IADC DEC Q2 Technology Forum
30 June 2021

Geothermal Drilling Challenges

3 Things I Wish I Knew Transitioning From O&G to Geothermal

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Agenda

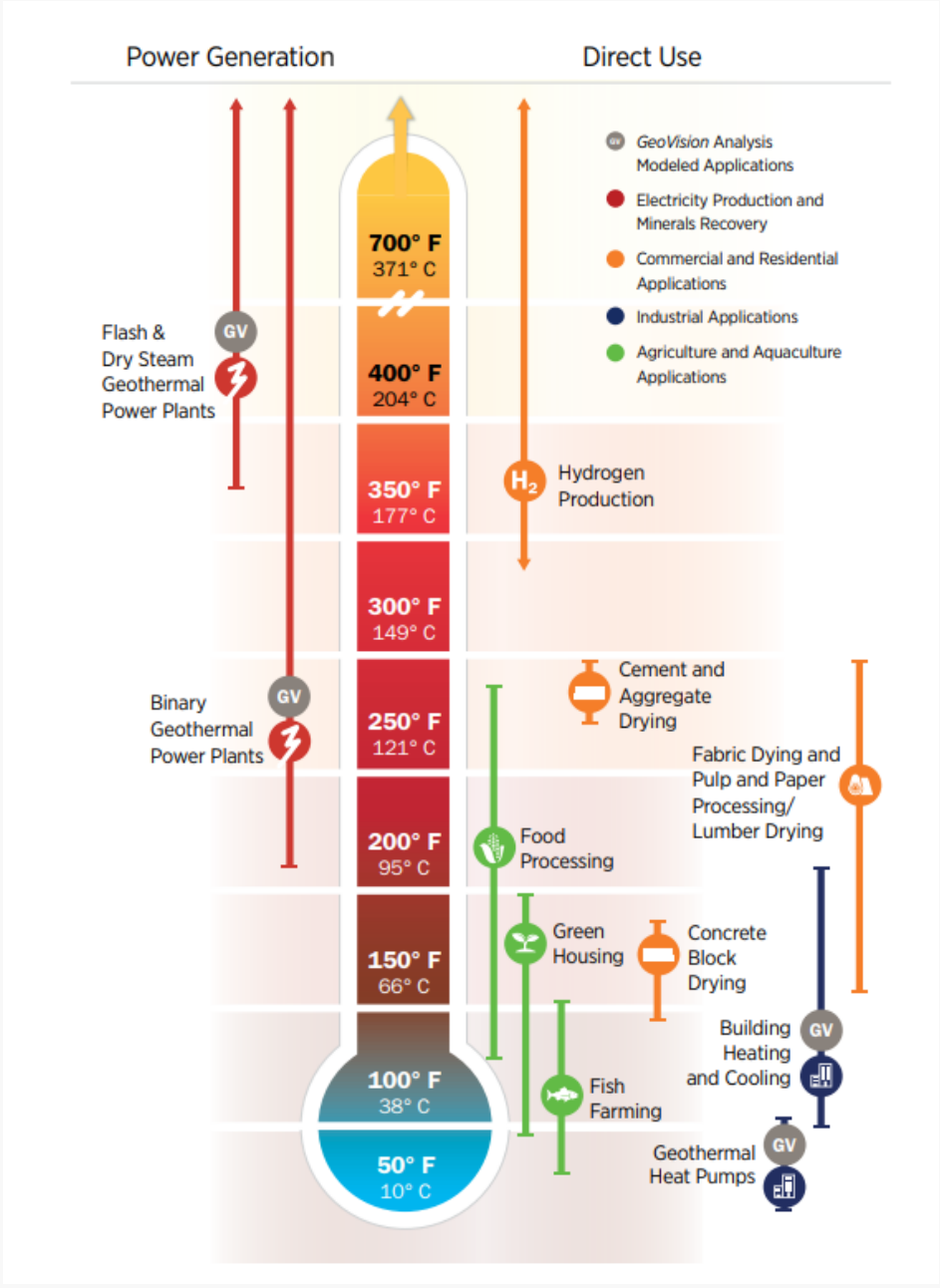
- Background Info/Value Proposition
- Underappreciation of high temperatures
- Rock strength and naturally occurring fractures
- Cost conscience decision-making and small data sets have driven approaches
- Conclusions

Background Info/Value Proposition

- Geothermal focused wells – ~ 10-20 US
- Resource difference
  - At 200C a flow rate of 23 L/s (12,500 BWPD) = 1MWe[2, 3]
- Value proposition is fundamentally different
  - Hot fluids must be consumed quickly and on location, there is no Cushing, OK for geothermal brines
  - Hot brines are worth $0.10s compared to oil at $10s
- Drilling typically accounts for 30-50% of geothermal development costs[4]

High Temps

- Hot, by definition–generation cycles are more efficient at high temps
- High temps themselves are a failure mode for electronics, seals, and circuit boards
  - Can also hasten other failure modes
  - Mismatch in CTE of materials
  - Corrosion from fluids
- Understand the magnitude and variation in HT for geothermal
- Adapt materials and technologies from other industries



High Temps Affect All Downhole Tools-

- Wireline tools max to ~260C
- MWD and some LWD max to ~200C
- Directional Tools ~ 175-200C
- Temporal variability, the above ratings usually include a time component
- Other mechanical tools
  - Pkrs up to 300C
  - Bridge plugs 300-350C
- EGS Development will require tools to perform multi-stage frac jobs consistently

Packer

Damaged Jar

Bridge Plug

Images provided by Dr. Joseph Moore, Utah FORGE Team PI, the University of Utah

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Rock Strength and Naturally Occurring Fractures

- Rocks can be from 2-3 times to 2-3 orders of magnitude “harder” than typical sedimentary rocks
- Naturally occurring fractures – in traditional hydrothermal systems, total losses and drilling blind typically indicate a good well
  - Extremely high flow rates are needed for power conversion, large open fractures are the key

Rock Type	UCS (ksi)	Young’s Modulus (10^6 psi)	Poisson’s Ratio
Granite	15 – 40	1 - 10	0.1 – 0.30
Basalt	15 – 45	1 - 5	0.15 - 0.25
Shale	0.75 – 15	1 - 10	0.15 - 0.5
Sandstone	3 – 25	0.1 – 3	0.1 - 0.35
Limestone/Dolomite	4.5 - 40	2.1 - 8	0.3 - 0.35

1. Compressive Strength of Rocks, https://petrowiki.spe.org/Compressive_strength_of_rocks
2. Unconfined Compression Testing, https://www.geoengineer.org/education/laboratory-testing/unconfined-compression-test
3. “Advancements in the Geothermal Industry Attributed to Oilfield Technologies,” Dr. John McClennan, presentation delivered 4/14/21
4. ELASTIC MODULI and PHYSICAL PROPERTIES of ROCK, http://www.geol.lsu.edu/jlorenzo/PetroleumSeismology7900/lectures/MSWord/6.%20Elastic%20moduli.pdf

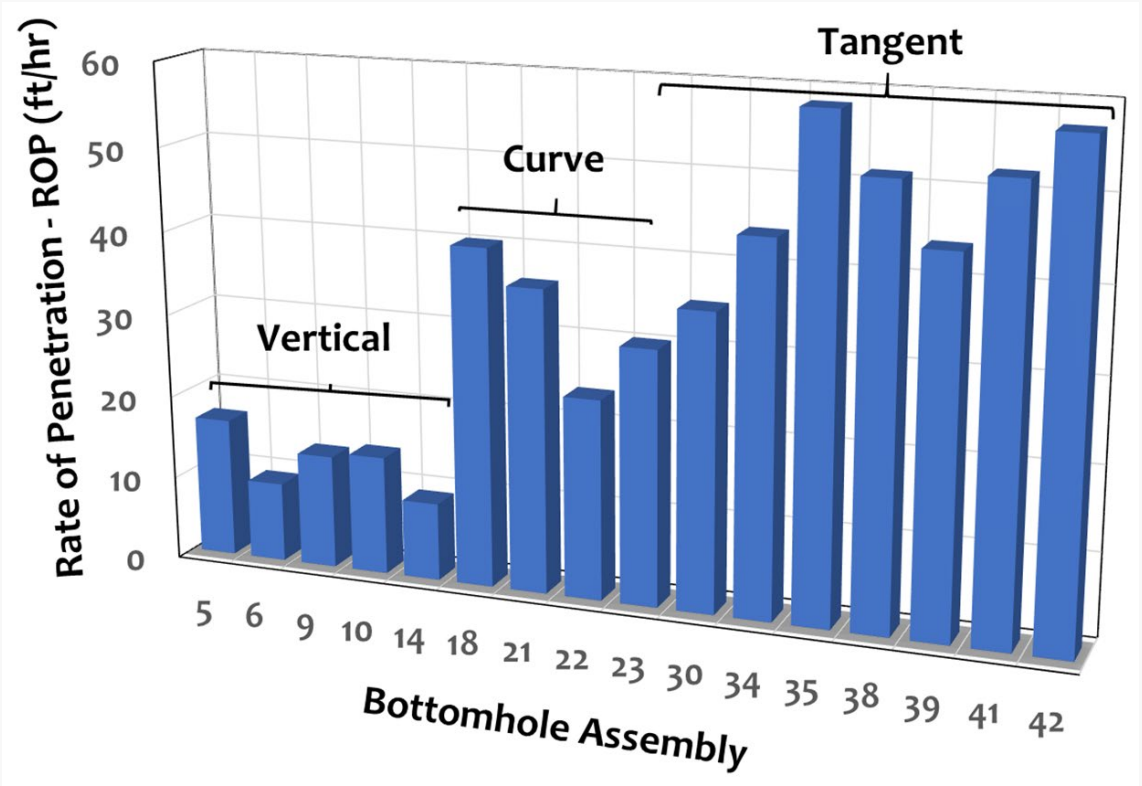
Historic Approach - Cost Conscience Decisions

- Cost conscience decision making has led to typically lower spec older rigs and technology
- Move to more modern rigs with enhanced capabilities allows for more data collection and utilization
- Still have the low well counts, leverage existing data
- MSE and PDCs– optimization has been a big part of recent gains in ROP and efficiencies
- Daily reporting inadequacies
  - Not unique to Geothermal, O&G has this issue too
  - Complete and detailed reporting of non-productive time (NPT)
  - NPT is not a performance metric of what went wrong

Image provided by Dr. Joseph Moore, Utah FORGE Team PI, the University of Utah

Traditional Approach – Roller Cone bits

- Roller cone bits remain common in geothermal drilling – but strides are being made to use more PDCs
  - PDC technology was funded by DOE and its predecessors in the 1980s
  - When appropriately applied, PDCs have been shown to be reliable and their higher ROPs offset the higher costs[1]
- PDCs coupled with MSE – MSE and physics-based limiter redesign during drilling operations and the modification of drilling parameters to optimize the “next foot drilled” have proven extremely useful in recent wells



FORGE 16A EOW Report – ROP in Production Section, PDCs

Image provided by Dr. John McClennan, Utah FORGE Team, the University of Utah

Daily Reporting

- How do we drill the perfect well if we don't know what that is?
- Employ a probabilistic approach
  - How do we do that with only 20 geothermal wells a year?
- Only through complete reporting can we systemically reduce the range of outcomes and drive to the "perfect" well
- Ripe for application of data analytics and lean sigma
  - NPT is a measure of where things can be improved
  - Recent DOE work – 40+ ways to report running csg

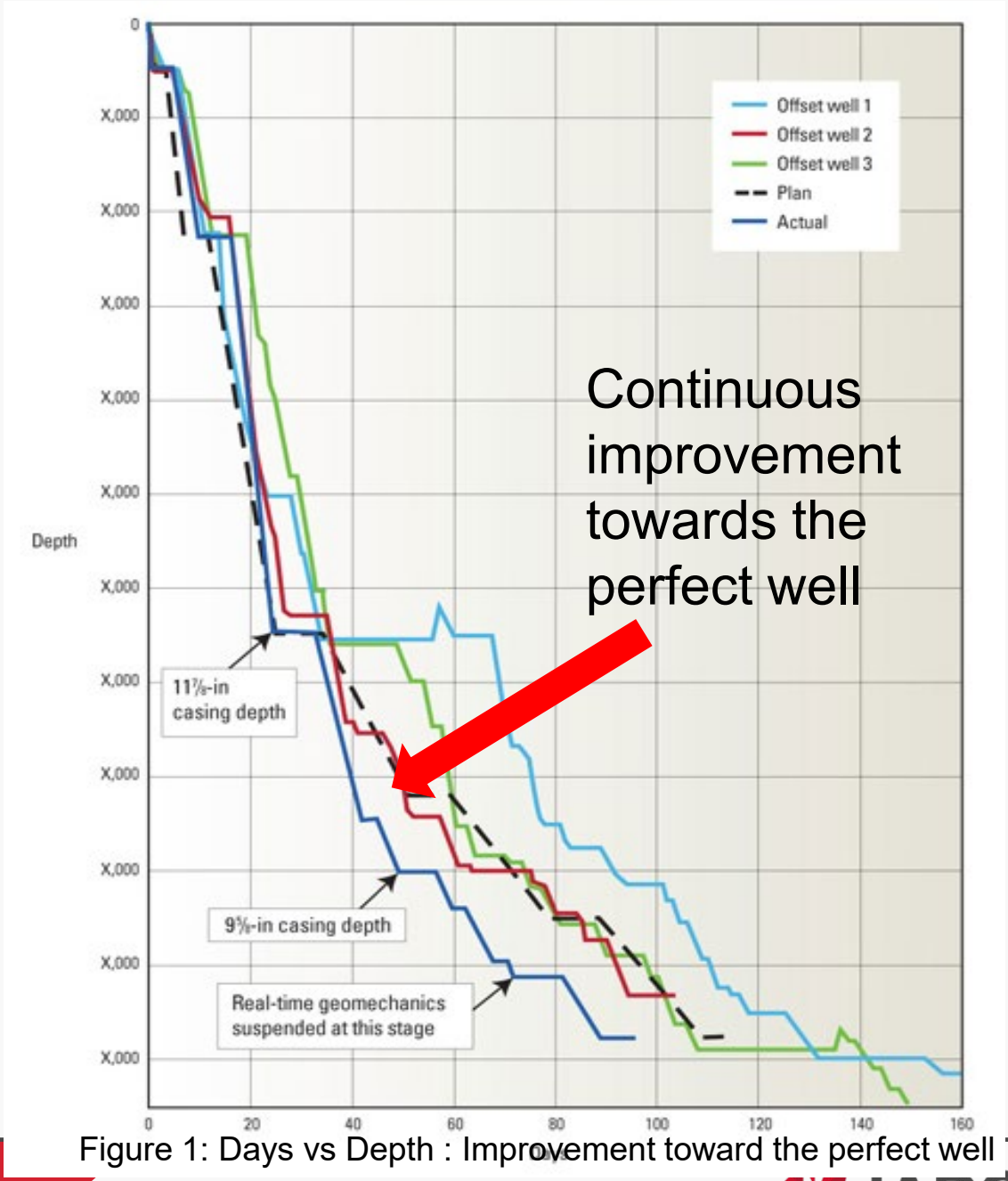


Figure 1: Days vs Depth : Improvement toward the perfect well

Conclusions

- Don’t underestimate just how “hot” and just how “hard” the rocks are
- The value proposition is different
- Help continue the adoption of oil and gas and modernization of geothermal
  - Ask the right questions and be forthcoming on current limitations of techniques and equipment

Wells of Opportunity 2021: Amplify & ReAmplify

DOE's Geothermal Technologies Office (GTO) recently announced an exciting funding opportunity for well owners or operators who would like to partner with DOE to use their existing wells to help bring geothermal power online.

Topic Area 1 – Amplify (EGS Near-Field RD&D)
This field validation effort will culminate in new power production, adding to the commercial viability of existing geothermal fields. The goal of Amplify is to illustrate that near-field and in-field EGS can be successfully deployed now as a result of recent technology advancements and that low permeability/underproductive wells near and in existing hydrothermal fields can be turned into valuable assets using EGS techniques.

Topic Area 2 – ReAmplify (Geothermal production from hydrocarbon wells)
The objective of this initiative is to establish the commercial viability of geothermal energy production from existing hydrocarbon fields. The goal of ReAmplify is to establish a pilot program where the production of geothermal heat from existing hydrocarbon fields can be demonstrated for electricity production or direct use applications.

FOA Released – June 10, 2021

Full Applications Due – July 26, 2021

Expected Selections Notification – October 6, 2021

Federal Funding: $14,500,000

Cost Share: 20%

Projected # of Awards: 3-13

Link to Funding Opportunity Announcement:
https://eere-exchange.energy.gov/Default.aspx#FoaId74cc4316-04af-476d-bd6d-18ab53cf120b

Agenda

08.30-08.35 Welcome – **Dennis Moore**, DEC Chairman, **Roy Long and Robert Estes**, DEC Board members

08.35-09.05 Geothermal Wells and Drilling Challenges, **Ozgur Balamirl**, GeothermEx

09.05-09.35 Geothermal Drilling Challenges & Concerns, **Hani Ibrahim**, Drilling Performance SME

09.35-10.05 Lessons Learned and Performance Improvement: Drilling Case Study from Sarulla Geothermal Operation, North Sumatra, **Hadi Permana**, Halliburton

10.05-10.35 It's Just a Hole in the Ground (or is it?): Physics-based Practices Achieve Ground-breaking Performance In Geothermal Drilling Application, **Sam Noynaert**, Texas A&M University

10.35-10.45 Break

10.45-11.15 3 Things I Wish I Knew Transitioning from O&G to Geothermal, **George Stutz**, US Department of Energy

11.15-11.45 A Comprehensive Tubular Design and Materials Selection Approach for Geothermal Wells, **Suri Suryanarayana**, Blade Energy Partners

11.45-12.15 Making 'Geothermal Anywhere' a Reality: Drilling Technology Capabilities, Gaps & Needs, **Eric van Oort**, UT Austin