ARPA-E Geothermal Workshop: Enabling and transformative technologies for superhot geothermal

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Washington, DC

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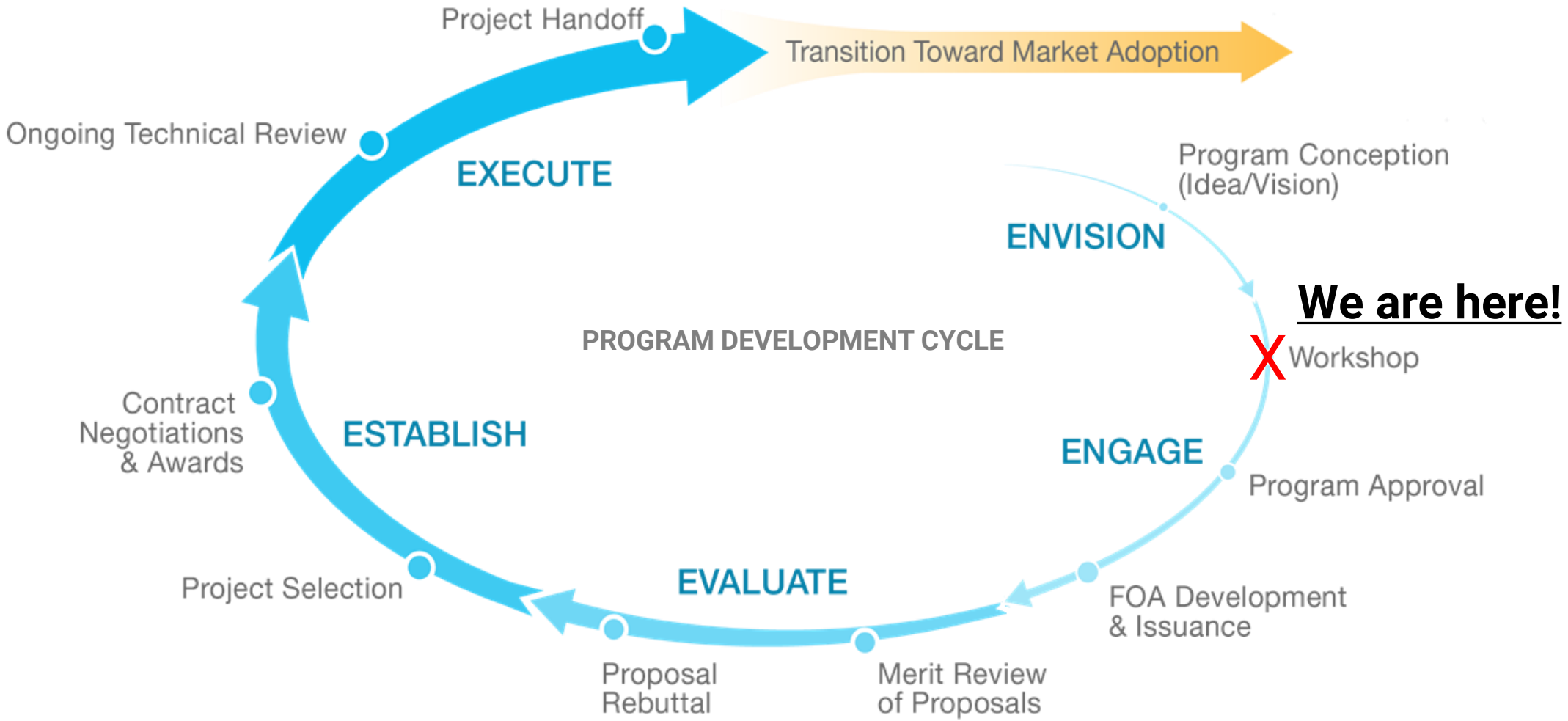
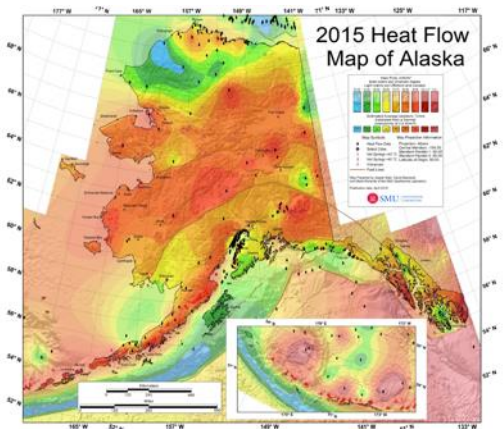
Process


Project Handoff
Transition Toward Market Adoption
Ongoing Technical Review
EXECUTE
Program Conception
(Idea/Vision)
ENVISION
We are here!
PROGRAM DEVELOPMENT CYCLE
X Workshop
Contract
Negotiations
& Awards
ESTABLISH
ENGAGE
Program Approval
Project Selection
EVALUATE
FOA Development
& Issuance
Proposal
Rebuttal
Merit Review
of Proposals

Superhot geothermal - the vision

The goal: Increase geothermal from ~2 GW to 60+ GW of baseload geothermal power across the U.S. in the near future.

Hawaii

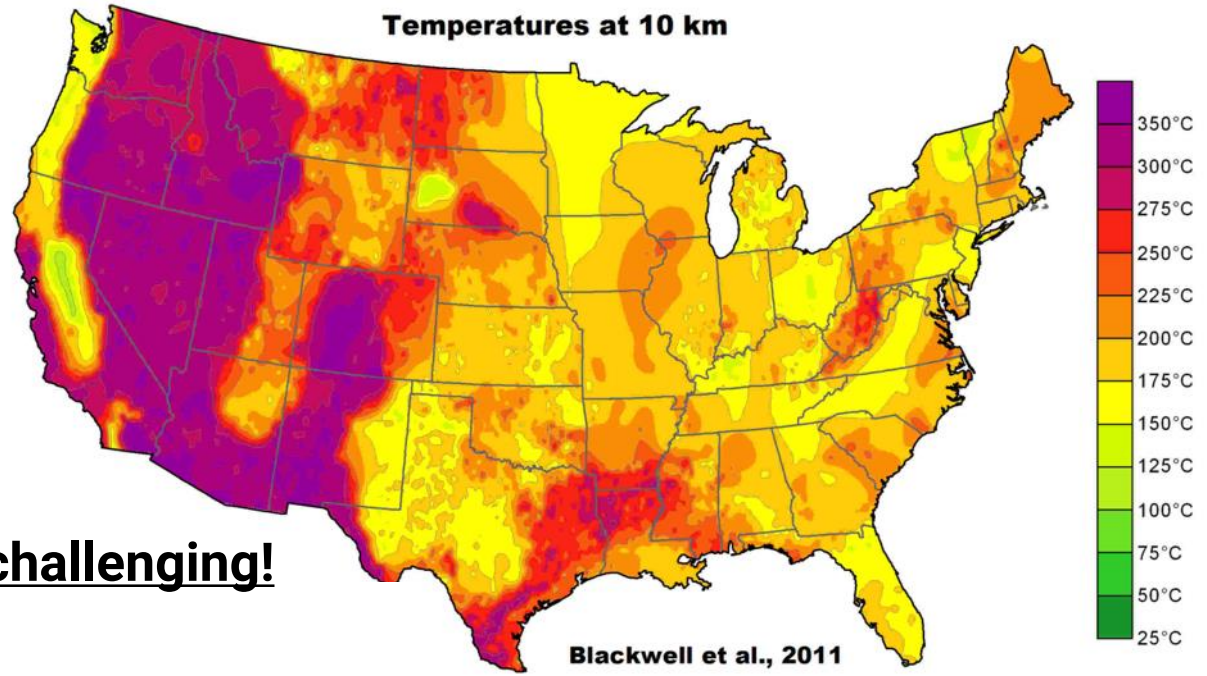


The challenge:

- Extract heat/power from high-temperature (~375°C) geothermal resources at a cost competitive with other low-carbon energy sources.
- Increase spatial availability; potential resource is 100's TW.

Current technology and need:

- Enhanced geothermal systems (EGS) are limited to < 250°C and ~10 MW per well site due to technological constraints.
- Exploitation of 400°C resources might produce 30 to 50 MW from each well site and lower the LCOE.



<u>But 400°C "superhot" EGS is technologically challenging!</u>

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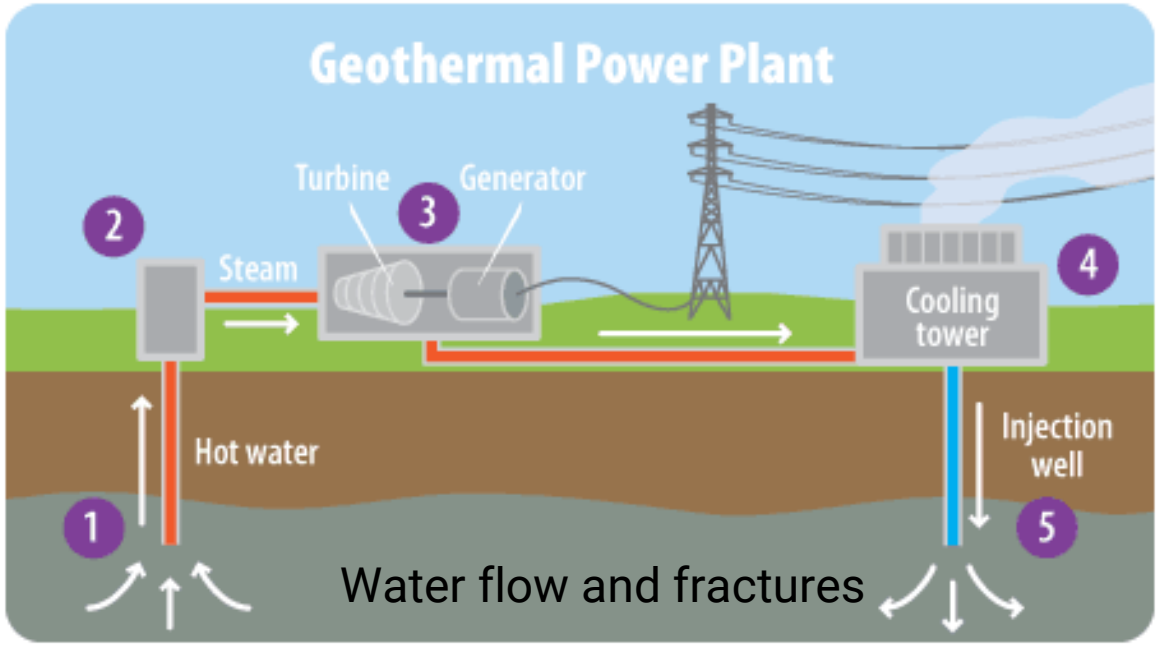
Workshop goals: How can ARPA-E help enable superhot geothermal?

- ARPA-E is exploring a possible program supporting research for superhot geothermal wells.
  - What are the challenges?
  - What can we address?
  - What is the impact if successful?
  - How should we organize the program?
  - What are the metrics?
- The results will be used to design the proposed program.

This where we need your help!

Background: geothermal energy

- Requirements:
  - Hot rocks
  - Subsurface water
  - Fractures and permeability for high flow rates
- Natural hydrothermal systems
  - Shallow hot rock
  - High permeability due to fractures
  - Relatively rare
- Enhanced Geothermal Systems (EGS)
  - Create fractures to enhance permeability
  - Recent developments based on oil and gas technology have shown remarkable progress (at temperatures < 250°C).

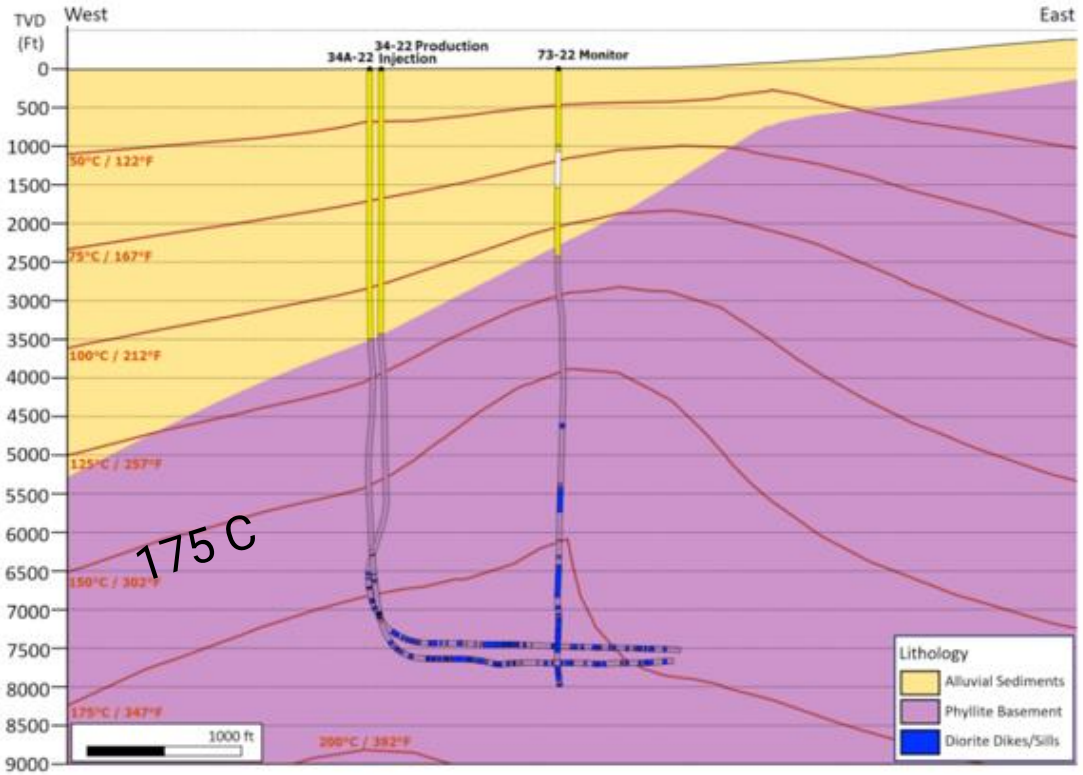


Geothermal Energy | A Student's Guide to Global Climate Change | US EPA

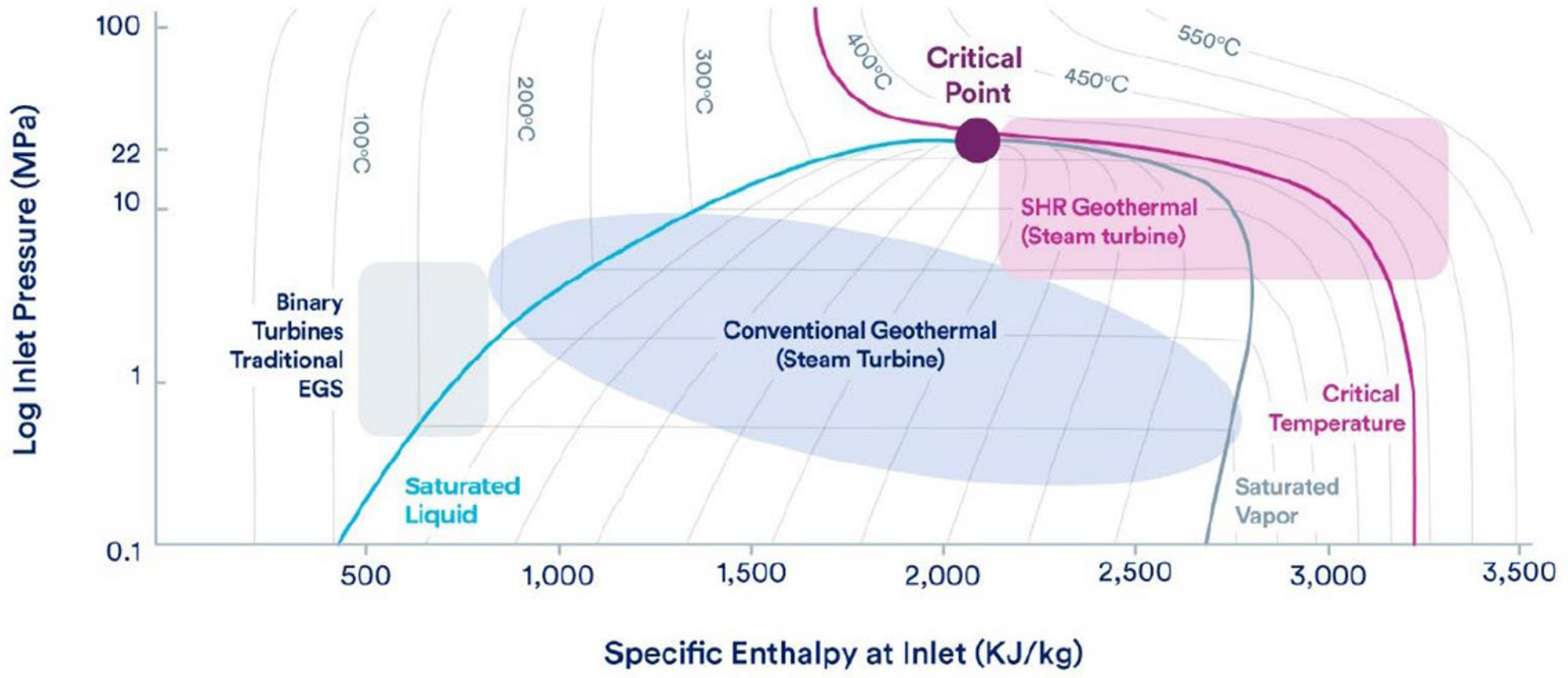
Enhanced Geothermal Systems (EGS)

- Create artificial fracture system around borehole to increase permeability.
- Inject cold water into one well, extract hot water from second well.
- Generate electricity from hot water using turbines.
- Current EGS technology limited to < ~250°C

Can we go higher?



What is “superhot” geothermal?



Superhot rock => higher temperatures and pressures near supercritical point of water.
Higher enthalpy; lower viscosity => improvement of 5-10X energy per well site?

Cladouhos and Callahan, 2024

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Many challenges for superhot geothermal

- Lots of problems and risk in implementing superhot energy.
  - What topics will have the most impact?
  - Which topics need more than incremental improvement?
  - Which topics are we likely to make progress on?

- Exploration methods for better resource assessment.
- Laboratory experiments to investigate in-situ fluid and rock properties.
- Adapted drilling and completion technologies.
- Logging and monitoring instruments and strategies.
- Numerical simulation tools capable of handling supercritical conditions.
- Field laboratories/wells to gain more knowledge about downhole conditions and test technological approaches along the entire development chain.

Reinsch et al., 2017

Some possible topics for an ARPA-E superhot program

Area	Example
Exploration and siting	Geophysical/geological sensing and analysis
Heat extraction and modelling	Numerical models; different types of fracturing; closed loop
Drilling	Rotary; jet; energy
Well design and construction*	Casing, cements under thermal cycling and corrosion
High-temperature borehole operations*	Downhole tools for fracturing and sensing
Power generation*	Reduce cost and test innovative solutions (alternate working fluids, thermoelectric)

We cannot fund everything!
Objectives: Develop the basic toolset to enable superhot

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Well design and completion

- A significant challenge for superhot
  - Changes in ductility from temperature
  - Connection failure
  - Thermal cycling
  - Corrosion
  - Well-head failure
  - Cement and integrity
- Wells need to last 15-20 years
- Validation and testing of materials

New materials? New Design?

Example superhot (IDDP) wellhead and liner

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High-temperature tools and sensors

- Most borehole tools are designed for oil and gas fail above 200°C
  - Optical fiber may survive
  - Steam flood tools may perform up to 300°C
- Existing tools with cooling/coating/insulation and encapsulation
  - Increases complexity
  - Increases cost and weight of drill pipe
- Power supply
- Standalone high-temperature sensors
  - Logging-while-drilling (LWD)
    - Evaluate geological formations
    - Measure resistivity, density, porosity, stress, borehole diameter, borehole image
  - Measurement-while-drilling (MWD) –
    - Improve drilling (especially directional)
    - Rate of penetration (ROP), inclination, azimuth, and temperature.
  - Well integrity and cement evaluation
  - Borehole and reservoir conditions (seismic, resistivity, temperature
- Validation and testing

Can we operate at 400°C?

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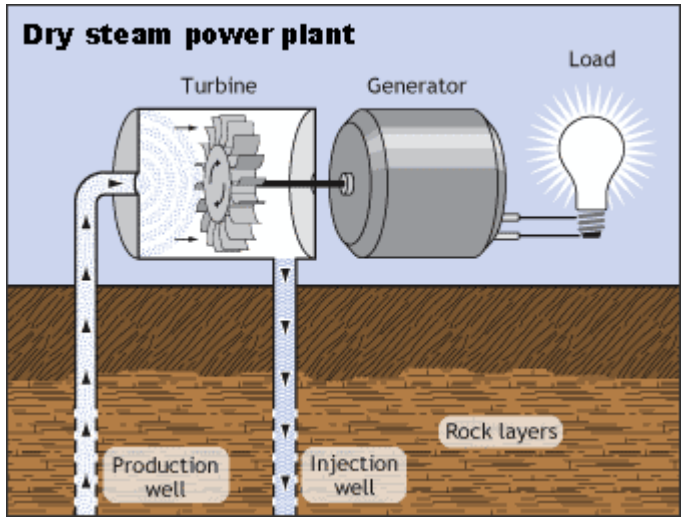
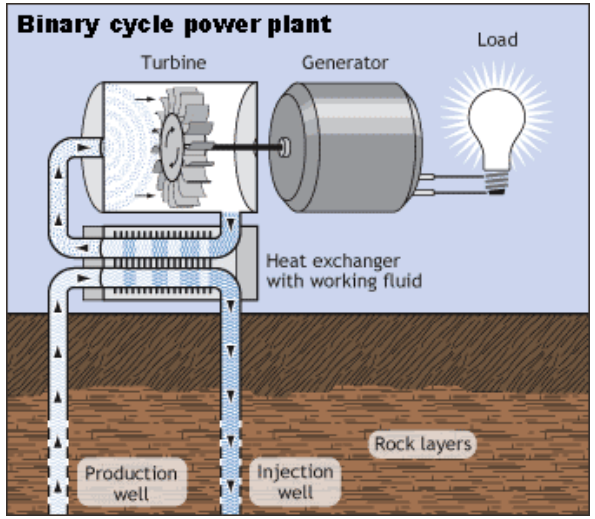
Power production

- Traditional turbines
  - Dry steam, direct use (or flash)
  - Binary with heat exchanger
  - Wellhead and pipes
- Innovative power
  - Alternate working fluids with turbine
  - Alternate technologies (thermo-electric?)
- Ancillary revenue
  - Thermal storage
  - Critical minerals (e.g., lithium)

What are possible transformational changes?





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Question to think about

- What are we missing?
- How to address these problems?
  - Can we apply new methods of material discovery?
  - Synergies with other areas (e.g., high temperature electronics)
  - Collaboration with pilot wells and international efforts?
  - Testing facilities?
- What should the team structure look like?
- If solutions are developed, how to market? (technology-to-market - “T2M”)
  - Testing at pilot facilities
  - Licensing, start-ups?

Agenda outline

Day 1

- Overview
- Challenges
  - Speaker and panel
  - Breakouts
- High temperature electronics
  - Speaker and panel
- Day 2
- High temperature geothermal materials
  - Speaker and panel

Day 2

- High temperature geothermal materials
  - Speaker and panel
- Surface facilities
  - Speaker and panel
- Techno-economics
  - Speaker
  - Breakouts
- Conclusion
- One-on-one meetings

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