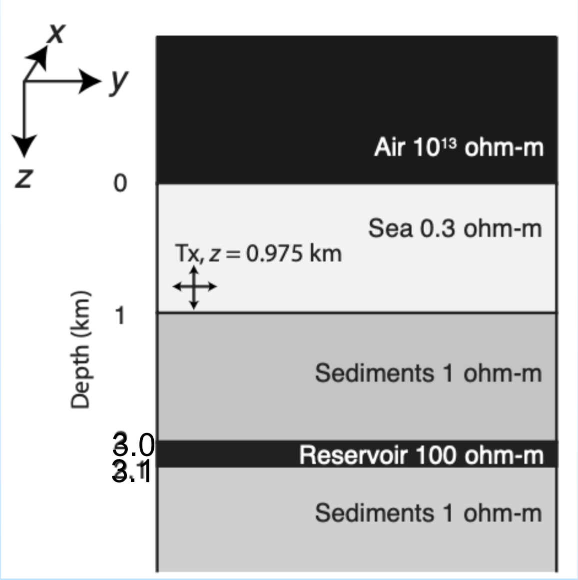
Technical Status

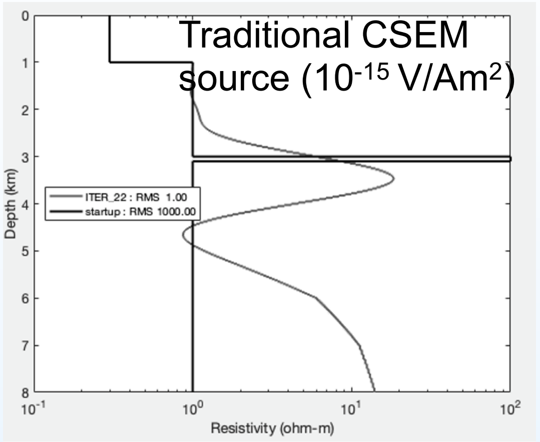
EY2019 & EY2020

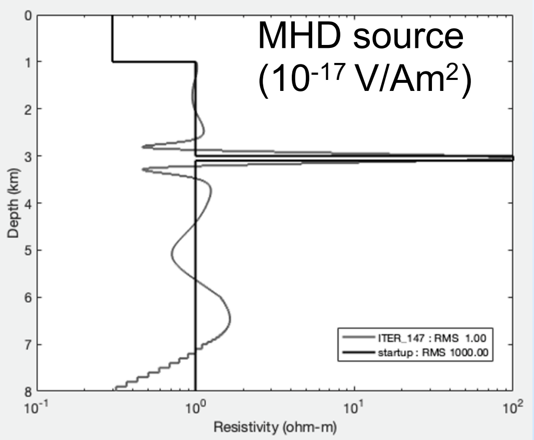
- CSEM performance evaluated via literature and analysis
  - Detailed evaluation of impacts of noise sources
- MHD power cycle selected, and numerical code built
  - 1D+ method provided conceptual design evaluation
  - MHD system optimized for 10 MWe pulse for 10 s every 120 s
- Simulations of CSEM conducted with traditional and MHD source

	Dipole moment [kAm]
EMGS dipole	3 x10^3
Proposed MHD based dipole	10^5

~30x Improvement/pulse





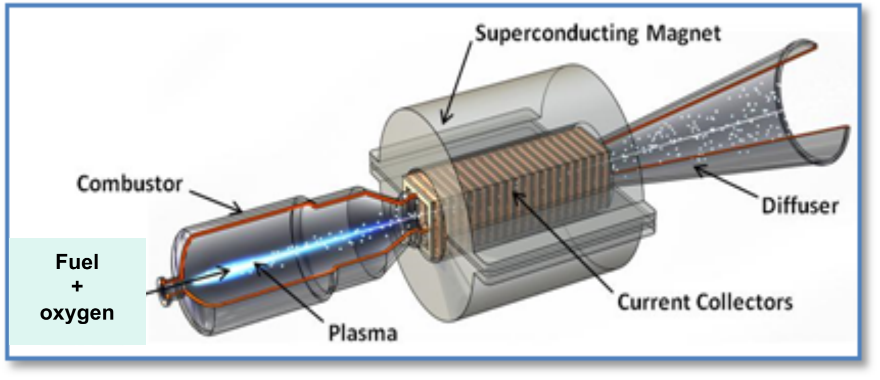


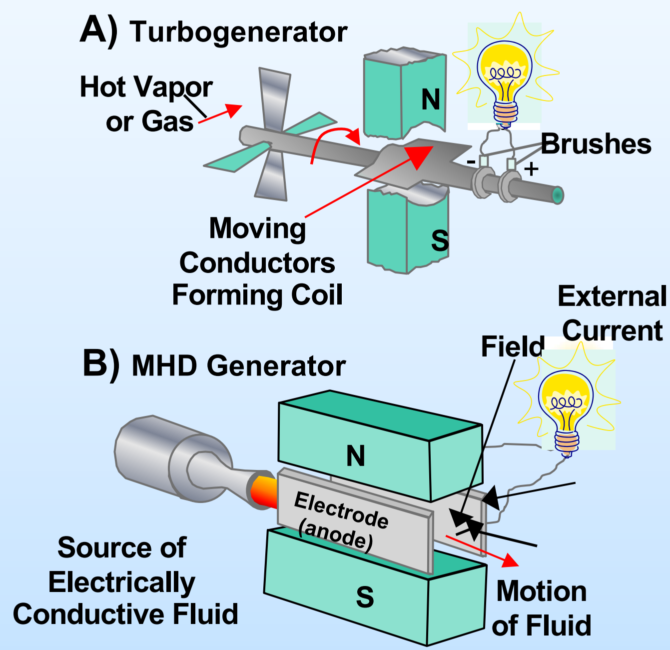
Simulations of CSEM with 1-D sub-surface, target 3 km depth, used 0.05, 0.25, 1.0 Hz source. Performed to evaluate impacts and benefits of improved source.

Technical Status

– Principles of MHD Generator

- MHD generator extracts electric power directly without moving parts, via interaction of plasma and an imposed magnetic field
- We have written a 1D python code for designing the MHD generator
- Multi-dimensional simulation of the system is underway using OpenFOAM and COMSOL





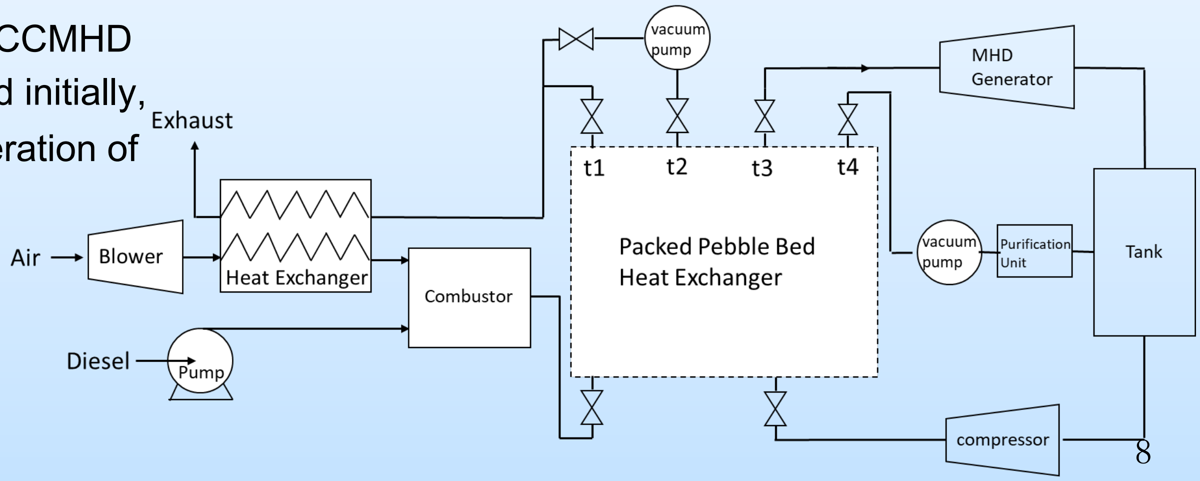
Technical Status

– MHD Power Advantages

- We have considered both open cycle MHD (OCMHD) and closed cycle MHD (CCMHD)
- OCMHD (e.g. Russian Sakhalin Generator) approach has relatively low efficiency and longevity at target size (10MWe)
- CCMHD more efficient at smaller scale, and no rocket exhaust containing alkali elements
- Conceptual designs for an CCMHD MHD power source pursued initially, leading to renewed consideration of open cycle approach

Technical Specifications

- $10MW_e$ Power Output
- Diesel powered air combustion w/regenerative heating
- MHD Generator is on board ship, replaces diesel generator
- High Voltage, Low Current transmitted to towed antenna
- Rectify for ~100,000 Amps and ~100 Volt pulse in underwater EM transmitter
- ~ 2-minute duty cycle with 10s pulse
- Eliminates need for “pulse stacking” while ship is moving

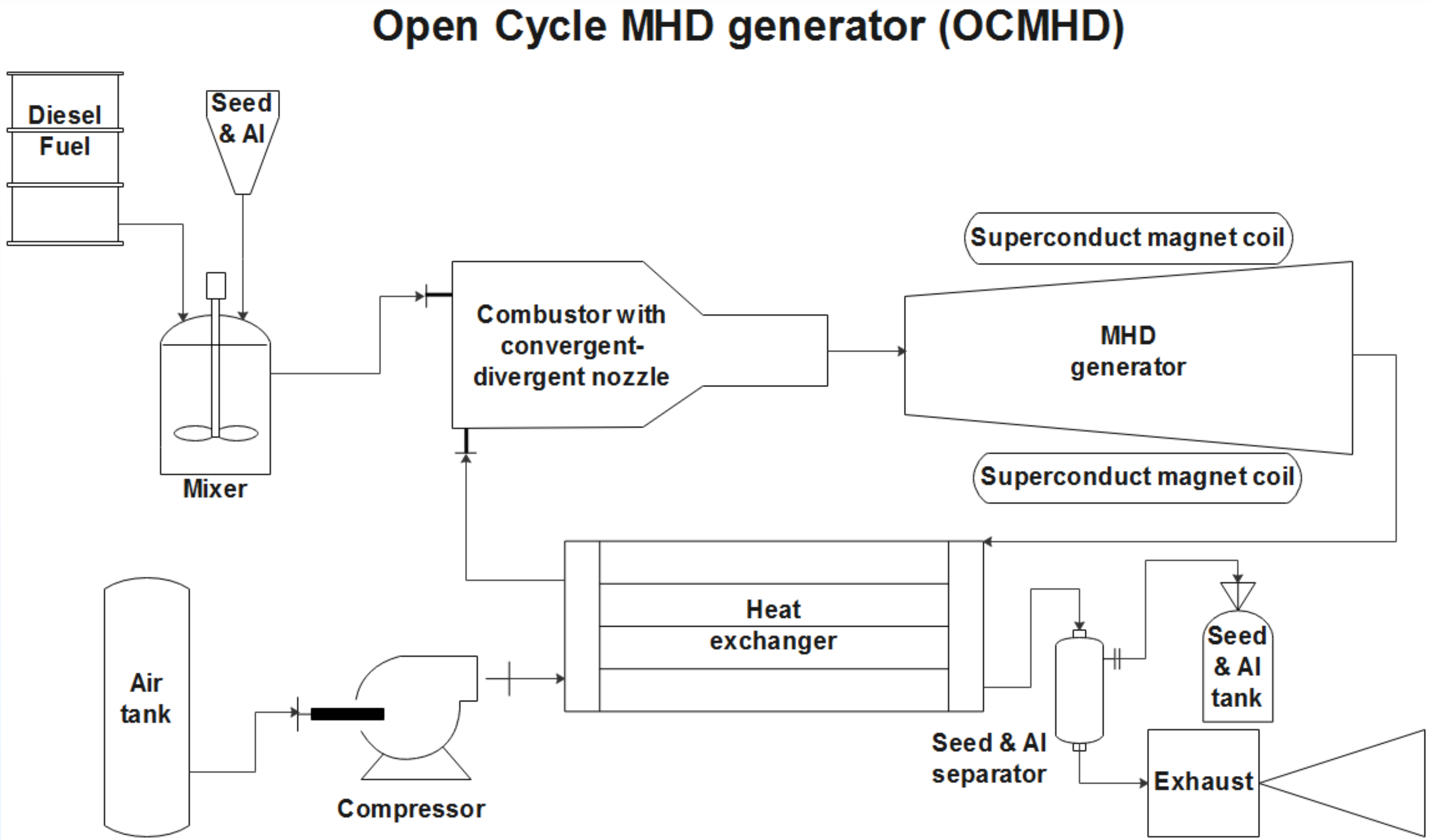


Technical Status

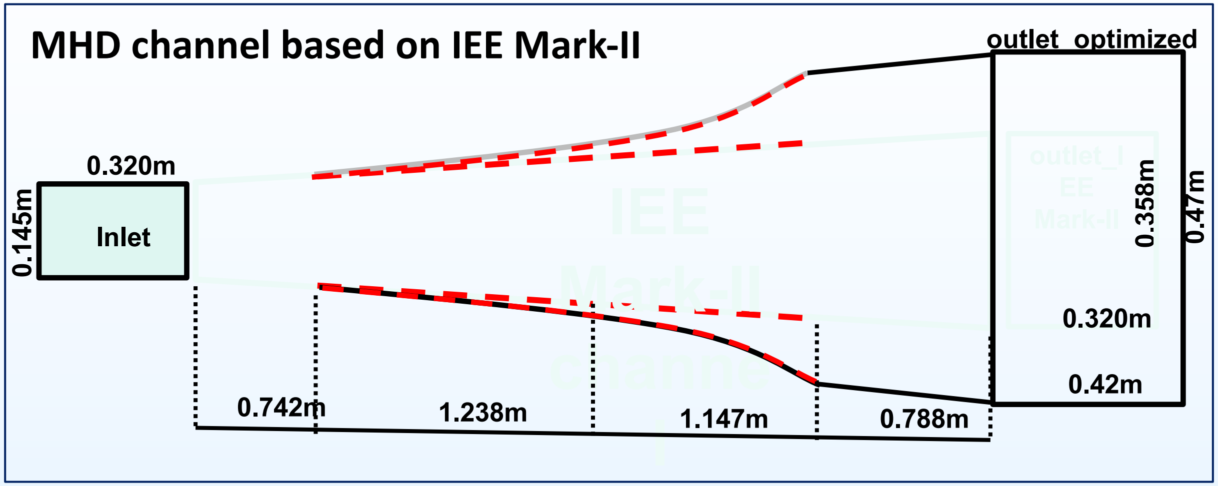
CCMHD efficiency from legacy experiment

classification	Legacy Experiment	Thermal Input (MW)	Power output (kW)	Efficiency (%)
CCMHD	USA NASA-Lewis 1968 ~ 1974	~ 1.6	~ 0.3	~ 0.02
	USA NASA-Lewis 1976	~ 1.6	~ 2.2	~ 0.14
	USA U. FL 1964 ~ 1966	~ 0.15	~ 0.001	~ 0.001
	Germany P. ARGAS 1966 ~ 1970	~ 4.7	~ 5	~ 0.11
	England IRD 1964 ~ 1968	~ 0.11	~ 0.001	~ 0.001
	FUJI-I, Japan 2004 ~ ?	~ 0.3	?	?
OCMHD using NETL in-house 1D code	Current optimization work at NETL	~ 161.7	~ 11000	~ 6.8

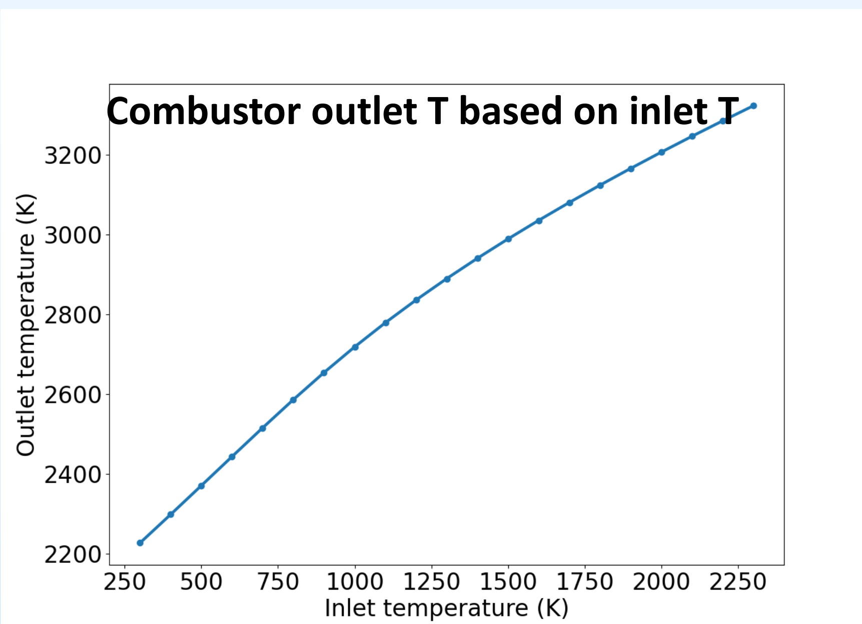
Technical Status



Technical Status



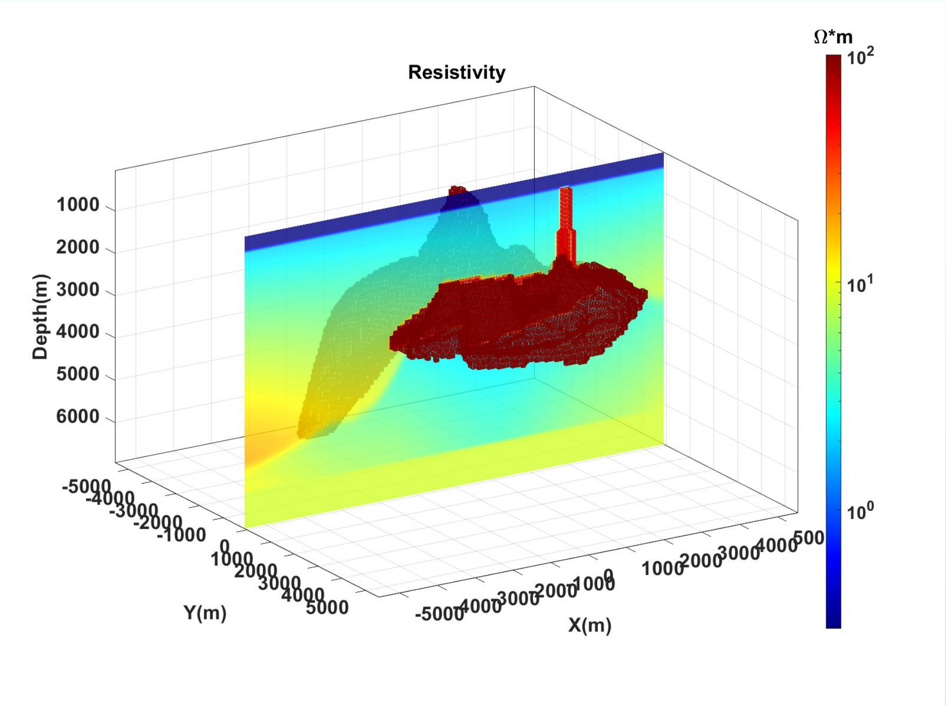
Superconduct Magnet
https://www.cryomagnetics.com/

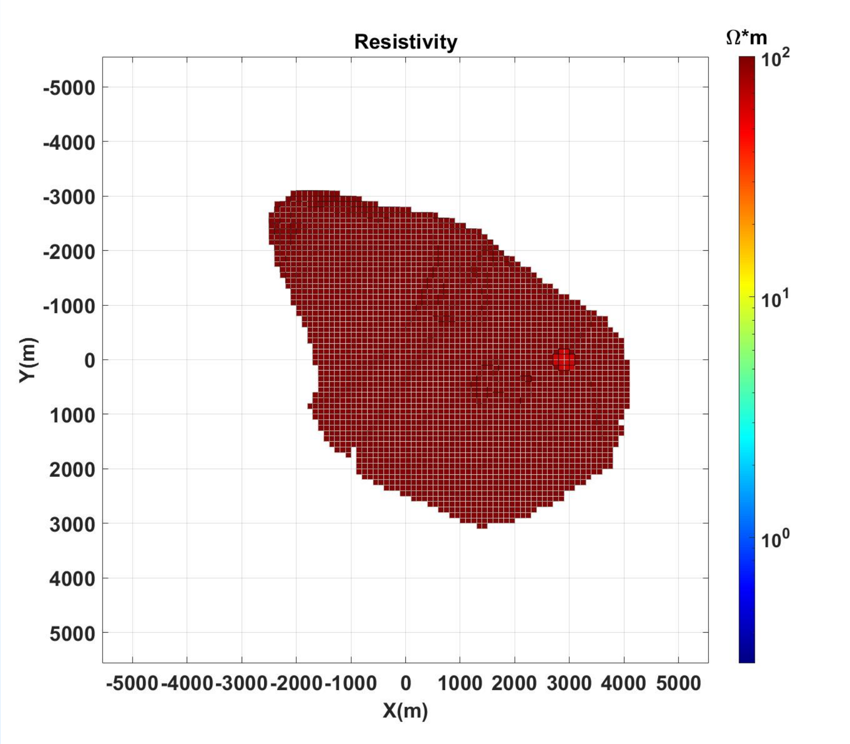


- MHD channel optimized based on legacy experiment of IEE Mark-II toward electric power output of approximately 11MW using fuel of around 3.5 kg/s, which is around 5 times more fuel than commercial diesel generator (https://www.hardydiesel.com) but MHD duty cycle of 10 s in 120 s, i.e. firing 8.3% of the time rather than continuous, so avg. consumption broadly equivalent.
- Cryogen-free superconduct magnet for affordable maintenance and energy efficiency.
- Combustor modeling with heated air temperature for higher outlet temperature.

Technical Status

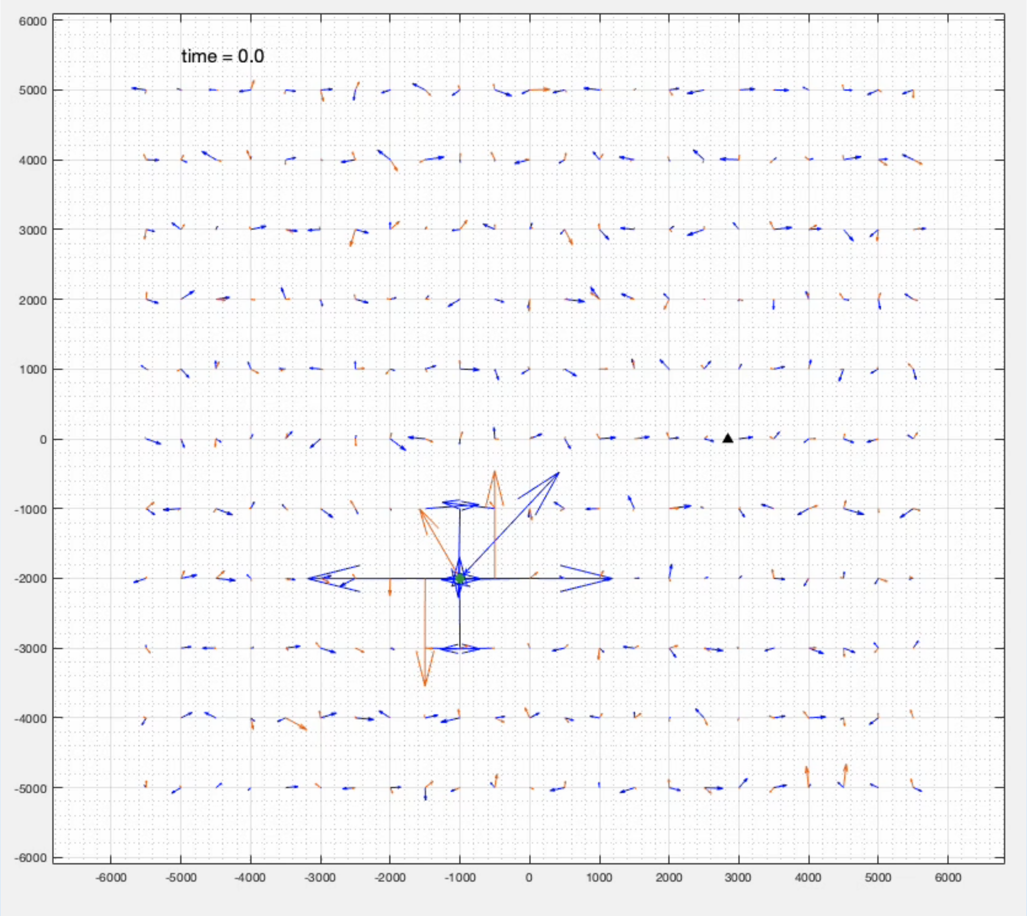
Marine CSEM imaging results – canonical 3-D model of gas vent from salt dome

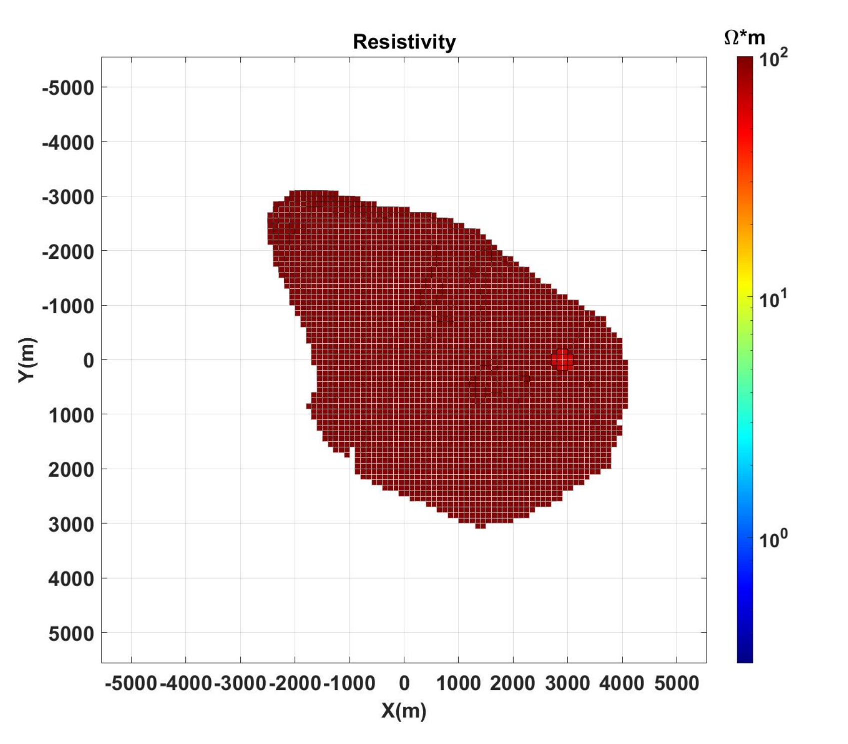




Technical Status

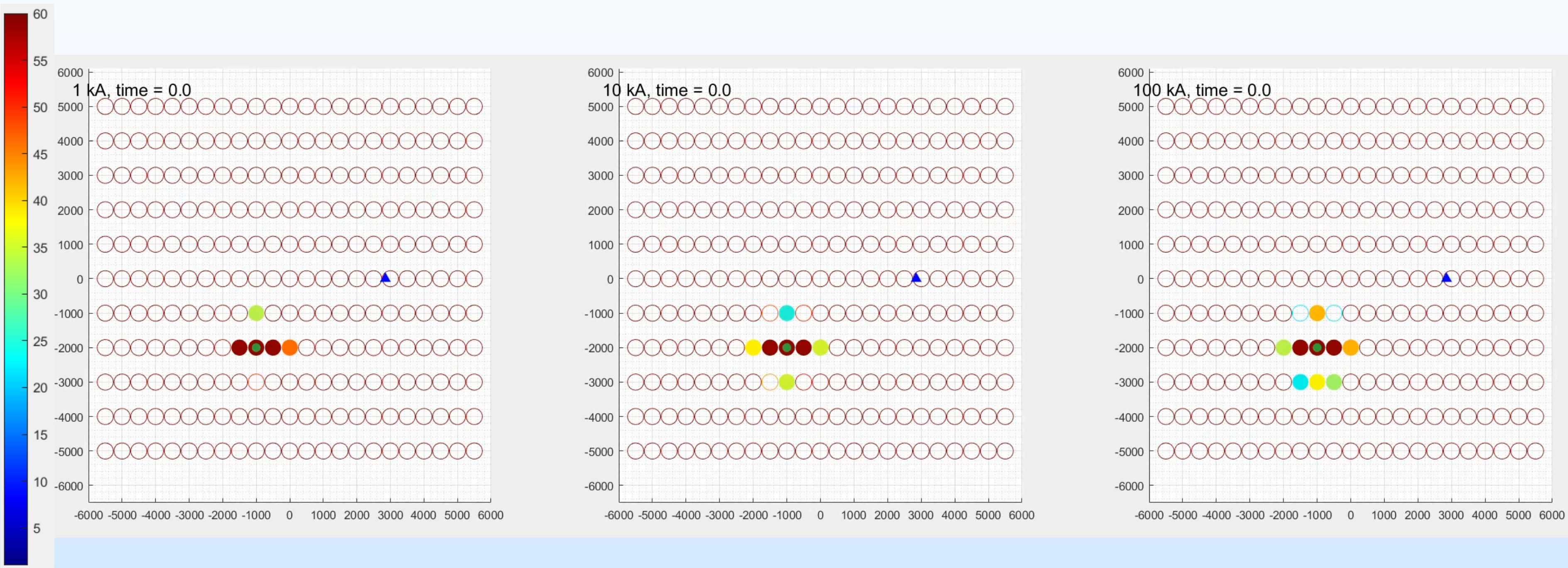
Seafloor electric (blue) and magnetic (red) fields vs. time (s) after xmitter pulse, 10^5 kAm MHD generator with vertical (not horizontal) xmitter antenna, realistic noise





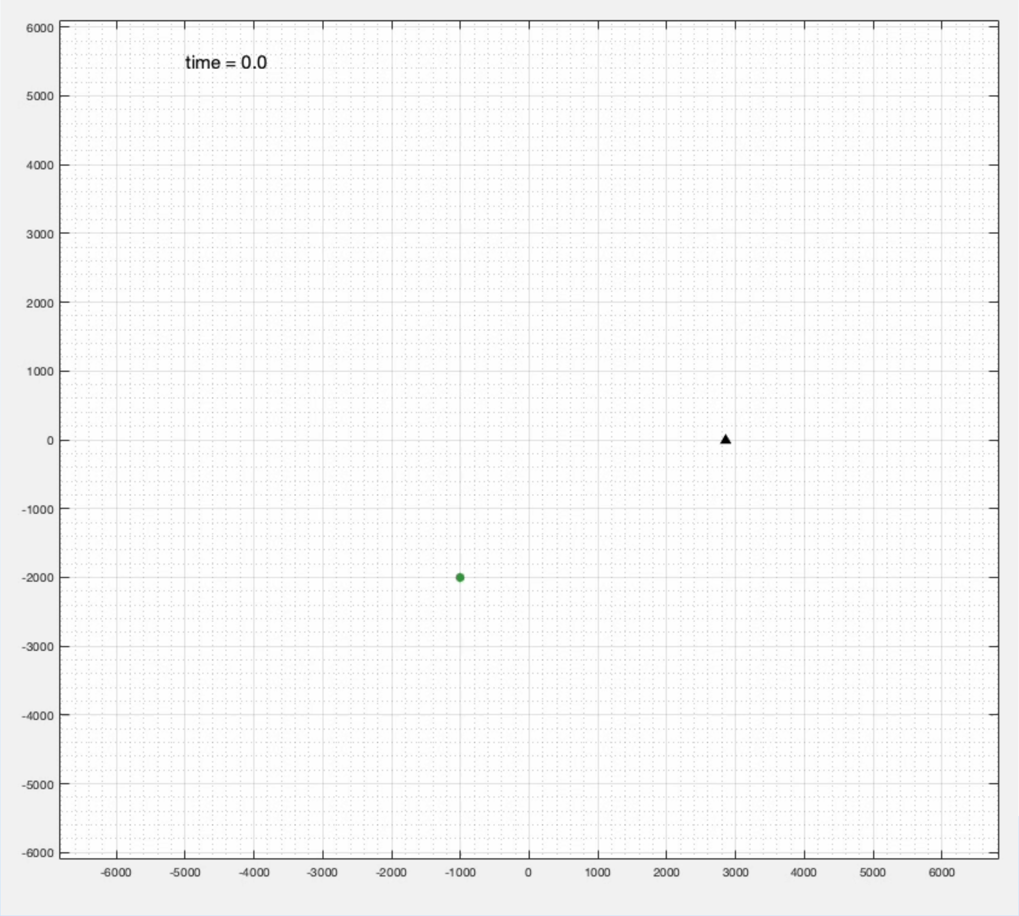
Technical Status

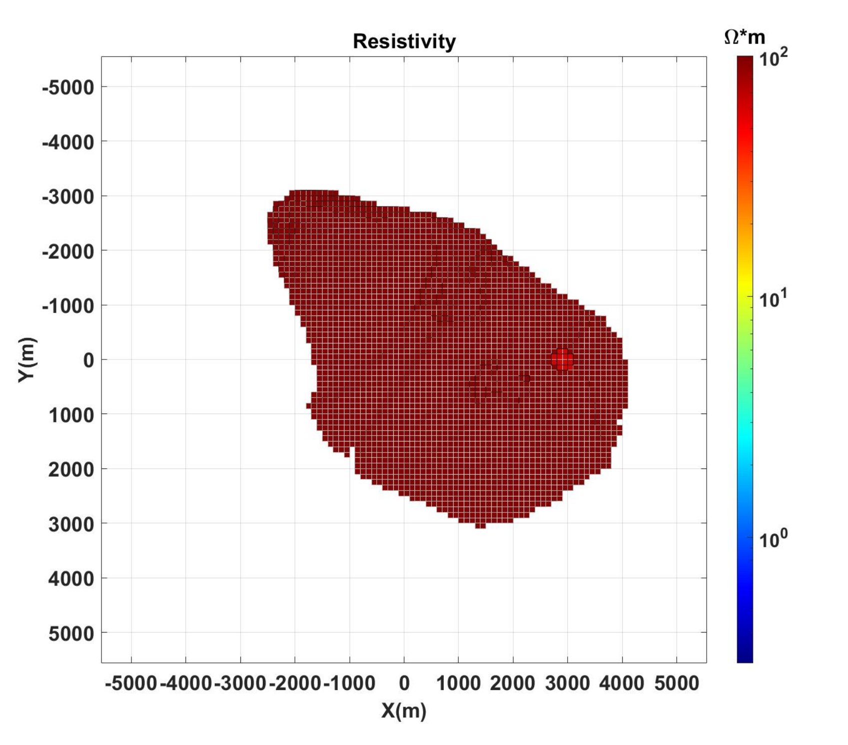
Signal to noise ratio (SNR) in dB for salt dome gas vent breakout model, 10^3 kAm (conventional), 10^4 kAM (supercapacitor boosted) and 10^5 kAm MHD generator pulses, vertical dipole antenna, realistic noise



Technical Status

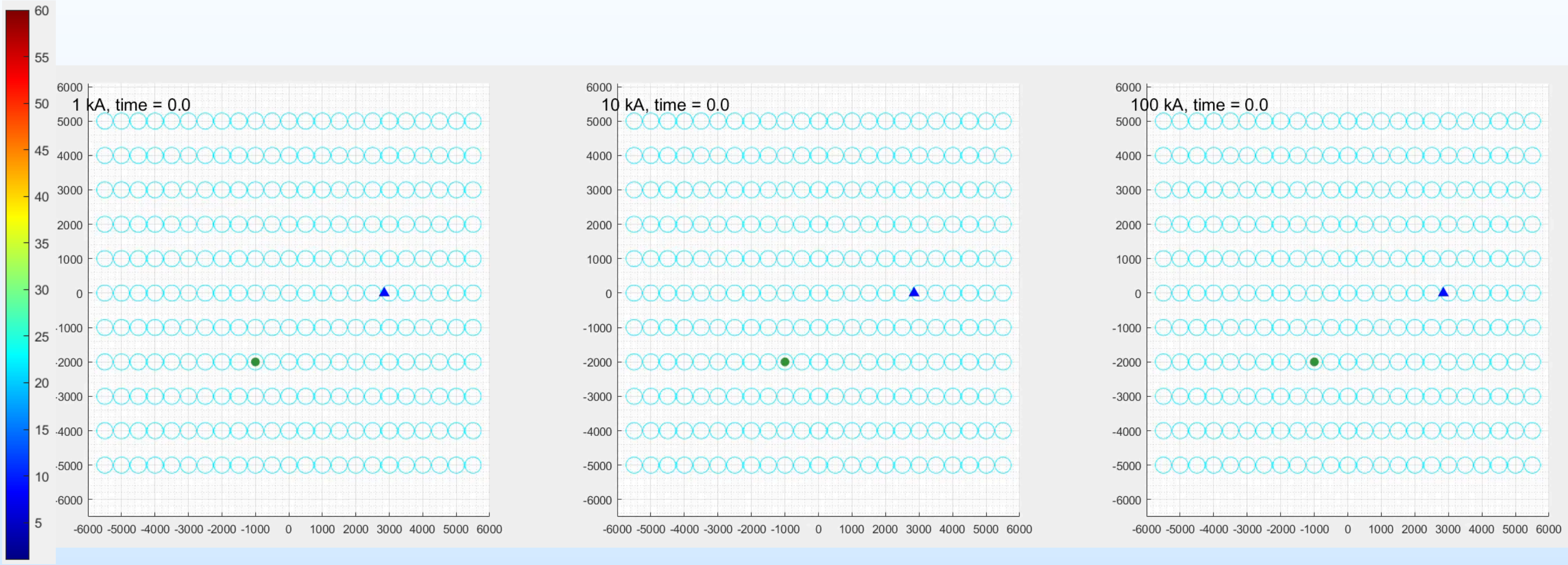
DIFFERENCE between pre-breakout survey and post-breakout survey in seafloor electric (blue) and magnetic (red) fields vs. time (s) after xmitter pulse, 10^5 kAm MHD generator with vertical (not horizontal) xmitter antenna, realistic noise





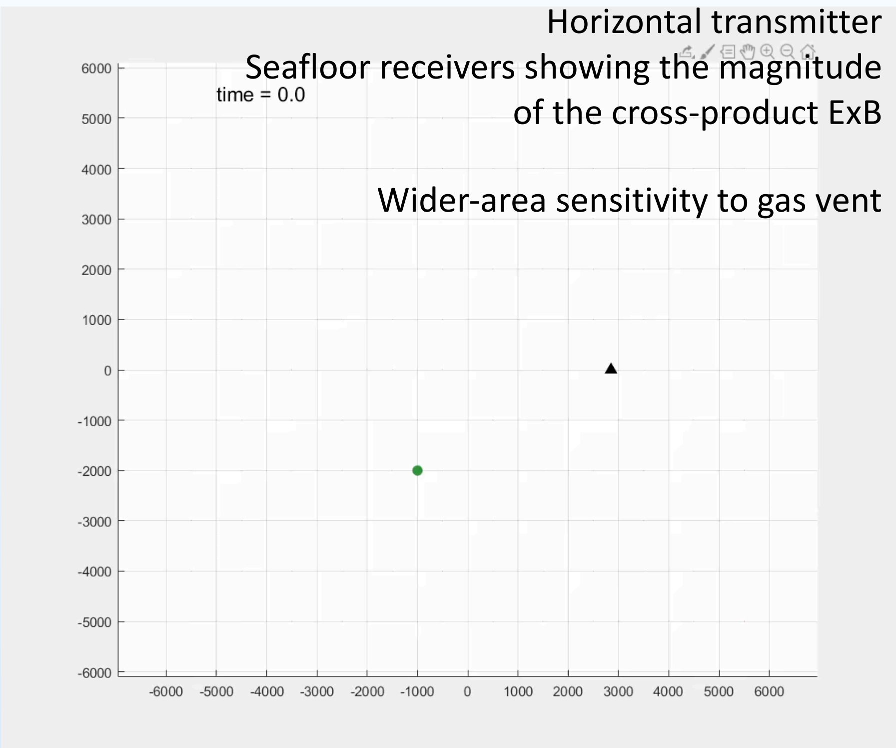
Technical Status

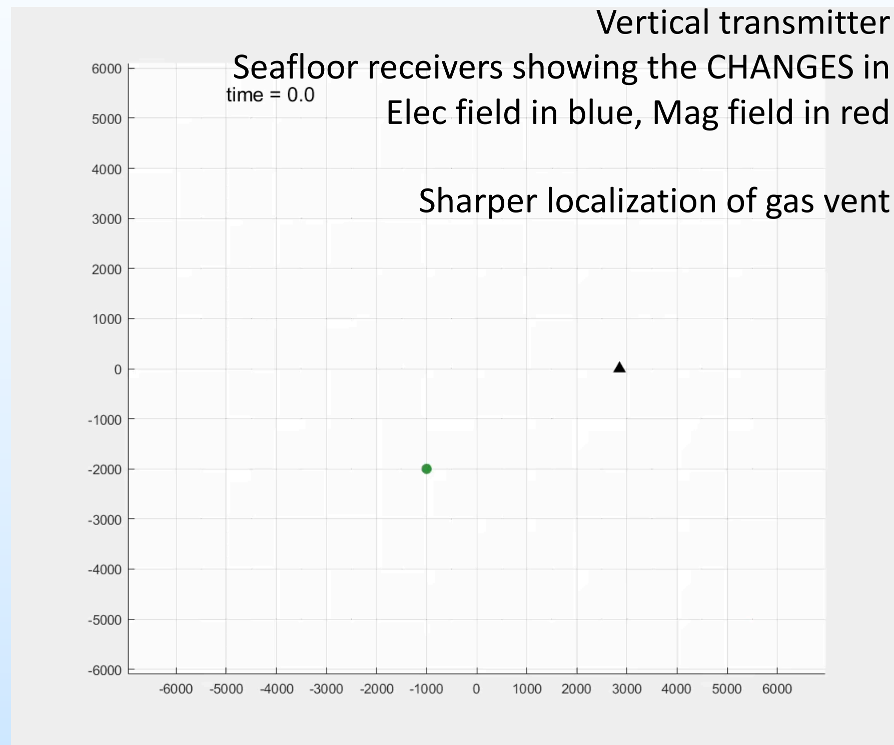
Signal to noise ratio (SNR) in dB of difference between pre-breakout survey and post-breakout survey data for salt dome gas vent breakout model, 10^3 kAm (conventional), 10^4 kAM (supercapacitor boosted) and 10^5 kAm MHD generator pulses, vertical dipole antenna, realistic noise



Technical Status

An alternative way to detect the gas pipe – here we display the difference in the between pre- and post-breakout survey Poynting Vector, the cross-product of the electric and magnetic fields on the seafloor, which measures directional energy flux (W/m^2)





Accomplishments to Date

Identifier	Type	Expected Completion Date	Description	Status
EY21.9.A	Project	~~6/30/2021~~ 9/30/2021	Integrated 1D Performance Code of the CCMHD System. Improve 1D performance code of the CCMHD system by adding the optimized combustion and pebble bed systems.	Delayed, due to changed MHD system from closed cycle to open cycle. New plan for code development was established.
EY20.9.B	Project	9/30/2021	Document of Verification and Validation Study of 1-D Performance Code. Verification and validation study using analytic models and legacy simulations & experiments.	In progress with code development in parallel
EY20.9.B	Project	12/31/2021	Optimization of the CCMHD system using 1D performance code for field application. Measurement of completion/product: Design of MHD Generator	In progress; now including OCMHD
EY20.9.B	Project	3/31/2022	Further improved design of the MHD channel of the CCMHD system via multi-dimensional simulation. Measurement of completion/product: Design of MHD Channel	Will now include OCMHD
EY20.9.E	Project	1/31/2022	3D simulation of improved CSEM imaging with new power supply/transmitter incorporating GPU acceleration and joint MT/CSEM inverse modeling, sensitivity analysis	GPU acceleration of 3D CSEM forward modeling code achieved; insertion of realistic noise into test data set achieved; inverse modeling initiated after delay related to FMLA leave

Lessons Learned

CSEM+MT Modeling

– Original plans to use an existing open-source 3D electromagnetic inverse modeling code (ModEM) for both MT and CSEM had to change since CSEM module was under development and required a commercial license. The slow speed and memory demands of the code were also limiting factors.

– A new 3-D FDTD CSEM forward modeling code written at OSU was brought into the project. This runs well on Joule and was optimized to efficiently use multiple GPUs to accelerate the solutions. Near Joule-like performance achieved on workgroup class hybrid GPU rack-mounted server suitable for shipboard use.

– A new inverse modeling code is being written around the FDTD forward modeling code. Both Fréchet matrix and adjoint-like solutions are being implemented – the latter to minimize the memory footprint.

Lessons Learned

CSEM+MT Modeling

– Accurately modeling very narrow and long structures such as a well casing is challenging using our structured grid approach, but computational advantages for most survey configurations outweigh the disadvantages. This should be fine so long as receivers are not clustered directly around the anomalous structure.

MHD Power Source

– The simulation/experiment data for verification and validation work of chemical kinetics for ionization and recombination of seed material is limited.

Lessons Learned

MHD Power Source

– It was necessary to expend considerable effort in initial CCMHD development to determine that an alternative OCMHD path would provide fewer technical challenges to a commercially deployable system

Unanticipated Research Difficulties

– Personnel issues included CSEM modeling postdoctoral researcher end-of-visa and return to Japan; recruitment of new postdoctoral researcher with long lead time for FN (PRC) approval to work on project, temporary departure of same for FMLA

– Project delays mitigated by availability of existing postdoctoral researchers at OSU who could continue with seafloor noise impact studies

– Main impact was to defer new code developments for several months, but that is now back on track

Synergy Opportunities

- We are developing a new capability for remote detection of emerging and existing geohazards by identifying zones of fluid incursion and changes over time of geologic fabric
- There are synergies with related projects in:
  - geohazards & subsurface uncertainty smart modeling,
  - assessing current and future infrastructure hazards,
  - constraining kick signals through advanced multi-phase data
- By leveraging research outcomes of related projects, we can improve on blind CSEM surveying and more efficiently identify candidate targets for CSEM baseline surveys and re-surveys of emerging hazards

Project Summary

– Key Findings

- Signal stacking of received CSEM waveforms generated by moving transmitter significantly degrades ability to resolve fine-scale geohazard targets
- Using both horizontal <<and>> vertical electric dipole transmitter antennas improves resolution of subvertical targets
- Key components of a 10 MWe OCMHD generator have been modeled, indicating the feasibility of such a system boosting signal outputs per pulse by nearly 2 order-of-magnitude over the largest commercial CSEM source reducing or eliminating the need for signal stacking
- Using our new GPU accelerated FDTD CSEM modeling code (GPU speedup of 30-100x) we have modeled such a signal source and hybrid vertical/horizontal dipole transmitter and using realistic seafloor EM noise data have shown that a small diameter gas pipe breakout from a subseafloor salt dome can be detected

Project Summary

- Next Steps
  - Completion of CSEM 3-D inversion code and integration of results with existing 3-D MT inversion code (ModEM) to run formal sensitivity analysis for detectibility of a range of geohazards targets under realistic seafloor noise conditions
  - Apply multigrid methods to CSEM forward modeling code to reduce memory requirement for complex geohazard models
  - Develop conceptual design and later lab bench prototype of 750 kW level supercapacitor system to achieve x 10 power increase/pulse over conventional diesel generators
  - Refine 1-D model and 3-D simulations of OCMHD generator confirming 10 Mwe output for 10 s in 120 s duty cycle is achieved

Appendix

– These slides will not be discussed during the presentation, but are mandatory.

Benefit to the Program

- Identify the program goals being addressed.

- Insert project benefits statement.
  - See Presentation Guidelines for an example.

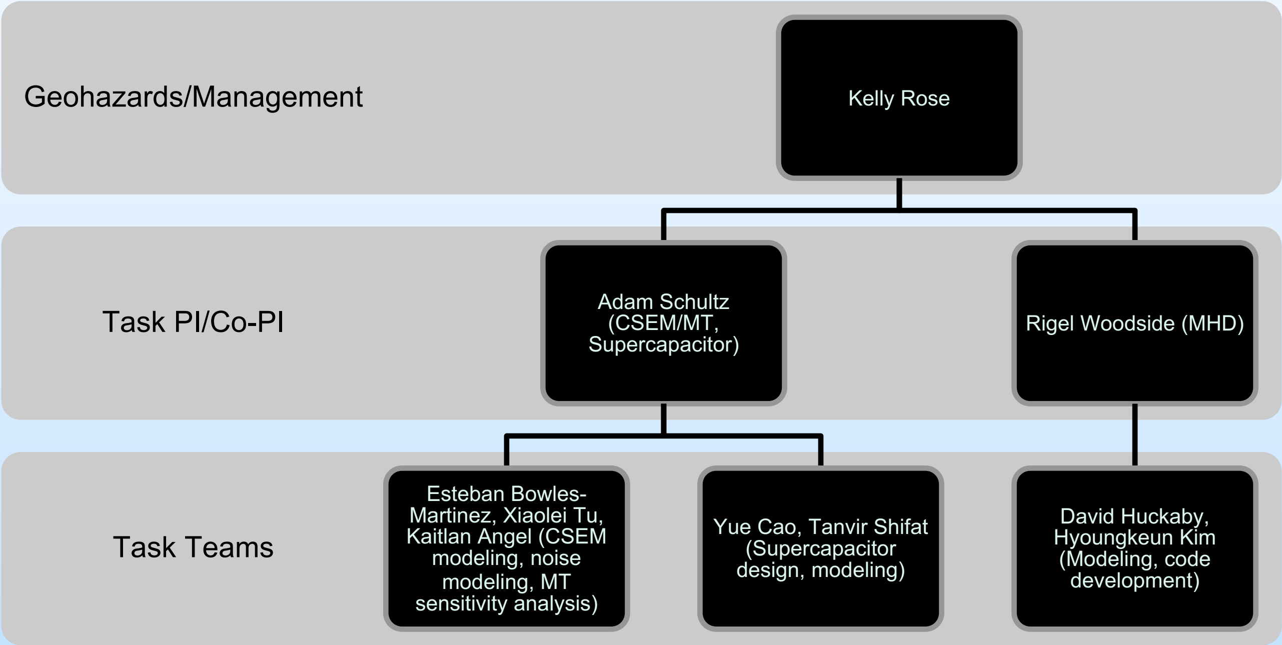
Project Overview

Goals and Objectives

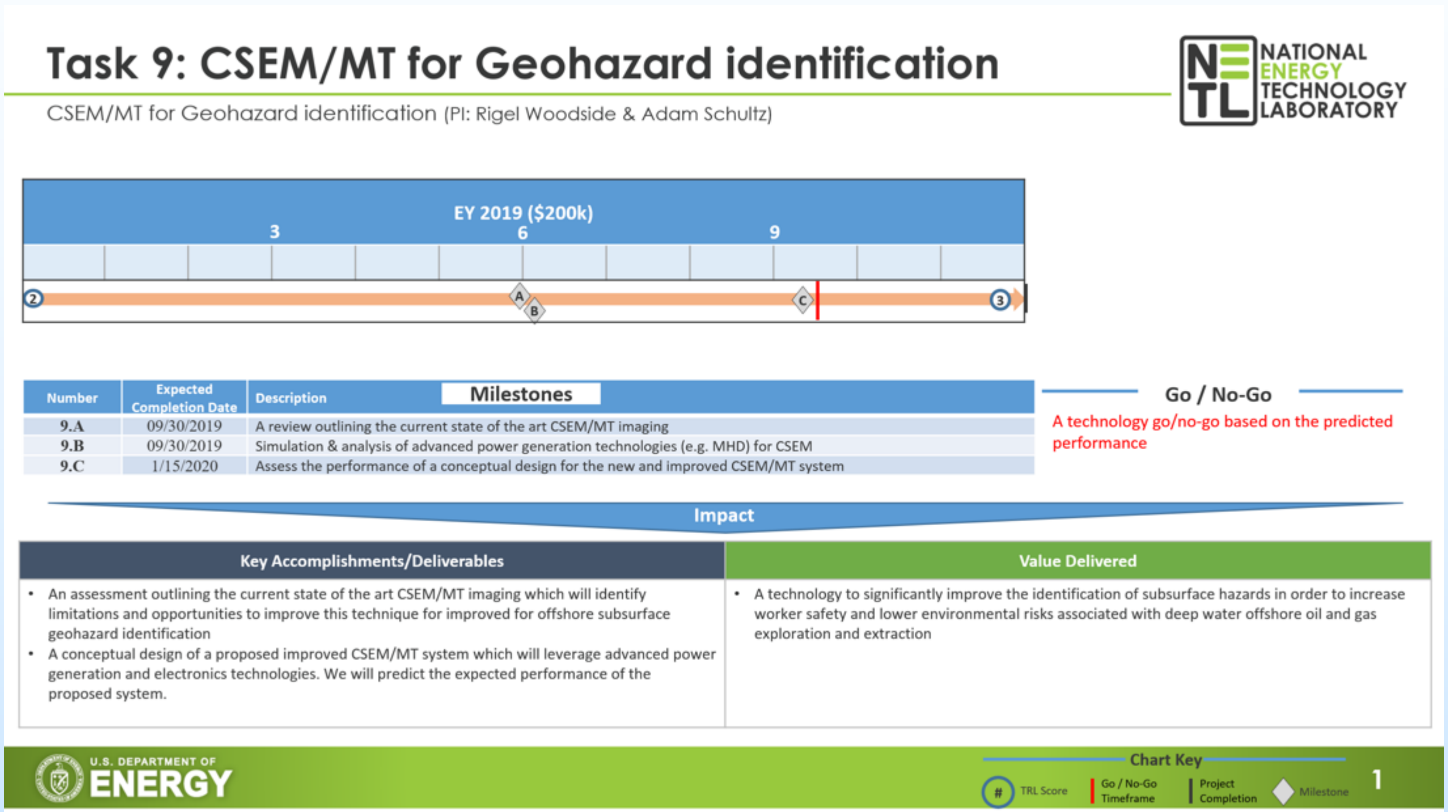
- The objective of this task is to develop and assess a concept for a significantly improved controlled-source electromagnetic (CSEM) imaging technology to identify offshore sub-surface and subsalt geohazards, to monitor the integrity and dynamic state of hydrocarbon reservoirs, and as a high-resolution, non-seismoacoustic exploration tool. The technology developed will also be transferrable to onshore geohazards, reservoir management, and exploration applications. The improvements will be enabled through the development of a novel system that leverages advances in electronics and a transformational leap in power generation technologies.
- How the project goals and objectives relate to the program goals and objectives.
  - Identify the success criteria for determining if a goal or objective has been met. These generally are discrete metrics to assess the progress of the project and used as decision points throughout the project.

Organization Chart

- Task PI: Rigel Woodside, Adam Schultz (Co-PI, OSU/ORISE)
- Other Key Personnel:
  - NETL (Hazards, MHD Lead) - Kelly Rose, David Huckaby, Hyoungkeun Kim
  - OSU (CSEM/MT, Supercapacitor Lead) - Esteban Bowles-Martinez, Xiaolei Tu, Yue Cao, Tanvir Shifat, Kaitlan Angel



Gantt Chart



Task 9: CSEM/MT for Geohazard identification

CSEM/MT for Geohazard identification (PI: Rigel Woodside & Adam Schultz)

NATIONAL ENERGY TECHNOLOGY LABORATORY

EY 2019 ($200k)

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Number	Expected Completion Date	Description
9.A	09/30/2019	A review outlining the current state of the art CSEM/MT imaging
9.B	09/30/2019	Simulation & analysis of advanced power generation technologies (e.g. MHD) for CSEM
9.C	1/15/2020	Assess the performance of a conceptual design for the new and improved CSEM/MT system

Milestones

Go / No-Go

A technology go/no-go based on the predicted performance

Impact

Key Accomplishments/Deliverables	Value Delivered
• An assessment outlining the current state of the art CSEM/MT imaging which will identify limitations and opportunities to improve this technique for improved for offshore subsurface geohazard identification • A conceptual design of a proposed improved CSEM/MT system which will leverage advanced power generation and electronics technologies. We will predict the expected performance of the proposed system.	• A technology to significantly improve the identification of subsurface hazards in order to increase worker safety and lower environmental risks associated with deep water offshore oil and gas exploration and extraction

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Chart Key: TRL Score | Go / No-Go Timeframe | Project Completion | Milestone

1

Bibliography

– List peer reviewed publications generated from the project per the format of the examples below.

- N/A