Cost Effective Optical Seismic for Unconventional Wells and Alternative Energy

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National Energy Technology Laboratory

Resource Sustainability Project Review Meeting

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Presentation Outline

- Program overview
- Background: Optical borehole seismometers
- Technology: Product and Field Results
- Achievements and Developments

Program Overview

- DOE Funding: $2.5M
- Cost Share total: $625k
- Performance Period: 10/1/2019 – 9/31/2021
  - Extended to 12/31/2022, field test planned in 2023
- Project Participants:
  - MagiQ Technologies, Inc. (prime)
  - HighPeak Energy – field operator
  - Borehole Seismic, LLC – deployment/acquisition
  - TotalEnergies SE – additional support and analysis

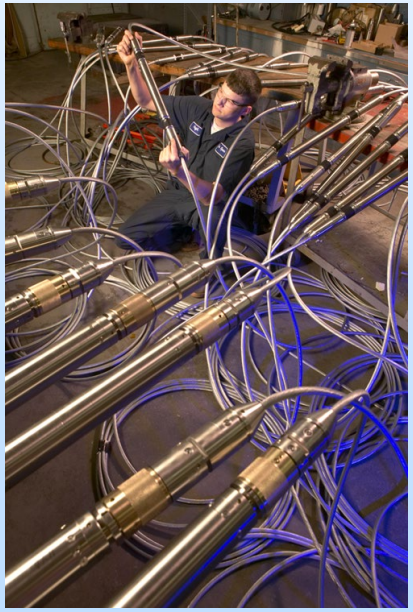
Program Overview

- Overall Project Objectives
  - produce a narrow diameter, high temperature, reliable optical seismic sensor system and demonstrate it in a field test an unconventional basin
  - perform a suite of data acquisition activities which will be analyzed to provide information on the reservoir and well operations including active surveys and passive seismic and microseismic monitoring
  - demonstrate the ability to cost-effectively provide useful data in a challenging environment

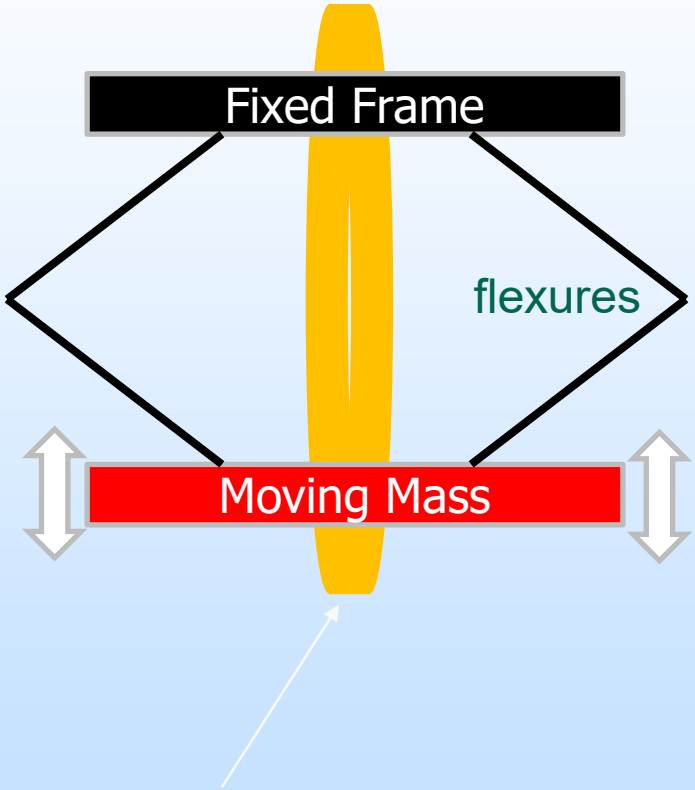
Background: Industry Need

- Accurate geophysical data with reliable, transparent analyses are essential for profit and safety in the energy industry.
- DOE pushing for better understanding of well dynamics in fractured wells to improve safety and efficiency.

- State of the art seismic wireline tools are bulky and require maintenance, so downhole sensor deployments are temporary, labor intensive, and disrupt production operations.
- DEPLOYMENT COST > HARDWARE COST



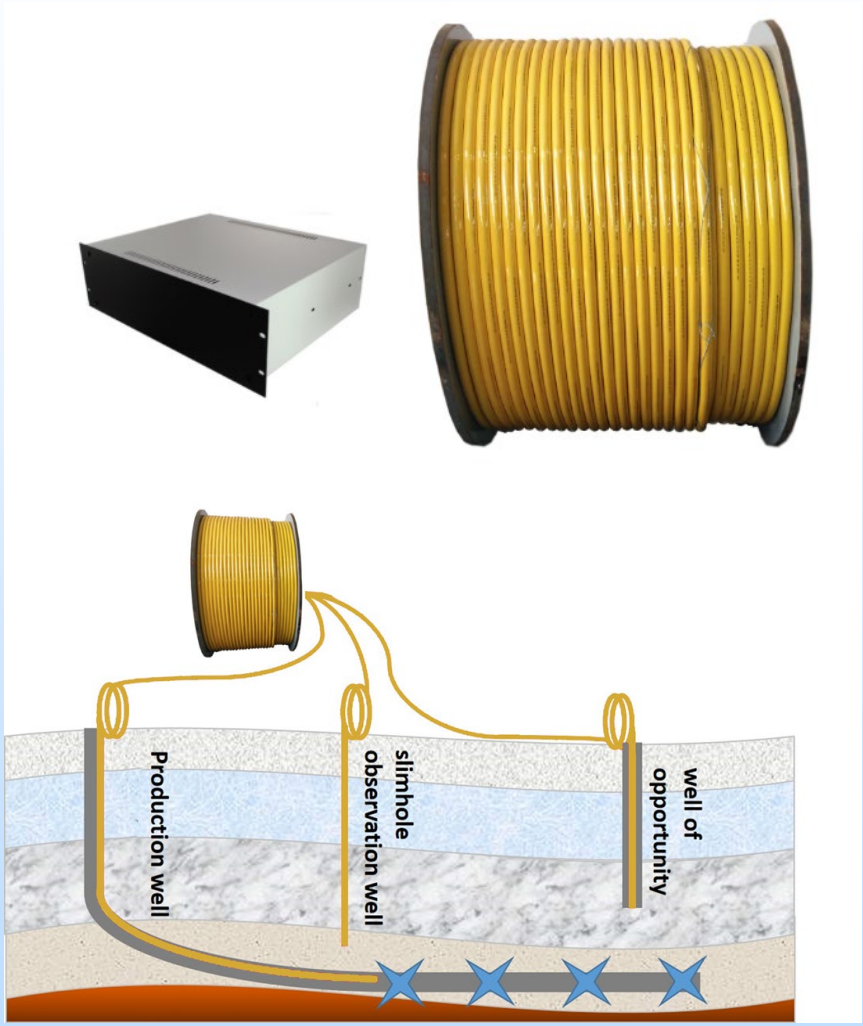
Background: optical accelerometers



- 'Mass on a spring' design moves under acceleration, stretching optical fibers
- Flexure offers high directionality, high linear dynamic range
- Multiple designs with different specs have been field tested and verified by comparison to geophones and accelerometers.
- All parts are passive and survive decades at high temperatures

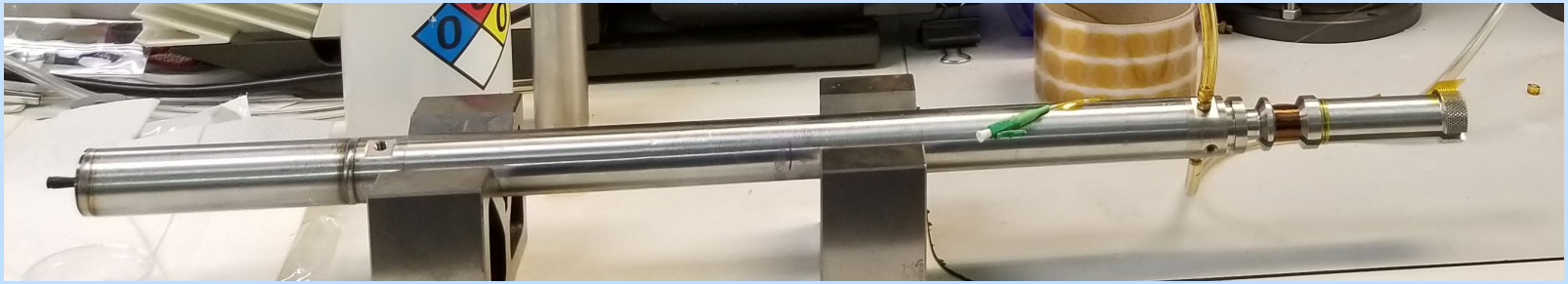
Background: MagiQ Sensor System

- The interrogator includes all electronics, while sensors can be kilometers away, connected by rugged optical cables
- Supports 10 3C sondes per fiber, many fibers per cable. DAS fiber including in cable.
- Field tested to be robust against laser noise and transmission line pickup.

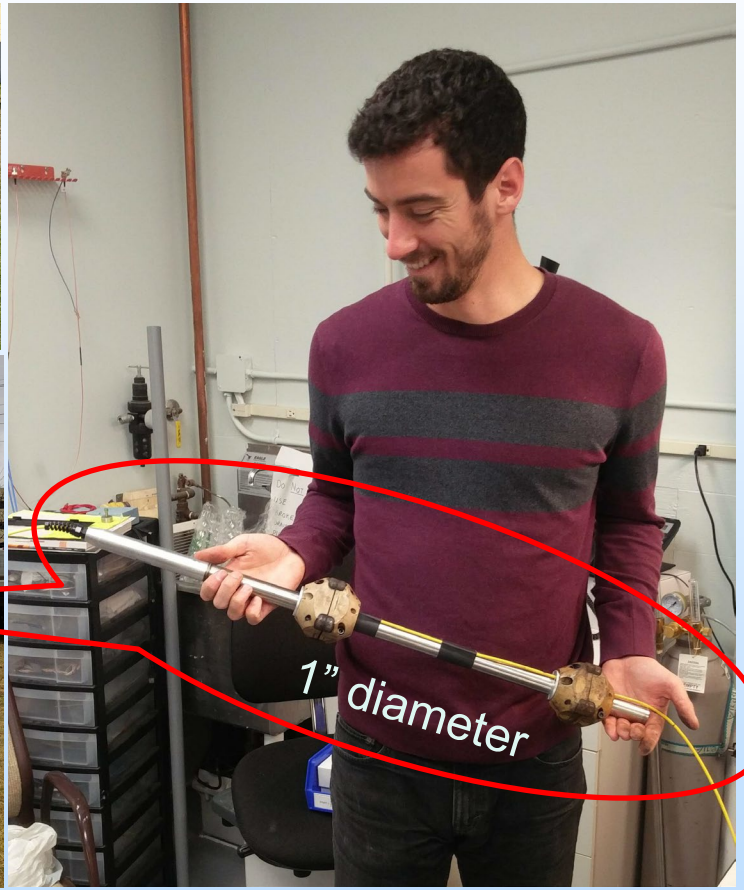


Approach: Sensor Assembly

- Sensor "core" elements are machined from metal stock and wound with fiber.
- The cores are assembled and enclosed in a tube with welded or threaded flanges.
- The sensors are fluid filled for pressure balance and damping.
- Response testing occurs at each step



Approach: Borehole Sonde



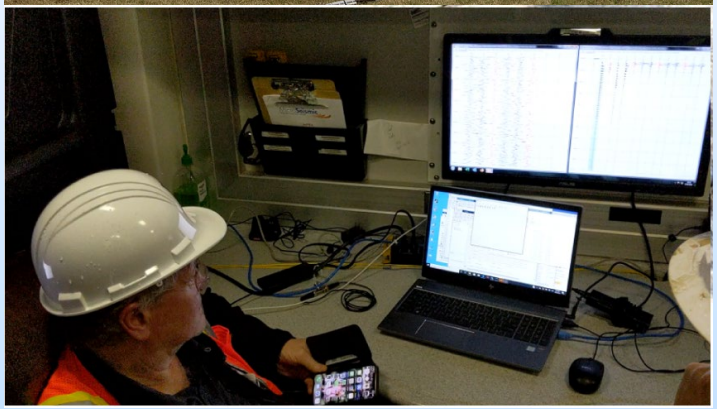
Magnetic clamps

6-Fiber cable, intended to be strapped to a DS-150 toolstring

Issues with cable attachment

Required repairs, changed to a "piggyback" config

Progress: Field test in Jan. 2020



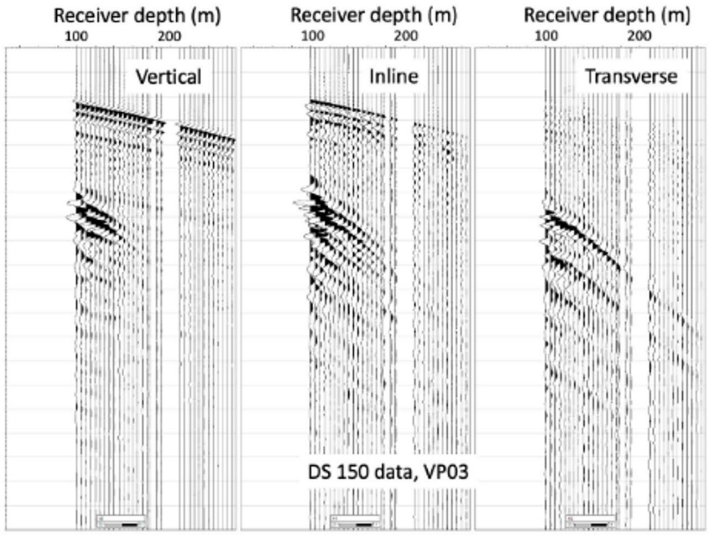
Field test with MSI, Aramco Services Co, and Total SA, partly funded by Phase II SBIR DESC0015781

MagiQ produced and tested 4 sonde prototypes (1 Flexible Sonde and 3 Rigid Sondes).
-Narrow diameter, broadband sondes with response comparable to GeoSpace DS-150s

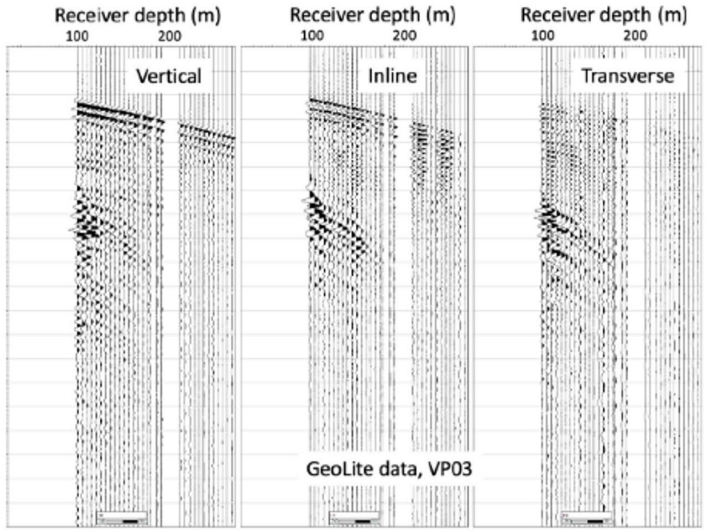
Interfaced with MSI's commercial seismic QA and analysis workflow.

Generated a variety of seismic analyses and visualizations

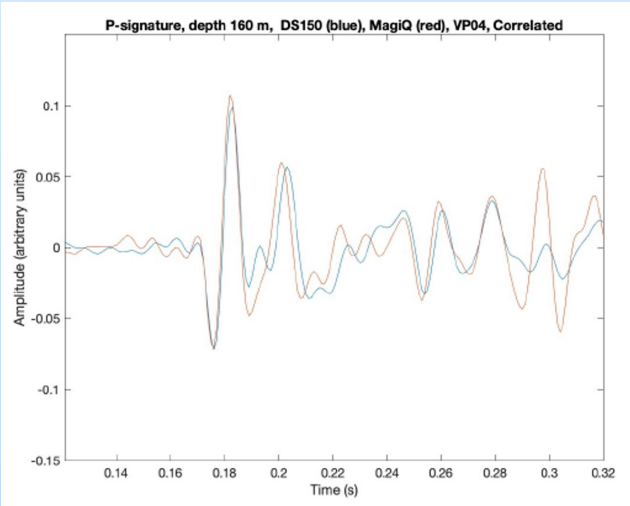
Comparison to DS-150 string



3C Electrical Geophone Downhole



3C GeoLite Sensor

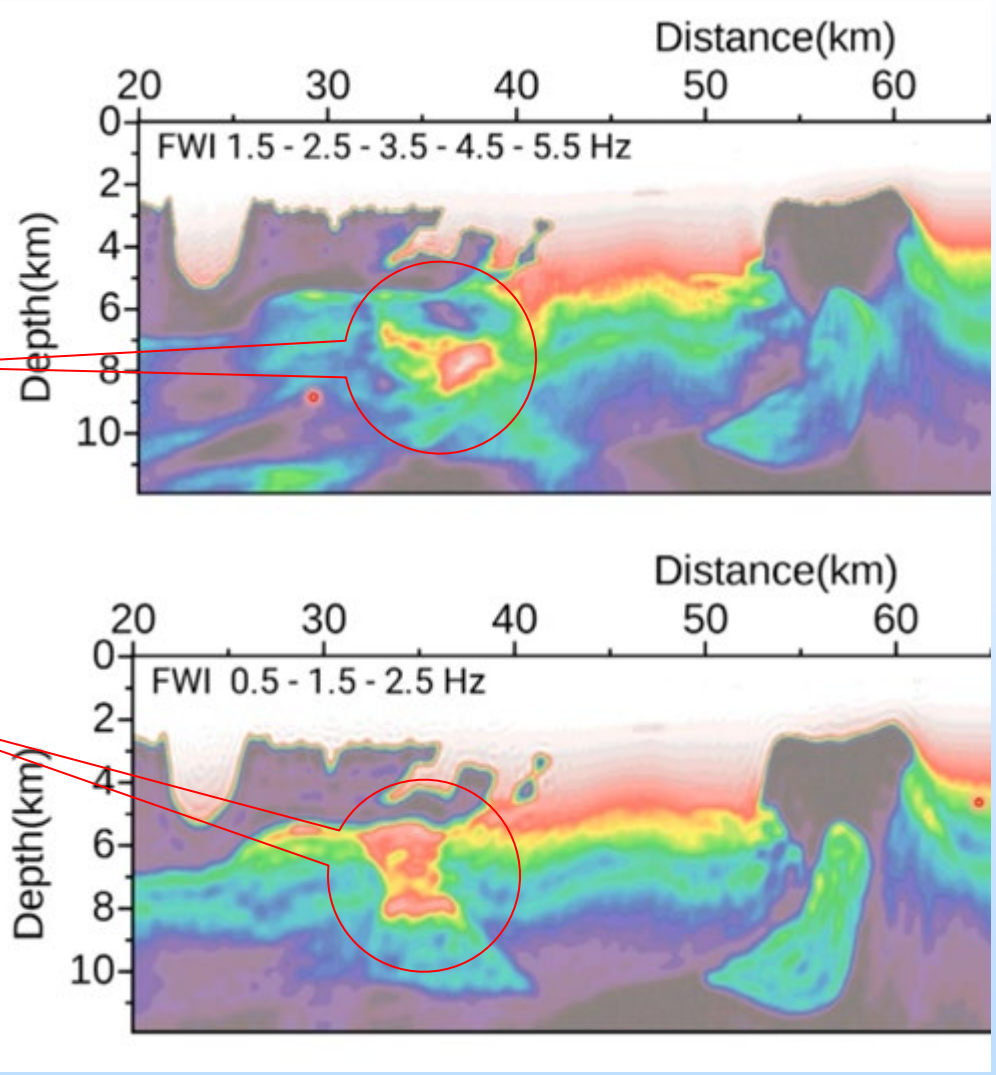


Conclusions: GeoLite can replace DS-150s for VSPs and microseismic, with added value at low and high frequencies

Value of low frequencies

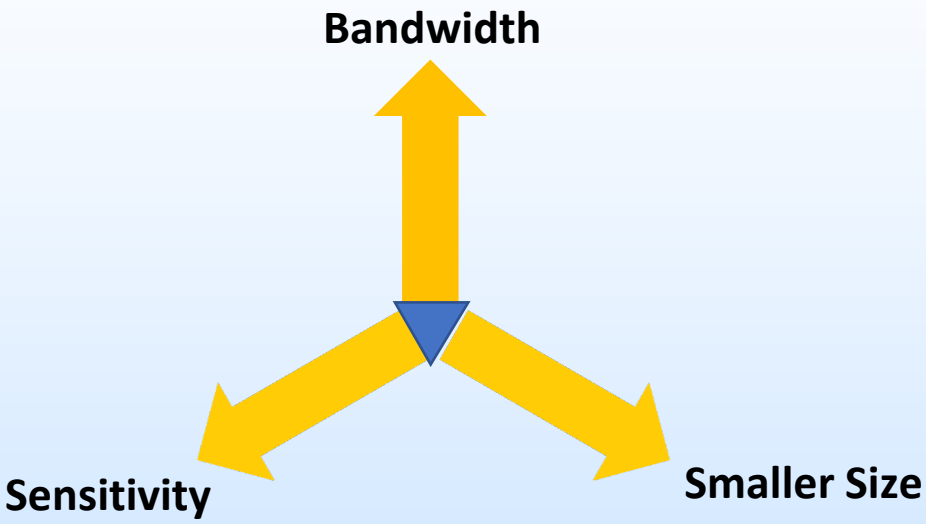
Before:
1.5-5.0 Hz

After:
0.5-2.5 Hz



S. Sambolian, S. Operto, A. Ribodetti, and L. Combe, 2020, From slope tomography to FWI: Is the conventional workflow viable in complex settings? SEG meeting 2020, https://doi.org/10.1190/segam2020-3428063.1

Optimizing for Application



Customer Requirements: maximum size, minimum detectable signal and bandwidth.

Balance costs and ensure reliability in the application (temp, pressure, duration).

Cable is a major cost driver of the system, and is influenced by channel count, optical architecture, total tool weight, and temperature. Fit for purpose, DON'T overdesign!

Accomplishments to Date

- Advanced latest design for efficient manufacturing, reliable cable/fiber attachments, and optimized sensor response
- Supply chain resilience with additive manufacturing, stock materials, and multiple sources
- Field Test date is delayed and being rescheduled, responding to partner schedules and goals
- Planning for applications and deployments in other sectors (geothermal, CO2 storage, defense)

Synergy Opportunities

- We are seeking future partners and customers with unique monitoring needs, especially in Carbon Capture (with Total) and Geothermal (planning activities with GTI and Fervo)

- A small number of wide bandwidth vector seismic sensors should be supplemented with DAS fiber in the same cables, to optimize coverage versus costs.

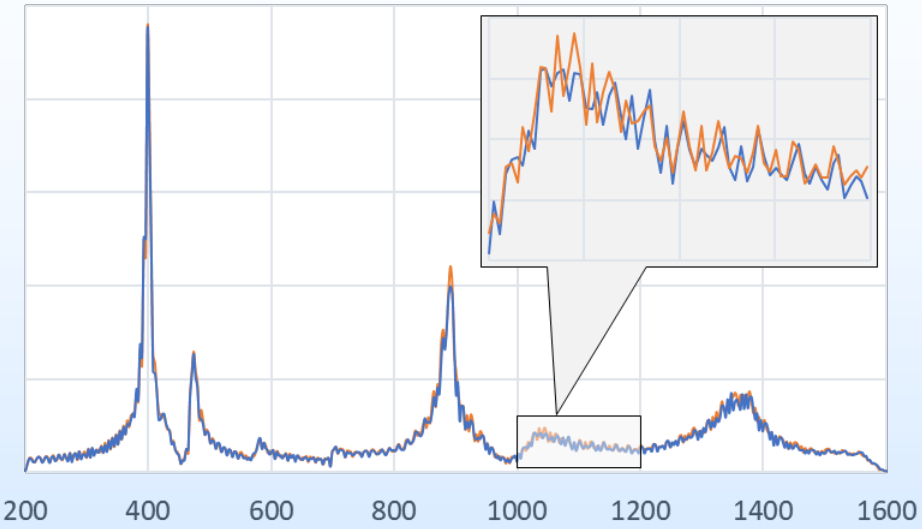
- Serious interest from the Department of Defense, especially:

Navy (harbor and range security, blue water monitoring)

Army ERDC (infrastructure and base security)

DHS, Coast Guard (operational assets for existing missions)

Added value: Hydrophones



Same interrogator, but broadband acoustic (includes <1 Hz)

Towed/floating sensor for defense apps

Adaptable to maritime vector sensors

Tested in Navy labs and at sea, calibrated against H48 Navy developed reference

Project Summary

- Objectives are to demonstrate advanced imaging and analysis methods in an unconventional well which benefit from bandwidth and time-lapse.
- performance optical sensors work very well, providing the capabilities of geophone strings with additional bandwidth and longer expected lifetime.
- Lessons from field tests with prior designs are informing ongoing work, reducing costs and improving manufacturability
- After some delays due to industry recession during pandemic, we expect to perform field tests in early 2023.

MagiQ.

Appendix

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

Benefit to the Program

- Project Benefits statement:
  - The research project is designing and fabricating a novel optical seismic sensor system, deploying the system in an unconventional fossil energy reservoir, and performing advanced analyses which take advantage of the long-term deployment capabilities, wide bandwidth, and high SNR of the sensor system. The technology, if successful, can reduce costs for real-time monitoring in long-term or permanent deployment of high performance seismic sensors, while delivering better signal quality at low frequencies and high frequencies compared to state of the art geophone systems. The analysis methods specifically take advantage of the broadband vector information to improve subsurface characterization, visualization, and diagnostics.

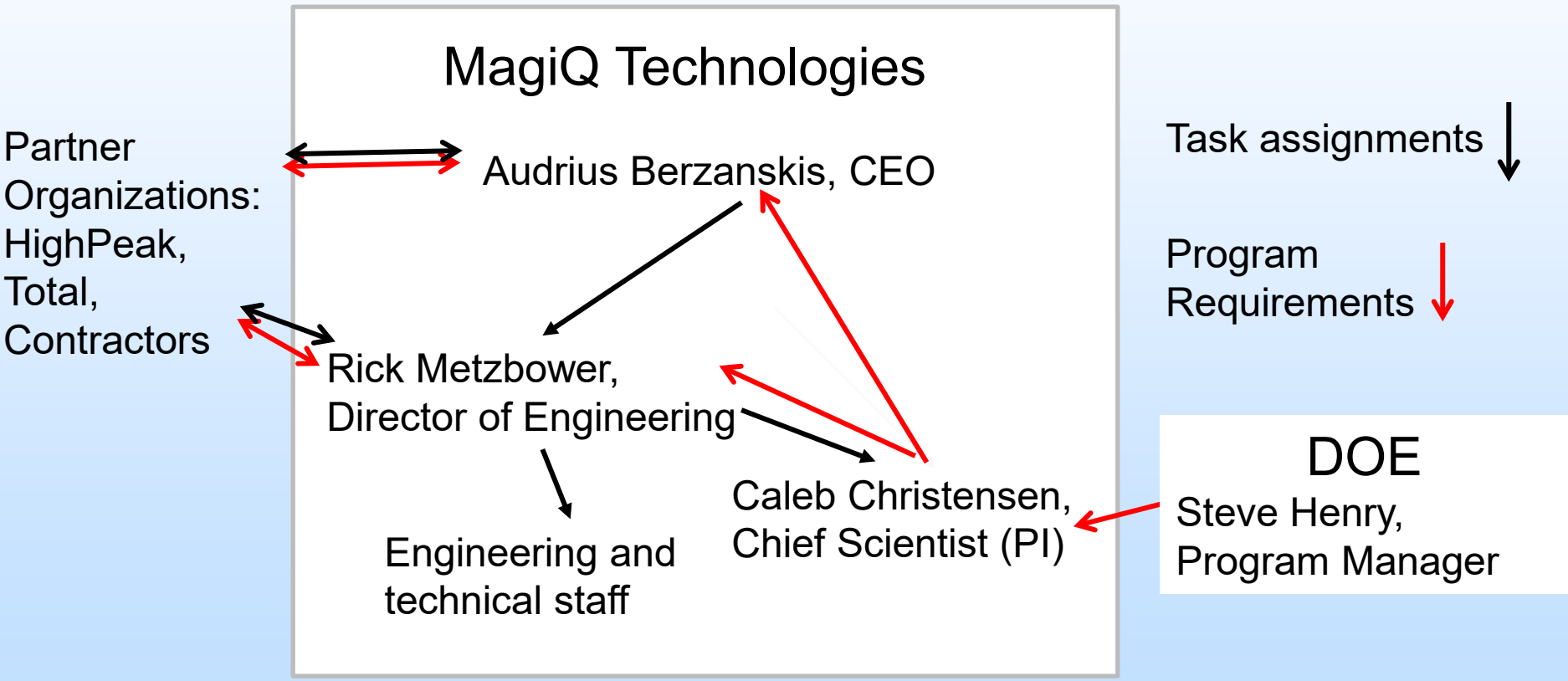
Project Overview

Goals and Objectives

- Describe the project goals and objectives in the SOPO:
  - produce a narrow diameter, high temperature, reliable optical seismic sensor system and demonstrate it in a field test in an unconventional basin success = field test commenced
  - perform a suite of data acquisition activities which will be analyzed to provide information on the reservoir and well operations including active surveys and passive seismic and microseismic monitoring success = data acquisition complete
  - demonstrate the ability to cost-effectively provide useful data in a challenging environment

    Success = High Peak, DOE find interpretation and analysis results useful and interesting for O&G development

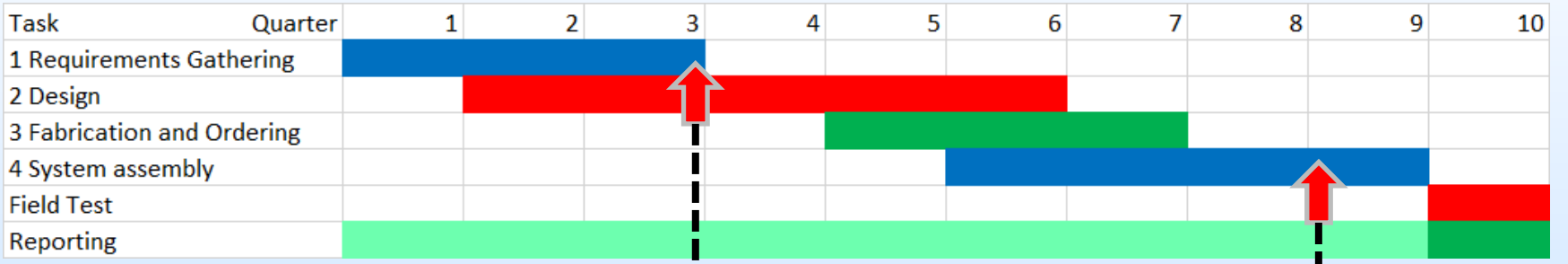
Organization Chart



Gantt Chart

Start: Oct. 1, 2019

End: Dec 31, 2022



Preliminary Design Review Completed Dec 2019

Field Readiness Review Completed Nov 2021

Field Test TBD (waiting for partner schedules to align)

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– Peer reviewed publications and conference proceedings:

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