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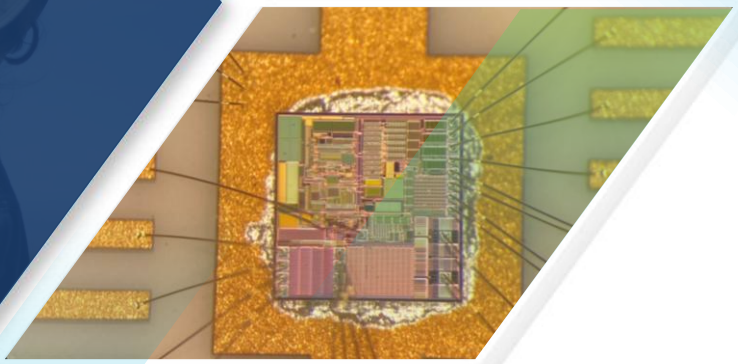
High Temperature High Pressure Cable for Subsurface Instrumentation

Sandia National Laboratories
Geothermal Research Program
Presenter: Andrew Wright

April 17 2025



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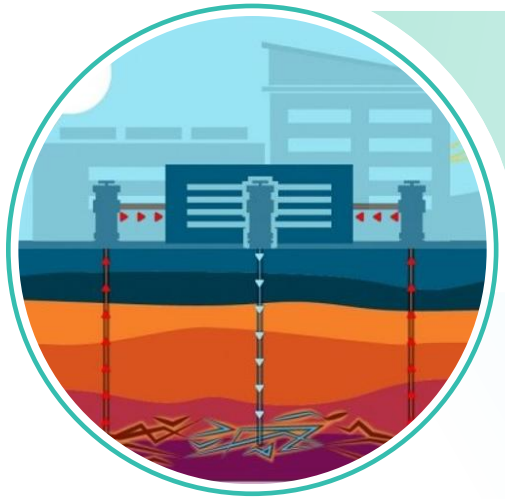
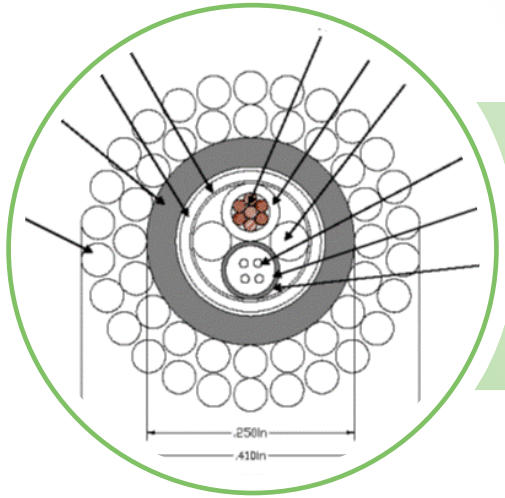
PRESENTATION OVERVIEW

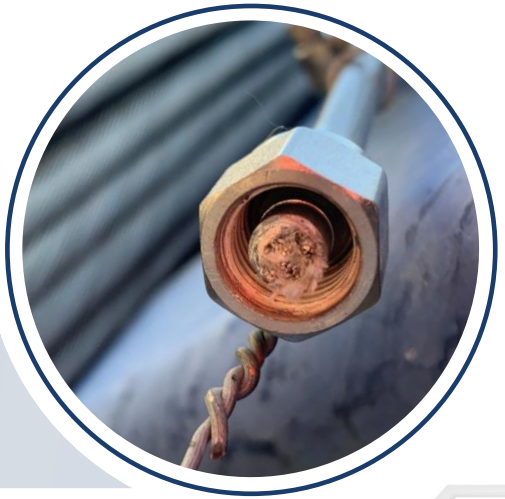


Background Information

Problem Identification



Proposed Solution



Data Review

HOW WE HARNESS GEOTHERMAL ENERGY

POWER GENERATION

Hydrothermal Resources

Naturally occurring geothermal environment

- Subsurface heat
- Groundwater
- Rock characteristics

https://www.xanterra.com/stories/great-geyser-gazing-in-yellowstone/

HOW WE HARNESS GEOTHERMAL ENERGY

POWER GENERATION

Hydrothermal Resources

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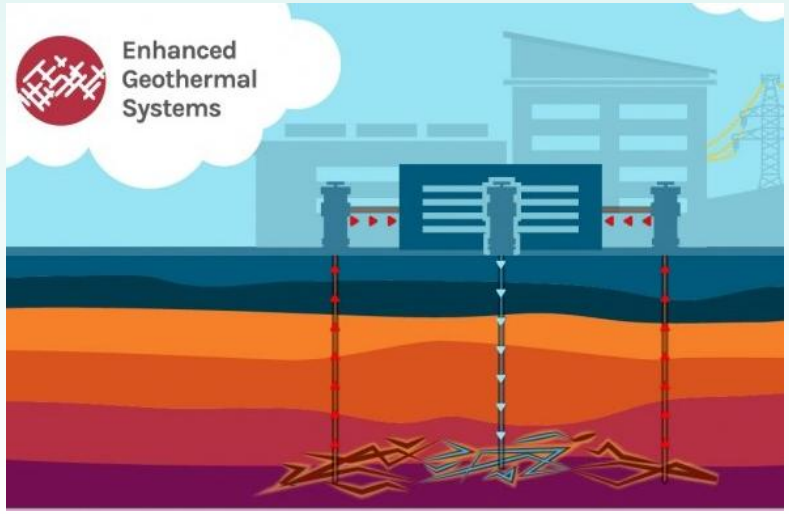
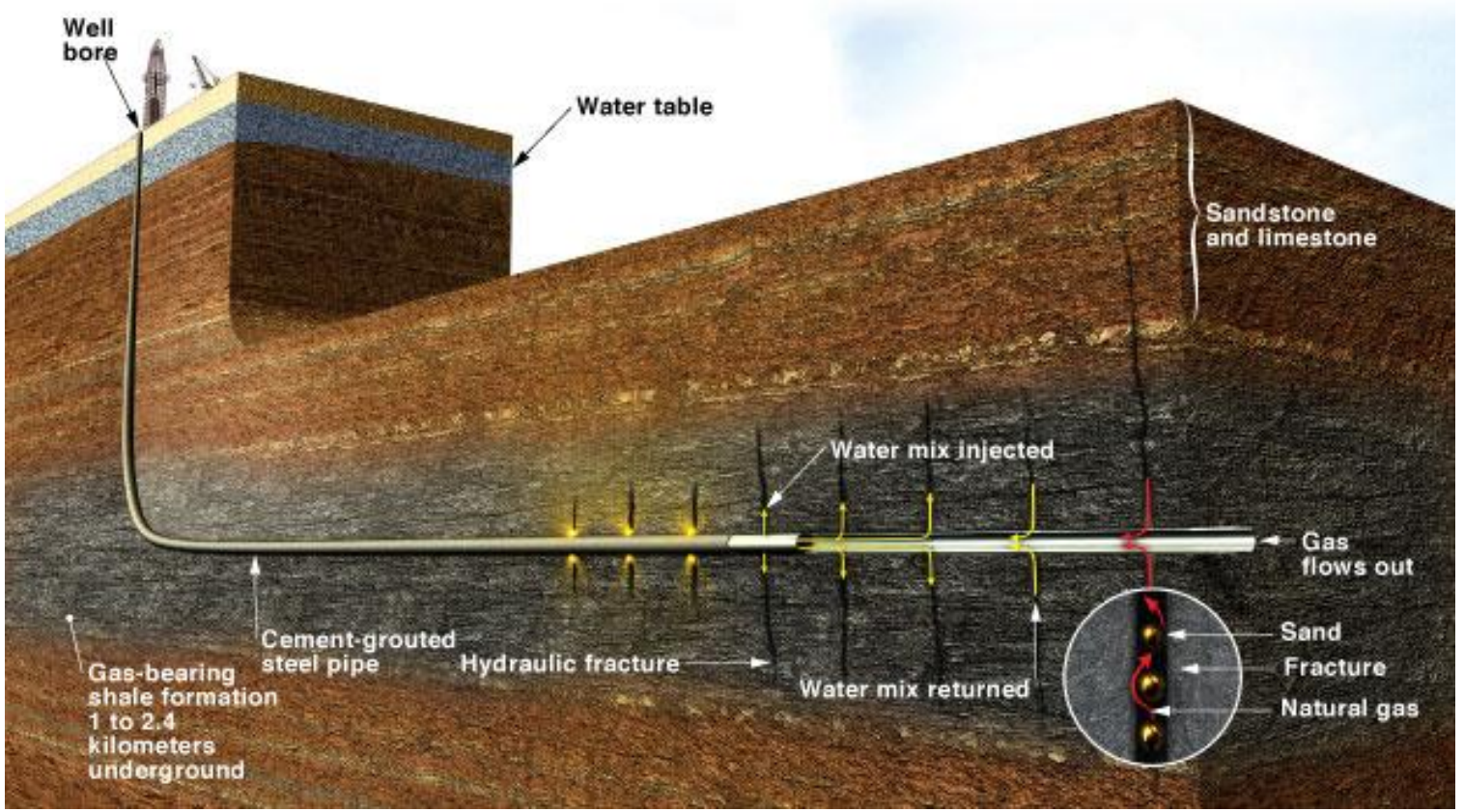
Enhanced Geothermal System

Manmade geothermal environment

- Subsurface Heat
- Lacks groundwater and/or
- Lacks Rock characteristics





Office of ENERGY EFFICIENCY & RENEWABLE ENERGY
https://www.energy.gov/eere/geothermal/enhanced-geothermal-systems

https://str.llnl.gov/past-issues/julyaugust-2014/closer-look-rocky-underground

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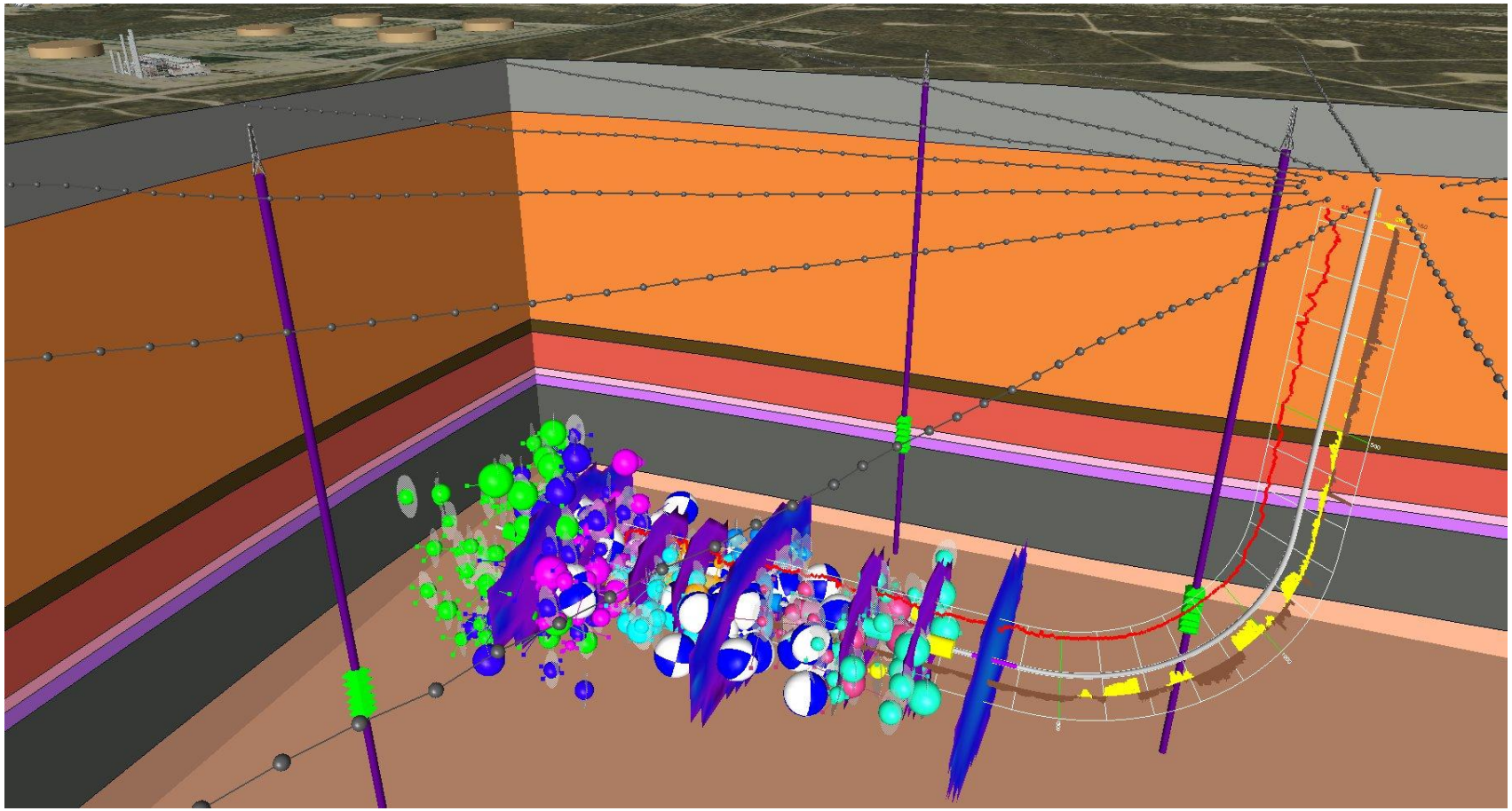
EXAMPLE – FORMATION DETECTION

Instrumentation can be emplaced in the subsurface to detect the formation of fractures

- Requires long-term observations
- HT long-term instrumentation will be required to conduct the measurement
    - Require real-time data from multiple instrumentation to triangulate formation



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https://www.dgi.com/blog/fracture-stimulation/

EXAMPLE – WELL INTEGRITY

- Geothermal well casing endures heavy corrosion from the subsurface environment.
- Well integrity instrumentation can be lowered into the well to characterize the casing, cement, rock
  - Measurements can take extensively long due to the scanning techniques
  - Due to the amount of data, real-time data is required from the tool

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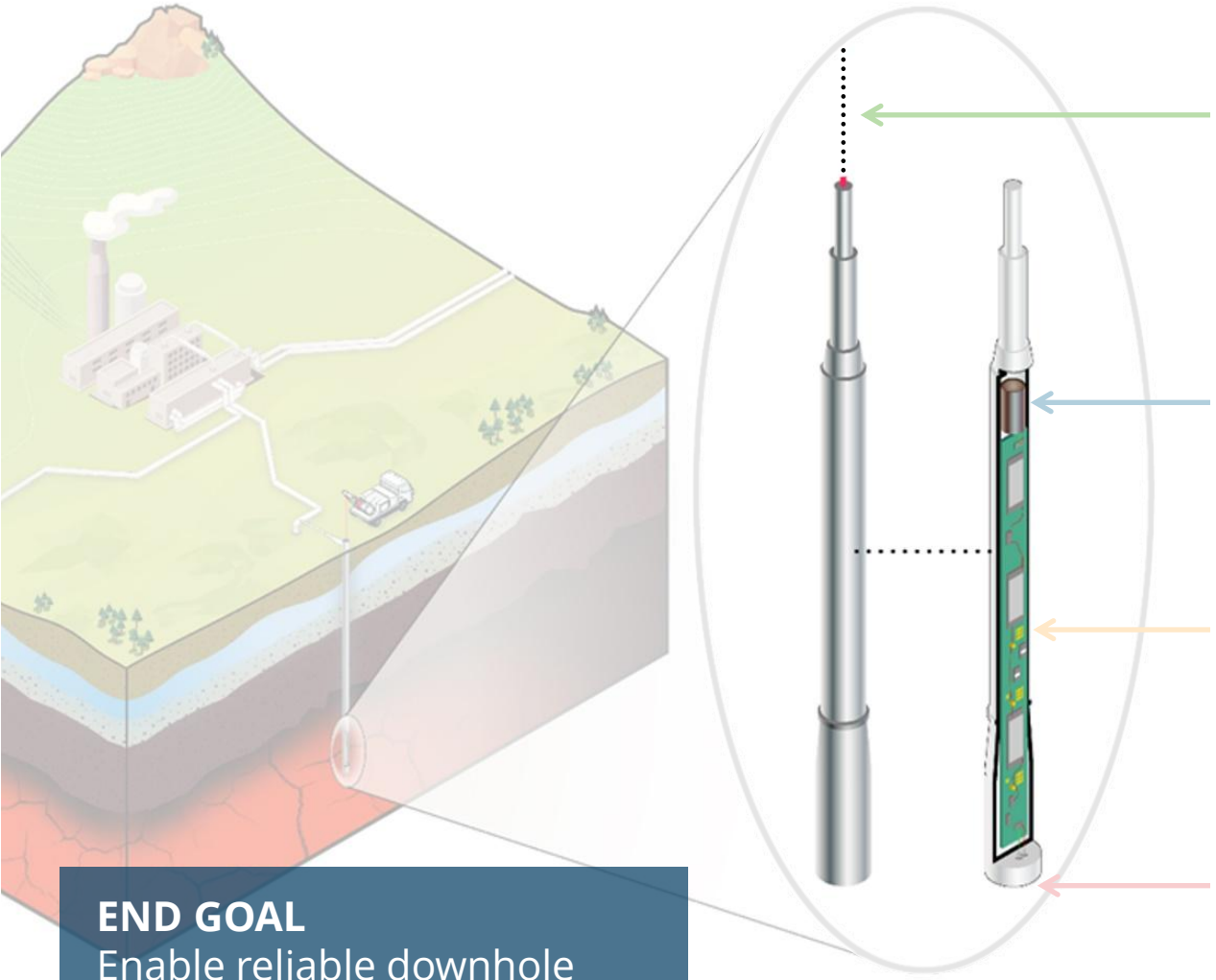
Kruszewski, M., Wittig, V.: Review of failure modes in supercritical geothermal drilling projects. Geotherm Energy 6, 28 (2018). https://doi.org/10.1186/s40517-018-0113-4

HIGH TEMPERATURE INSTRUMENTATION



END GOAL
Enable reliable downhole tool operation in geothermal environments

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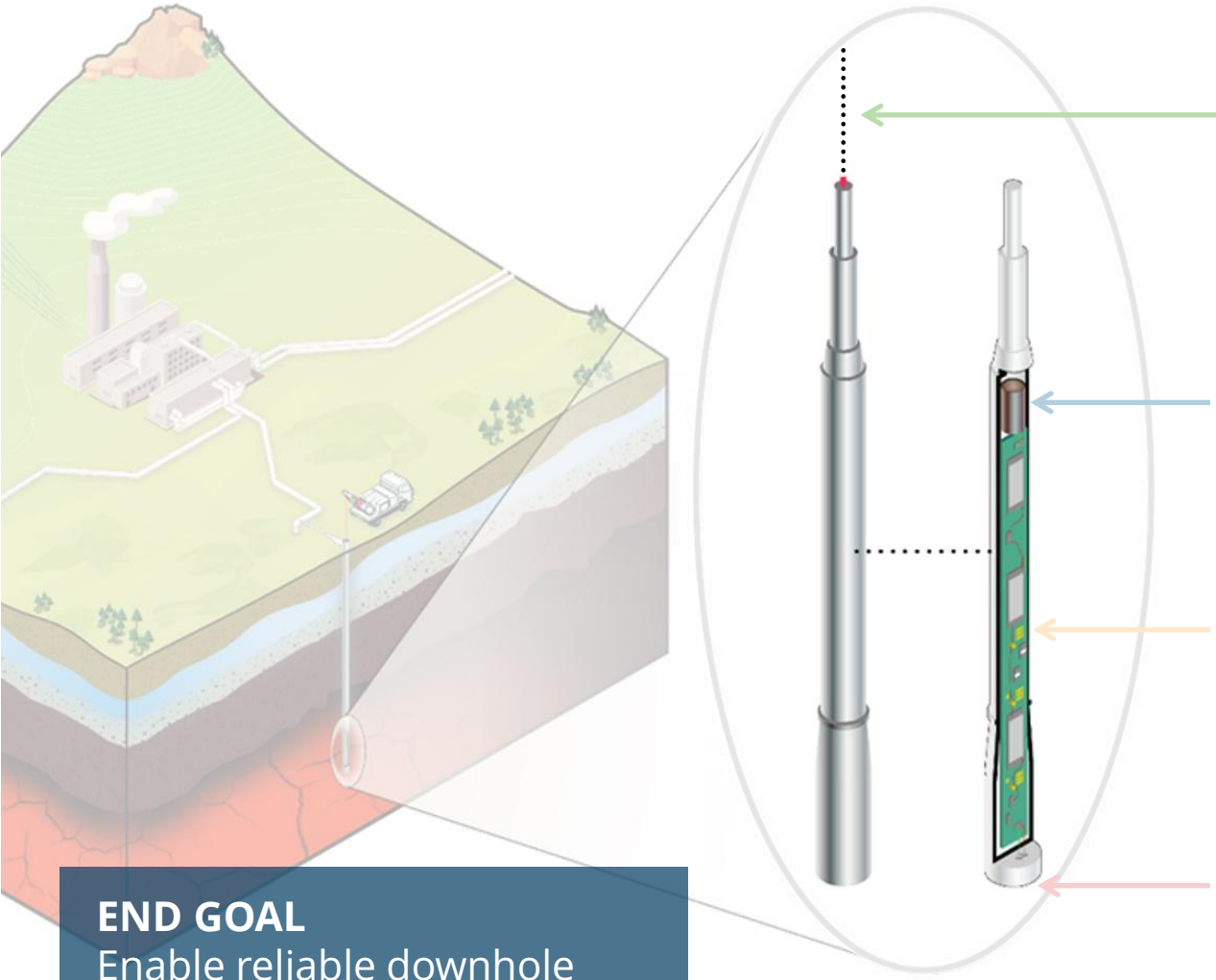
HIGH TEMPERATURE INSTRUMENTATION



Communications

- Conductor/Fiber Communications
- “Wireless” Communications

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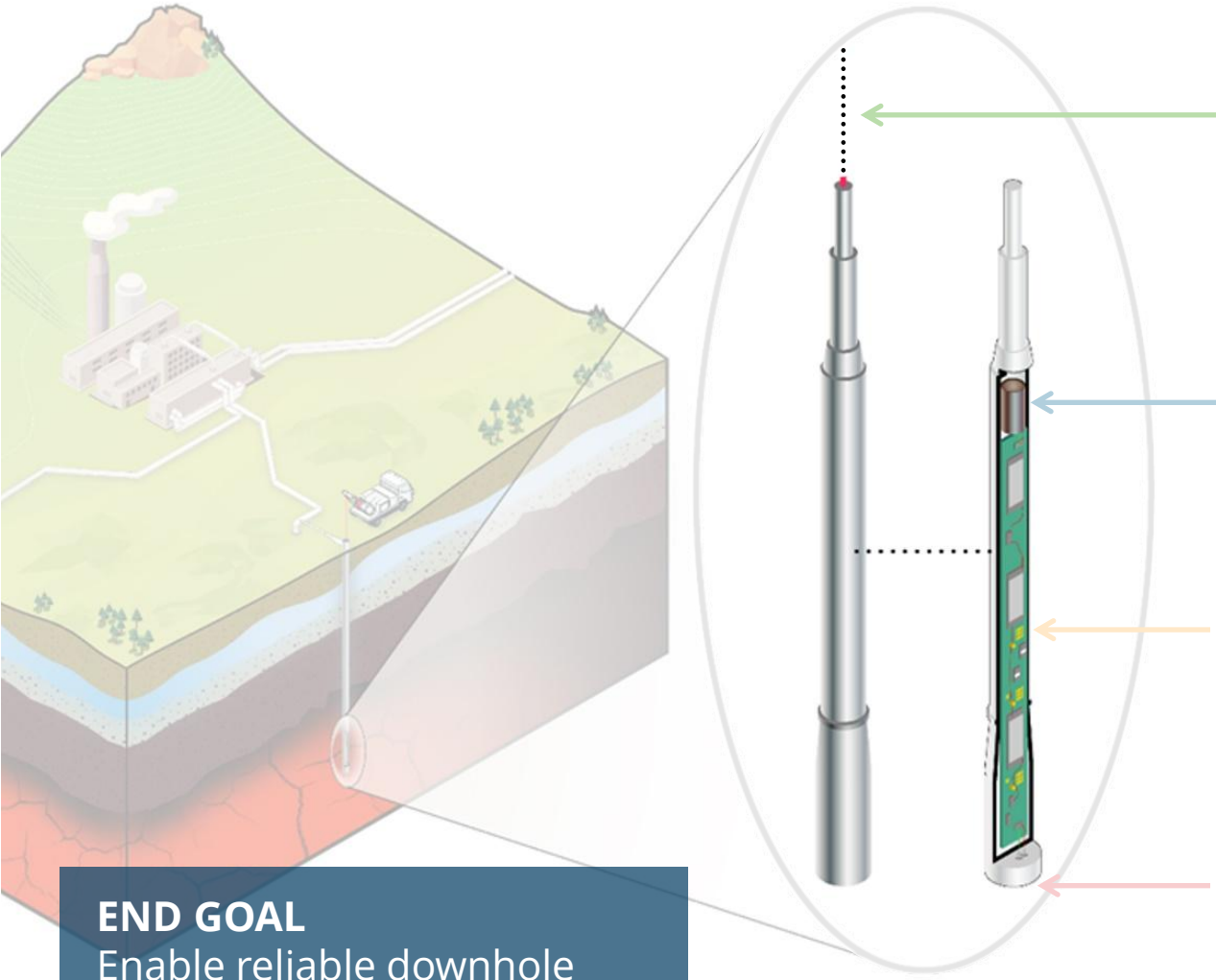
HIGH TEMPERATURE INSTRUMENTATION



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Energy Storage

- Local power source for electronics

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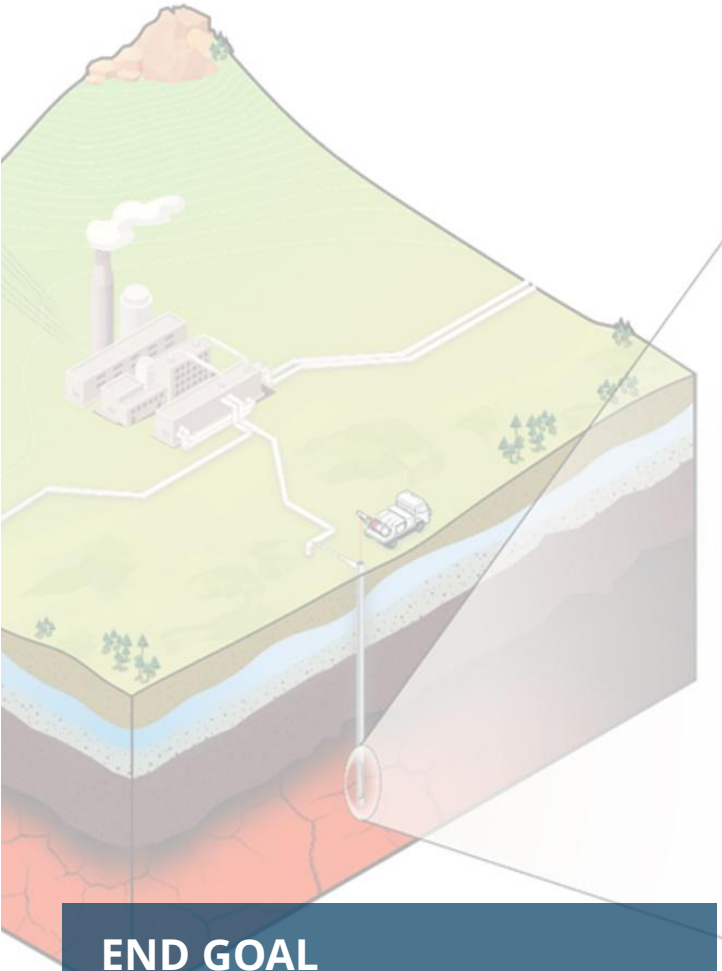

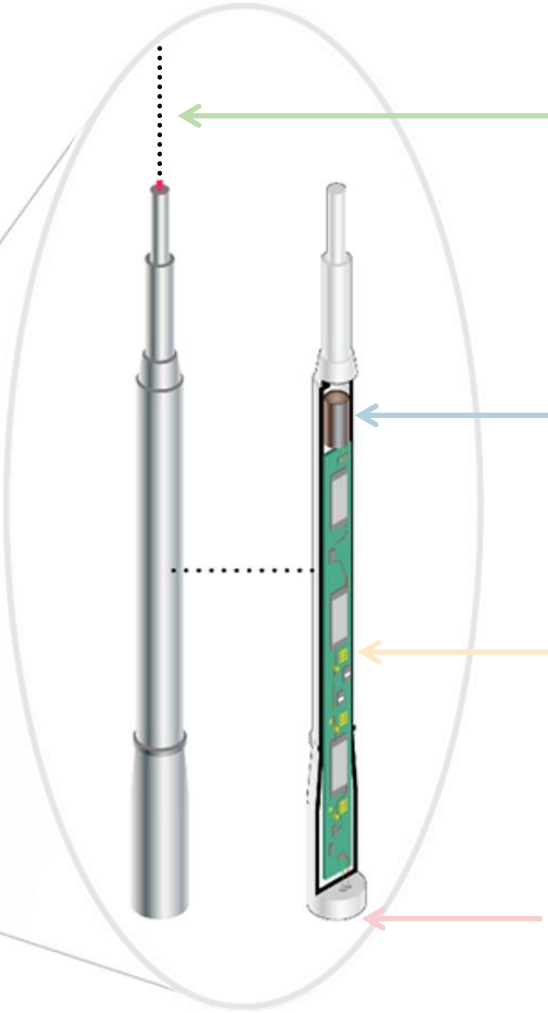

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Embedded Electronic System

- Local signal collection and processing

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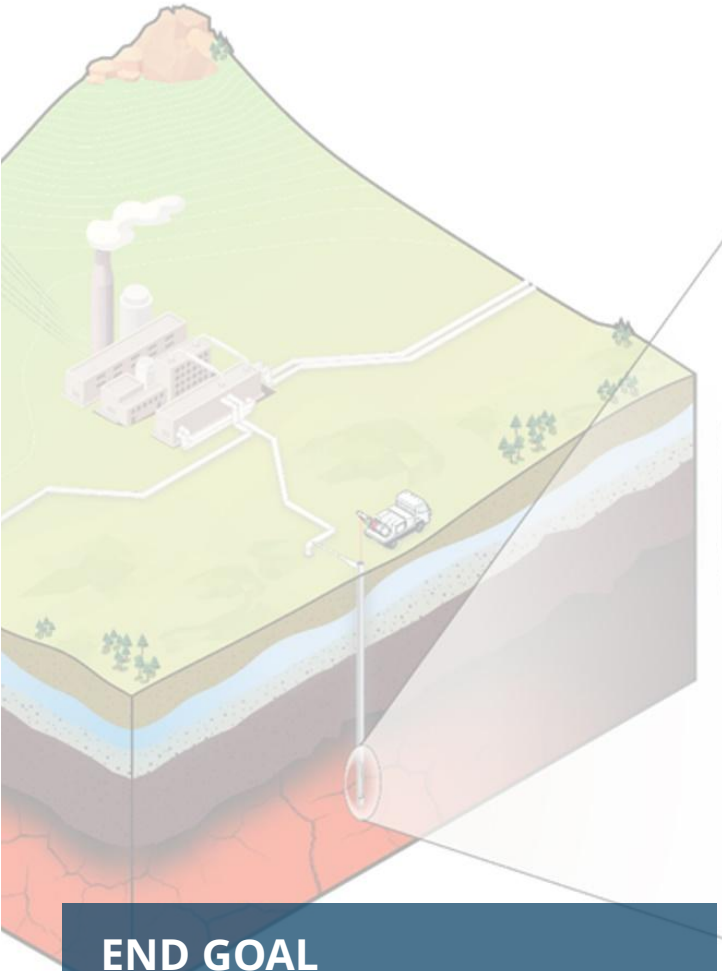

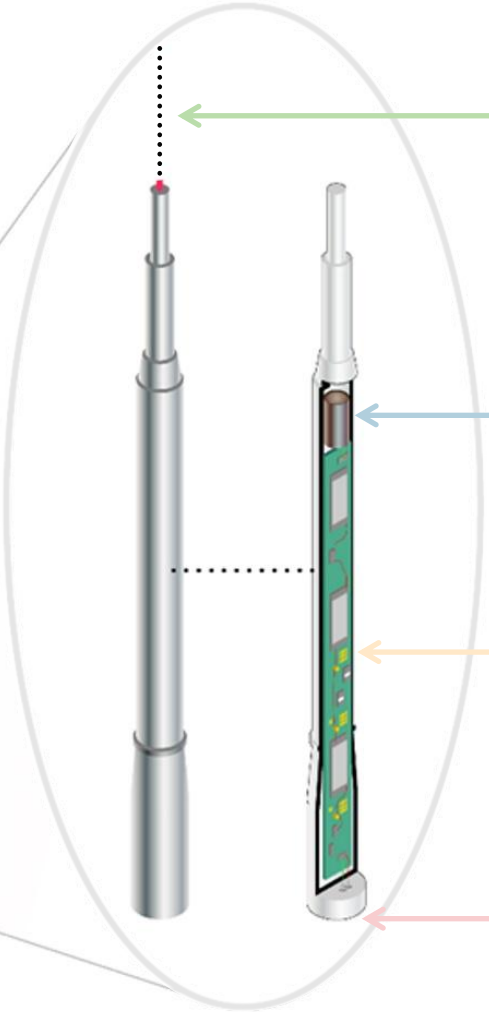

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Sensing

- Characterization of geothermal environment

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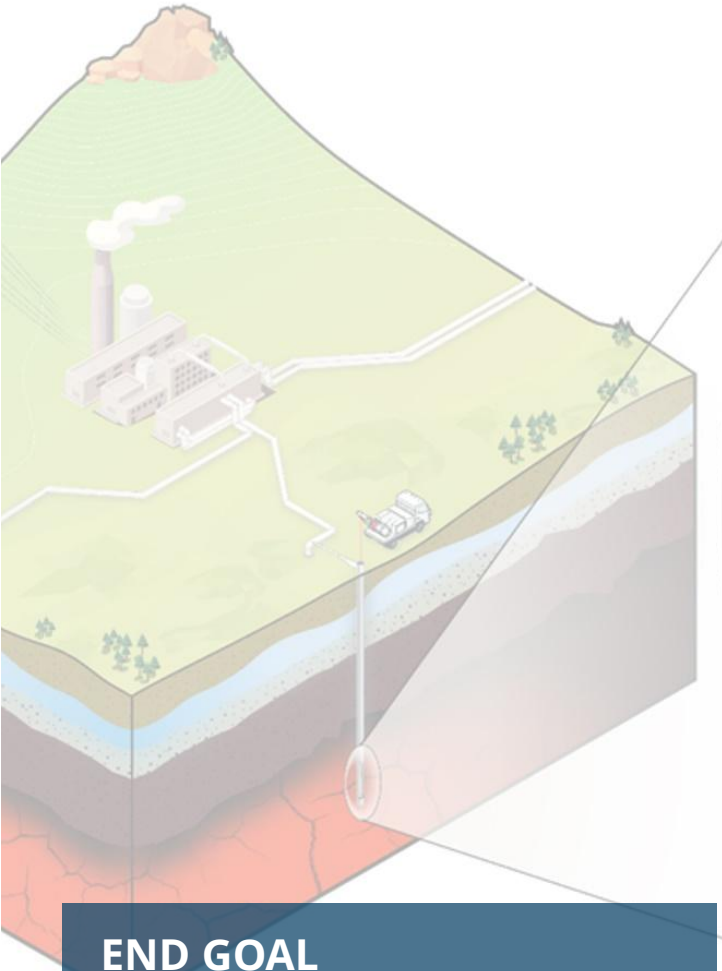

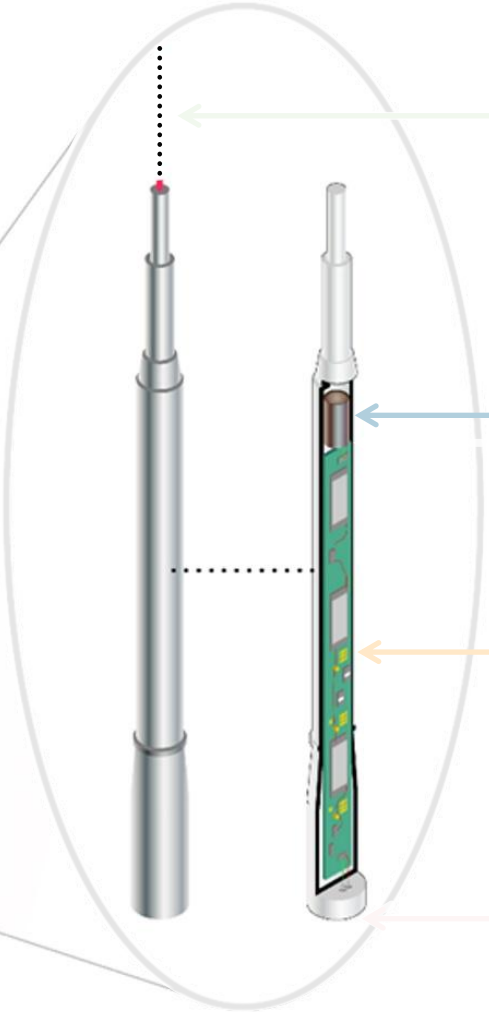

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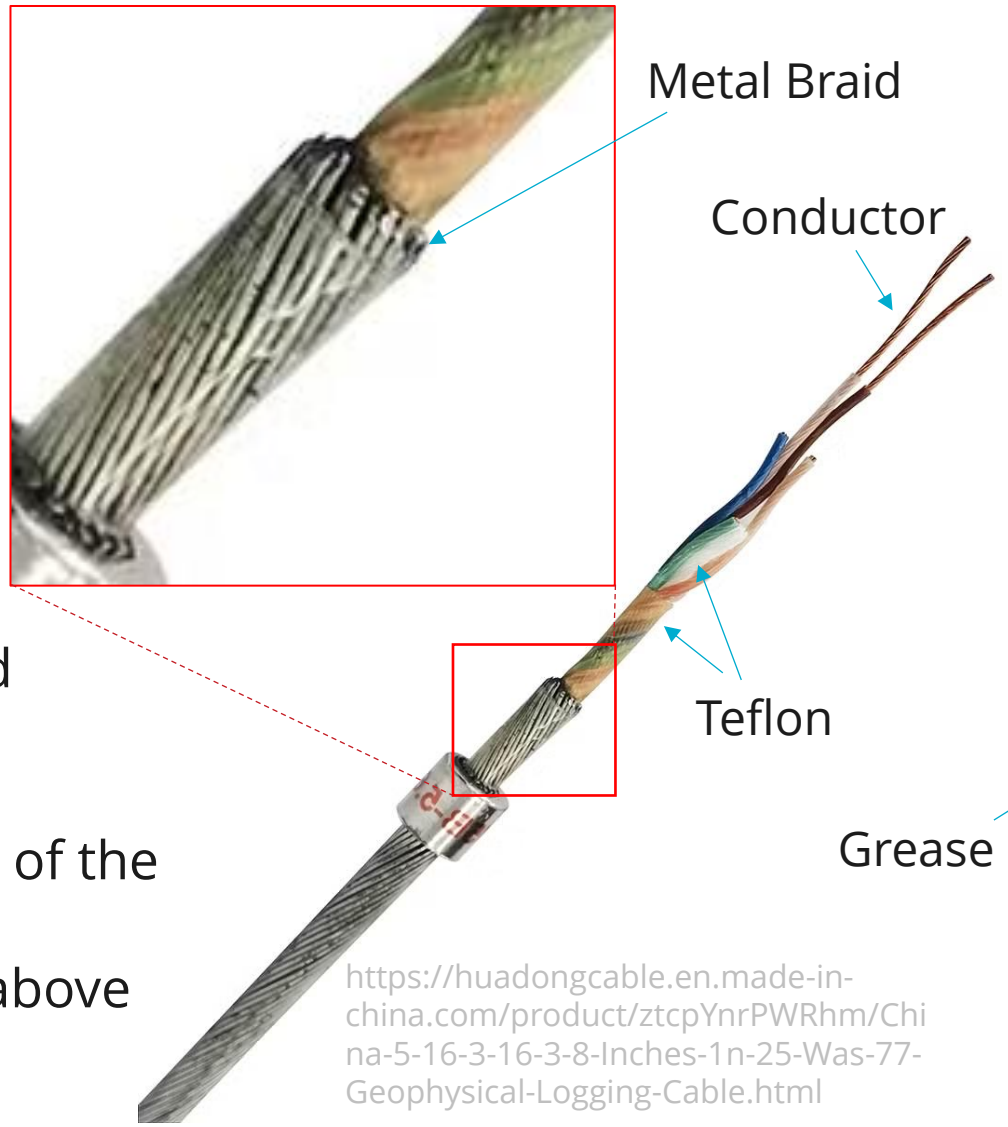
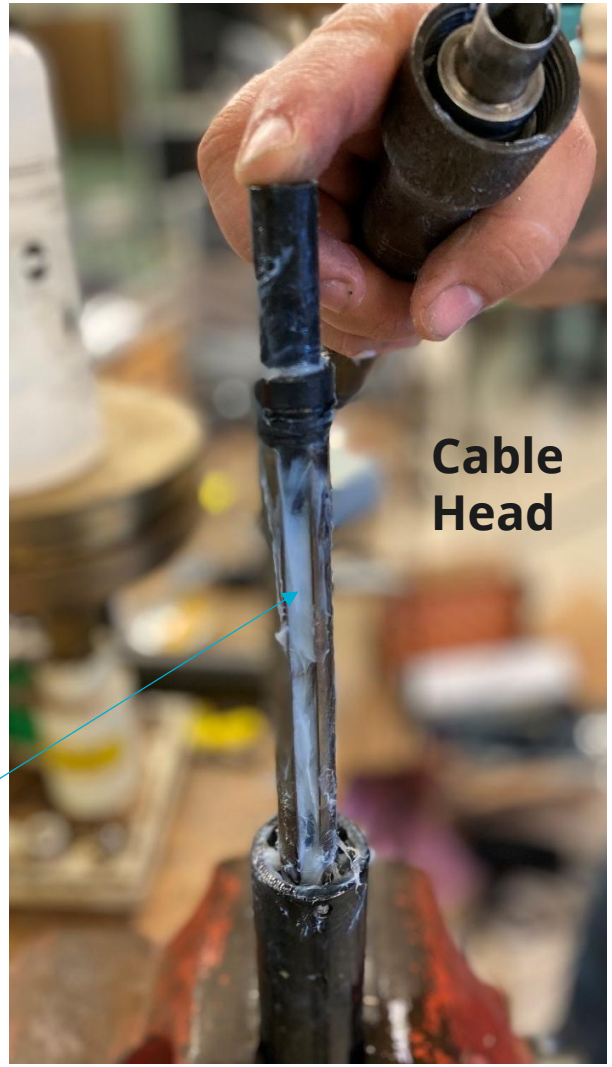
PROBLEM STATEMENT

- Traditional data cables for subsurface instrumentation use:
  - Teflon insulators
  - Metal braiding for strength and protection
- Challenge is that you can't seal against braiding
  - Thus grease is required within the cable head
  - Grease dissolves away limiting operation time of the cable
  - Teflon will also soften above 260 °C



https://huadongcable.en.made-in-china.com/product/ztcpYnrPWRhm/China-5-16-3-16-3-8-Inches-1n-25-Was-77-Geophysical-Logging-Cable.html



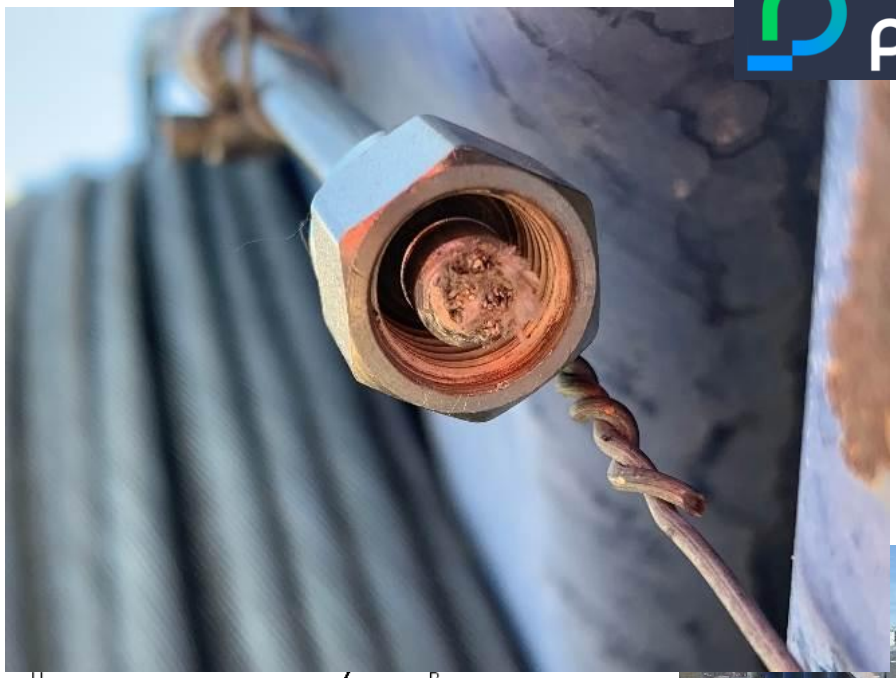
PRYSMIAN CABLE

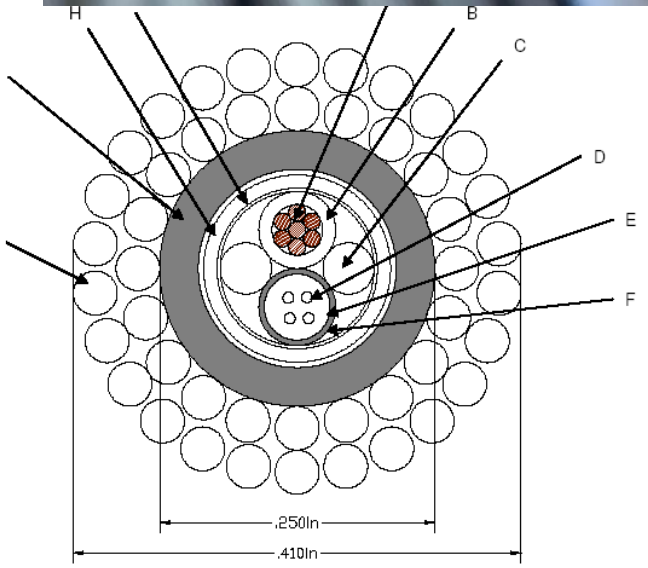
Prysmian Group developed two cables under American Recovery and Reinvestment Act (ARRA) in 2009 with a 374 °C goal

- Multi-conductor/optical fiber cable w/ HT epoxy insulator
  - Study complete in 2015
- Four-conductor cable w/ glass braid insulator
  - Study was incomplete, until now

Four-conductor cable spec's:

- Dielectric is a glass braid insulation
- Conductors are encased in Incoloy-825 tubing along the full length
  - Creates high-pressure seal between the cable and the tool, eliminating the need of a grease seal
- Conductors are nickel plated copper

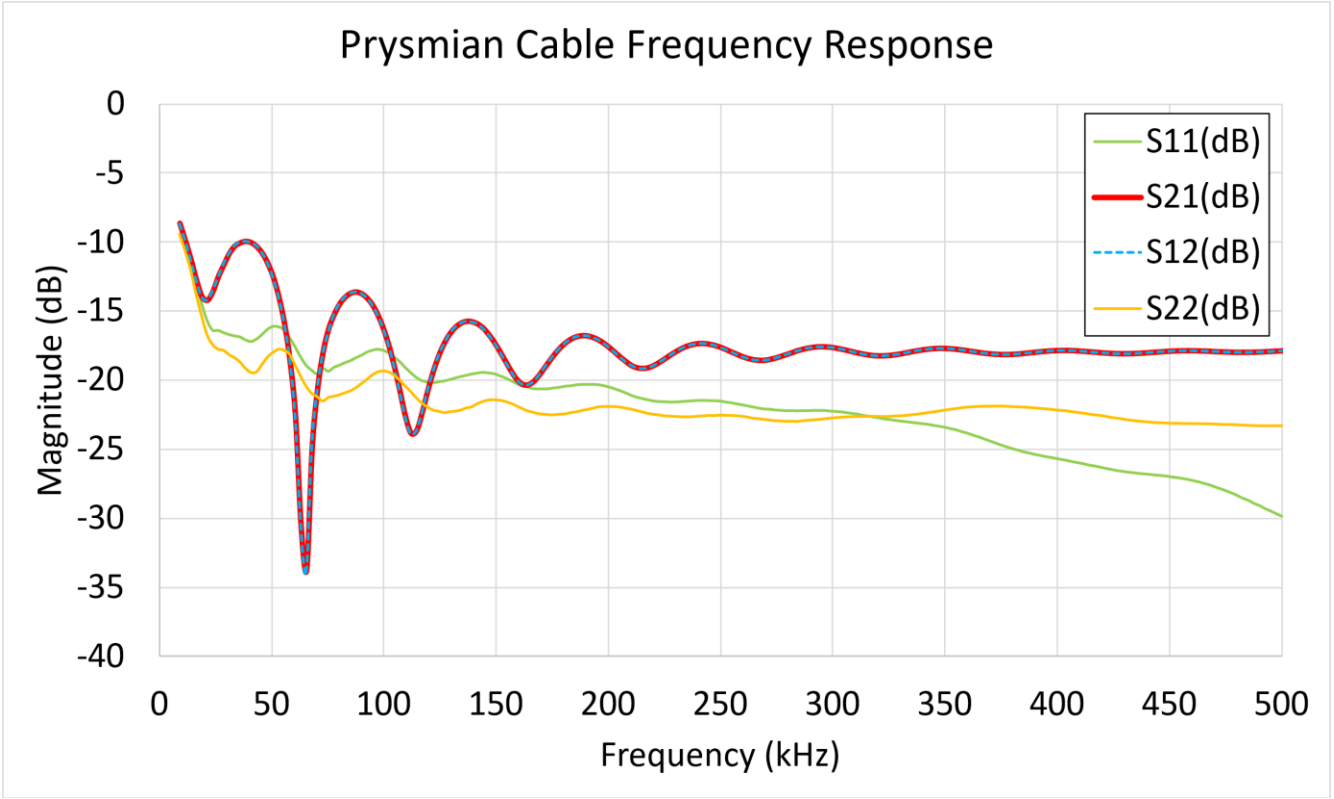




Prysmian Paper: Complete Fiber/Copper Cable Solution for Long-Term Temperature and Pressure Measurement in Supercritical Reservoirs and EGS Wells; doi:10.2172/1225845

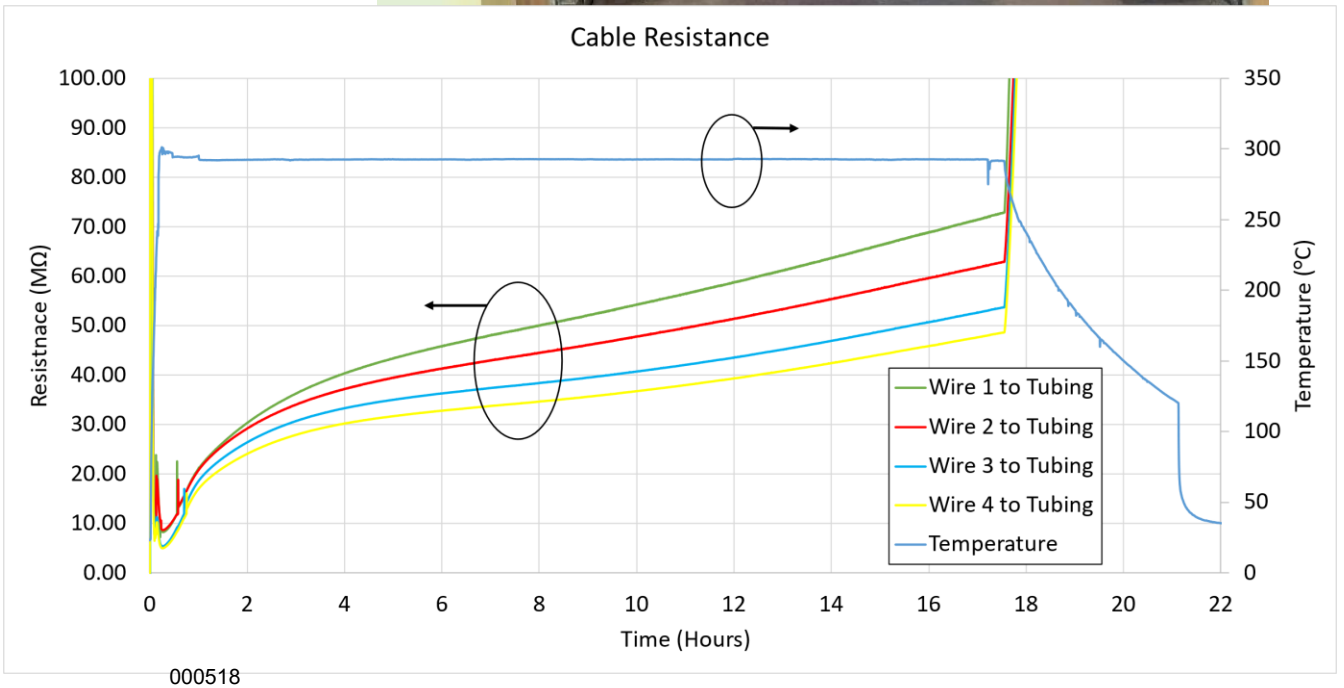
CABLE PERFORMANCE – ROOM TEMPERATURE

- Cable length is >5,000 ft
- Cable resistance characteristics @ room temperature:
  - Resistance between the conductors and the metal tubing is 50-70 kΩ
  - Resistance between conductors is 100-120 kΩ
  - Resistance of conductor from one end to end is ~73 ohms.
- Cable attenuation characteristics:
  - 10 dB @ 35-40 kHz
  - 17 dB @ 250-500 kHz



OVEN TESTING – 10 FEET OF CABLE

- Ten-foot section of the cable was evaluated at 300 °C for ~17 hours
  - Baking out binder from the glass braid
    - Observe the resistance between conductor and tubing increase over time
  - After binder bake out, parallel resistance matches room temperature conditions



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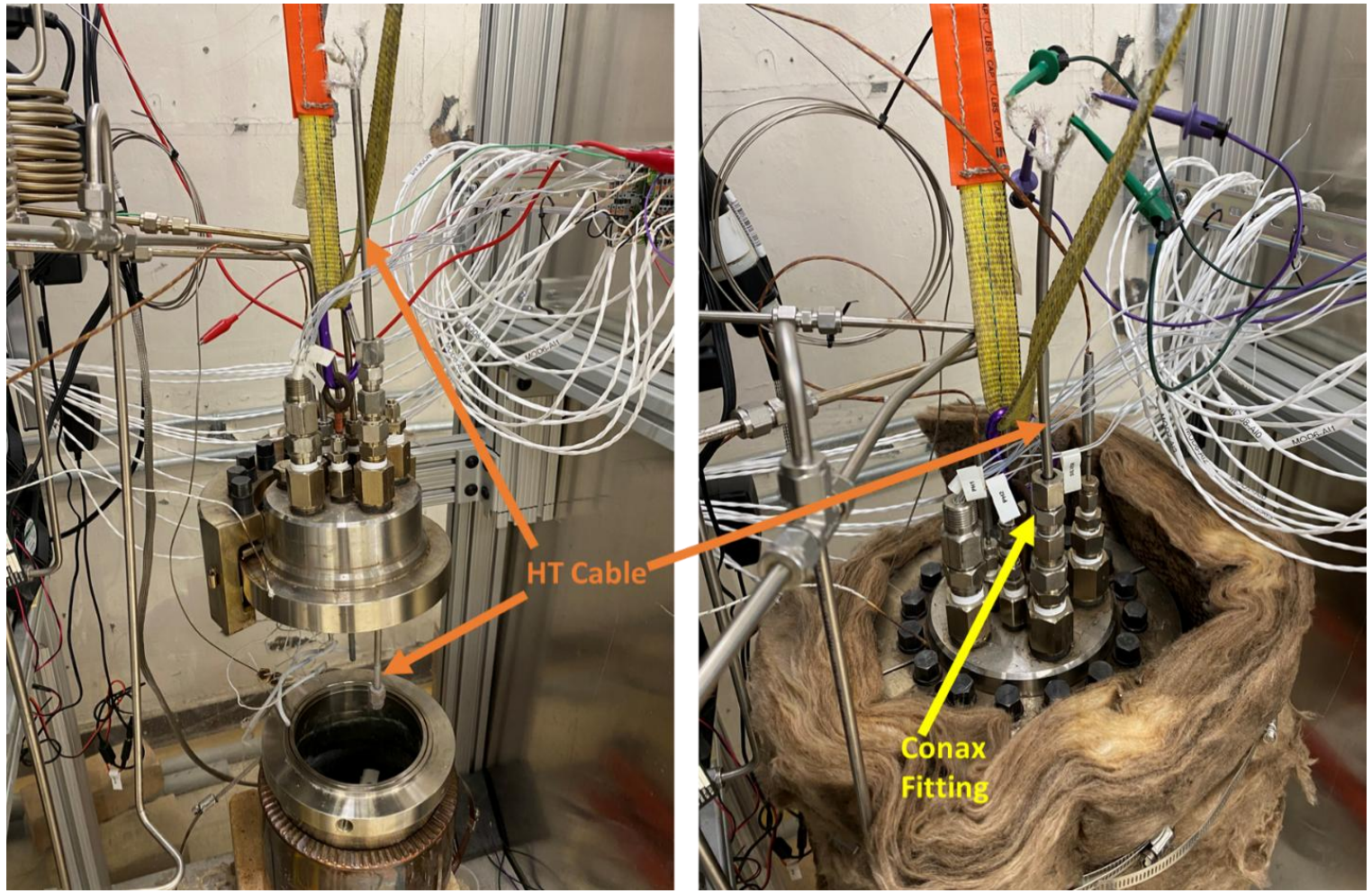
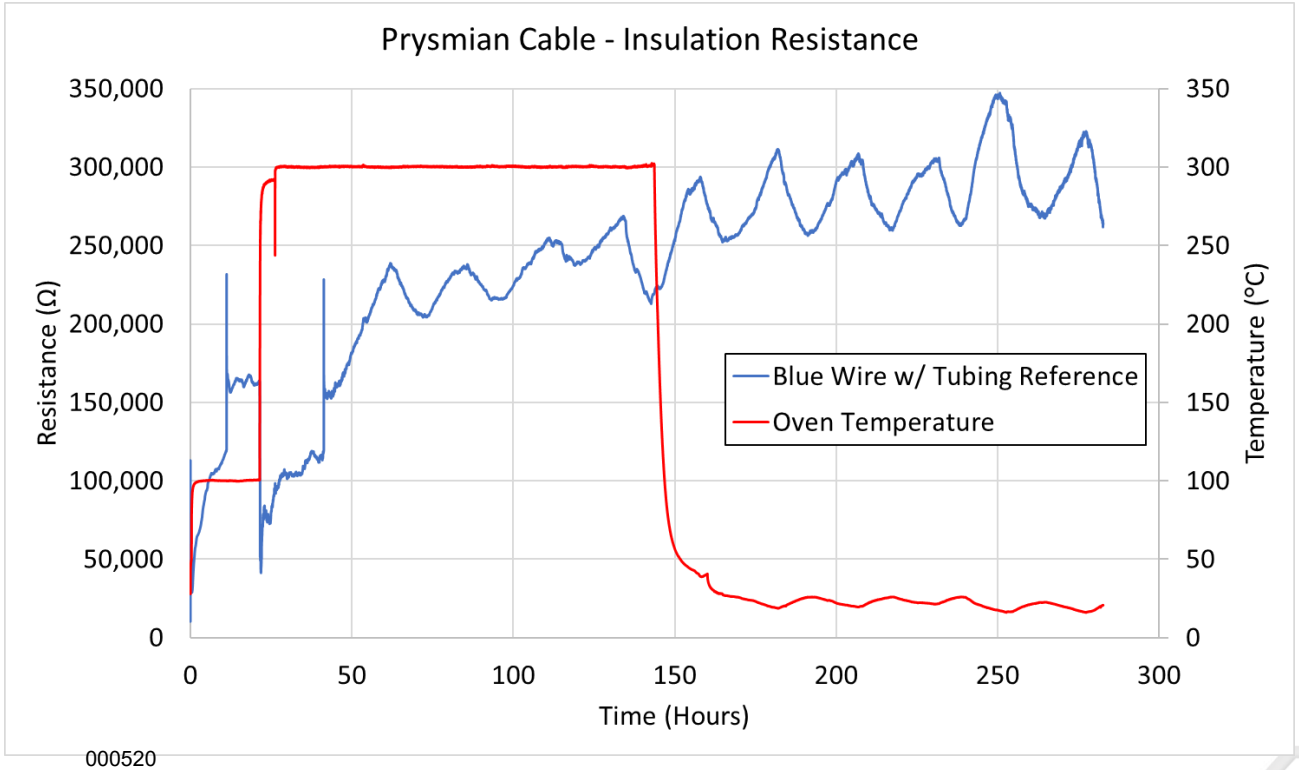
HIGH TEMPERATURE HIGH PRESSURE TESTING

- The cable was evaluated in a 300 °C, 5000 psi autoclave.
- Cable was sealed to the lid with a 0.25” Conax Lava seal fitting.
- Swagelok cap seal the tip of the cable tubing
- Wires on the other end were exposed to the air
- The autoclave was filled with tap water that has a pH of 9.
- The cable exhibited no observable leaks with the autoclave set to 300 °C and 5000 psi for 27 hours



FULL CABLE EVALUATION

- Evaluated full length of cable with 100 feet of cable placed within a large oven
  - Could not bake the entire cable within the oven due to concerns of damaging the cable
  - Observed low resistance at the beginning of the experiment
  - Appears binder bake requires >150 hours
  - Resonance maybe due to room temperature fluctuating through out the day



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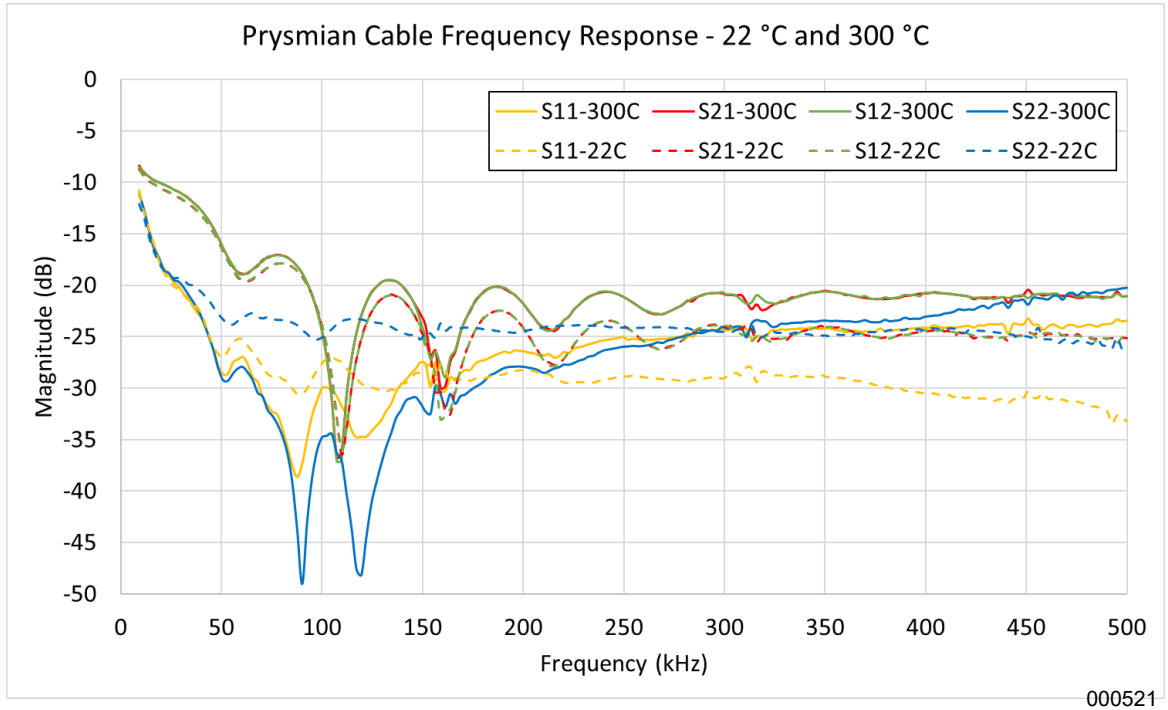
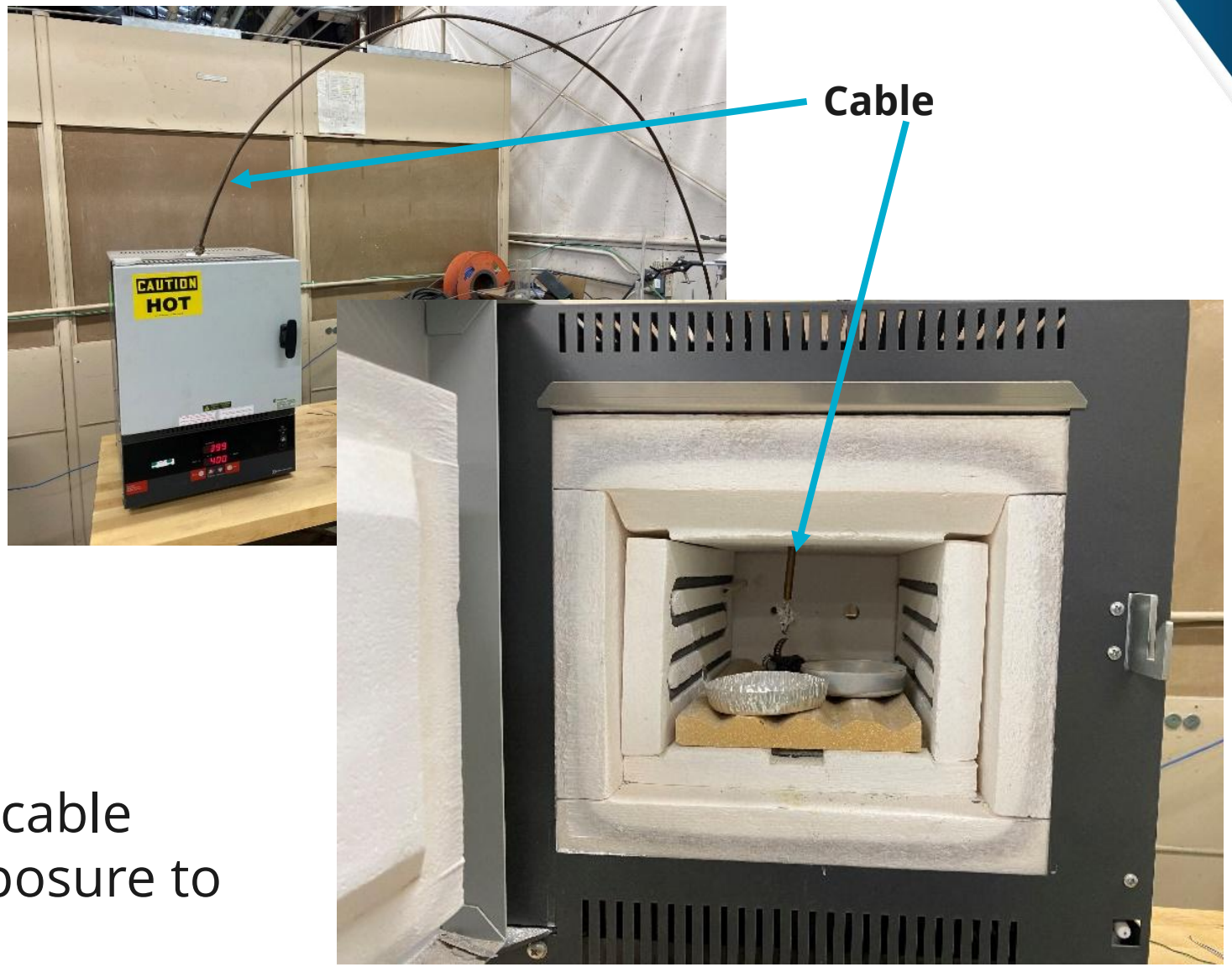
FULL CABLE EVALUATION

- Cable was kinked due to attempts to unspool the cable into a metal container
  - 13 dB @ 35-40 kHz @ room temperature
  - 25 dB @ 250-500 kHz @ room temperature
- At 300 °C, 120 hours of baking
  - 13 dB @ 35-40 kHz
  - 22 dB @ 250-500 kHz



SUPERHOT EVALUATION

- For additional testing, a piece of cable was evaluated at higher temperatures
- Cable was baked at 375 °C for 192 hours and 400 °C for 240 hours
- Observed:
  - Cable was structurally intact
  - Glass braid became bridle
    - Can cause challenges if retooling/resplicing the cable
  - Copper oxidized due to exposure to oxygen



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CONCLUSION

- Prysmian Group had developed a viable cable for geothermal subsurface instrumentation that can operate at temperatures of 300 °C and pressures of at least 5,000 psi.
- Cable is suitable for short-term operating tool required above 260 °C and tools that need to function for long-term under the harsh conditions
- Ideal for EGS applications that require long-term measurements
- Future efforts:
  - Two opportunities have been discussed:
    - Combine the cable with SLB's well integrity FOA
    - ThermoChem reached out with interest to incorporate with their HT instrumentation

ACKNOWLEDGEMENT

Sandia would like to acknowledge Taylor Myers for his work on evaluating the cable and preparing the test setups.

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