



Welcome!

The program will begin soon.
You will not hear audio until we begin.



0



The Technology to Drill High Temperature Geothermal Wells at Scale

John M Clegg
CTO, Hephæe Energy Technology



1



SPE Webinars are Sponsored by:

SPE
SPE Foundation



2



Outline

- Geothermal energy and why we should be interested in it
- Key similarities with well construction for oil and gas
- Key differences to well construction for oil and gas
- Our opportunity



3





A Broad Spread of Applications



Direct-Use Geothermal

- Heat for residential and industrial applications
- 38°C is adequate



Hydrothermal

- Steam turbine to generate electricity
- Provided approx. 6% of California's electricity in 2020
- Demand is growing faster than hydrothermal capabilities



Enhanced Geothermal System (EGS)

- Steam turbine generates electricity
- Artificial hydrothermal systems
- Using rock as reservoir, 135 to 500°C

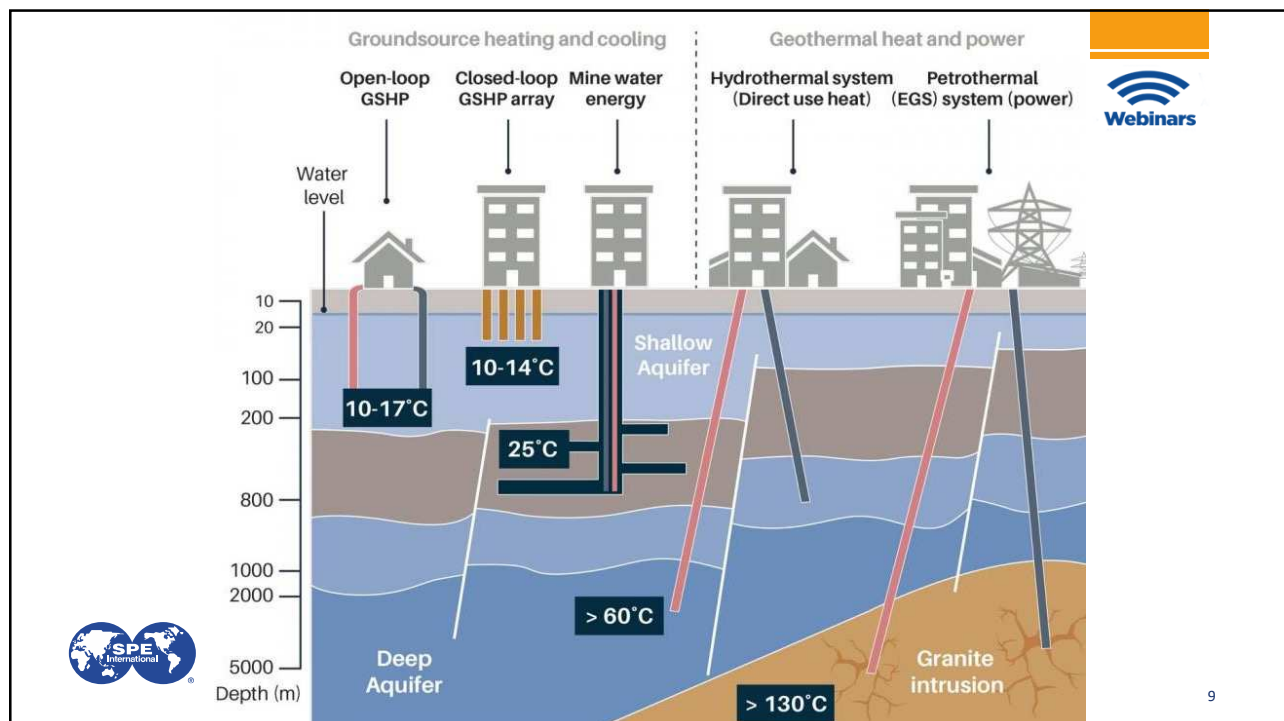


Advanced Geothermal System (AGS)

- Steam generates electricity
- Closed loop: relies on heat, 225 to 500°C (hotter is better)
- Independent of rock type or fractures



8

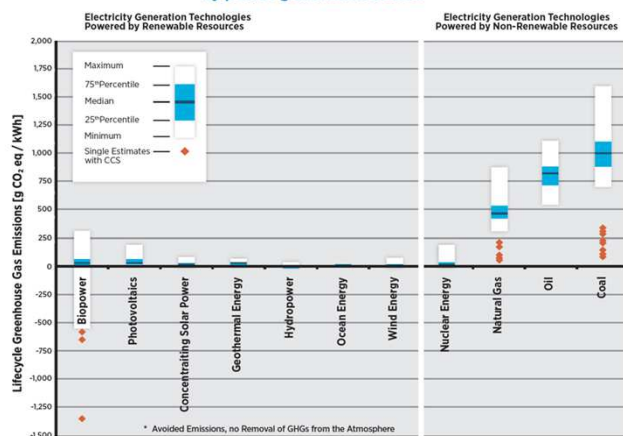


9

GHG Emissions



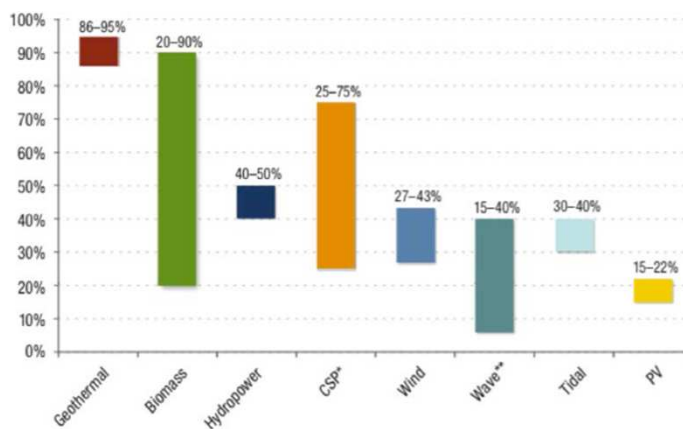
Figure 1: Estimates of lifecycle greenhouse gas emissions by power generation source



IRENA, 2017

10

Capacity



Geothermal Canada, 2018

11

LCOE Lower Than Coal or Nuclear



Levelized Cost of Energy Comparison—Unsubsidized Analysis

Selected renewable energy generation technologies are cost-competitive with conventional generation technologies under certain circumstances



Source: Lazard estimates.
Note: Here and throughout this presentation, unless otherwise indicated, the analysis assumes 60% debt at 8% interest rate and 40% equity at 12% cost. Please see page titled "Levelized Cost of Energy Comparison—Sensitivity to Cost of Capital" for cost of capital details.
(1) Unless otherwise indicated, the low case represents a single-axis tracking system and the high case represents a fixed-tilt system.
(2) Represents the estimated implied midpoint of the LCOE of offshore wind, assuming a capital cost range of approximately \$2,500 - \$3,000/kW.
(3) The fuel cost assumption for Lazard's global, unsubsidized analysis for gas-fired generation resources is \$3.45/MMBtu.
(4) Represents the midpoint of the marginal cost of operating fully depreciated gas combined cycle, coal and nuclear facilities, inclusive of decommissioning costs for nuclear facilities. Analysis assumes that the salvage value for a decommissioned gas combined cycle or coal asset is equalized by its decommissioning and site restoration costs. Inputs are derived from a benchmark of operating gas combined cycle, coal and nuclear assets across the U.S. Capacity factors, fuel, variable and fixed operating expenses are based on upper and lower quartile estimates derived from Lazard's research. Please see page titled "Levelized Cost of Energy Comparison—Renewable Energy versus Marginal Cost of Selected Existing Conventional Generation" for additional details.
(5) Unless otherwise indicated, the analysis does not reflect decommissioning costs, ongoing maintenance-related capital expenditures or the potential economic impacts of federal loan guarantees or other subsidies.
(6) High and incorporates 50% carbon capture and storage. Costs include cost of transportation and storage.
(7) Represents the LCOE of the observed high case gas combined cycle inputs using a 20% blend of "blue" hydrogen, (i.e., hydrogen produced from a steam methane reformer, using natural gas as a feedstock, and sequestering the resulting CO₂ in a nearby saline aquifer). No plant modifications are assumed beyond a 2% adjustment to the plant's heat rate. The corresponding fuel cost is \$5.20/MMBtu.
(8) Represents the LCOE of the observed high case gas combined cycle inputs using a 20% blend of "green" hydrogen, (i.e., hydrogen produced from an electrolyzer powered by a mix of wind and solar generation and stored in a nearby salt cavern). No plant modifications are assumed beyond a 2% adjustment to the plant's heat rate. The corresponding fuel cost is \$10.00/MMBtu.



Lazard, 2020

12

LCOE Potential



- Tim Latimer, Fervo Energy
 - ✓ "The impact of drilling cost decline, PTC extension, and lower interest rates probably lead to a 20 to 30% decline in geothermal from the \$65 to 75/MWh at the start of the year. We may see geothermal <\$60 soon, and maybe even <\$50."
- Michael Liebreich, founder of Bloomberg New Energy Finance
 - ✓ Eavor aiming for \$50/MWh by 2030

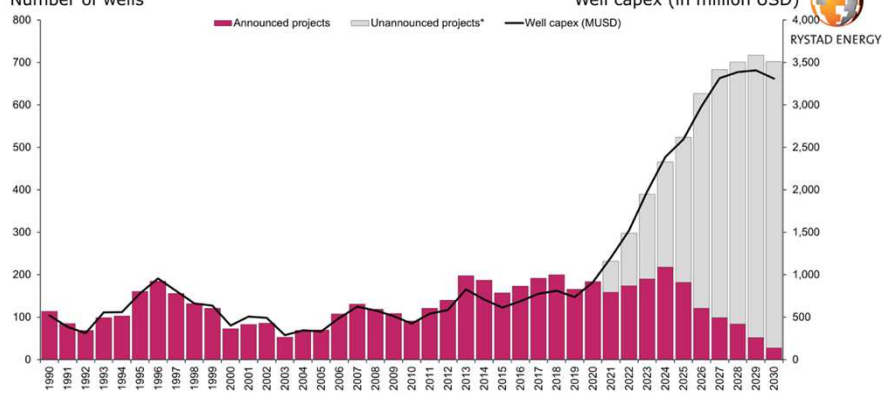


13

Rapid Growth, Modest Numbers



Wells drilled globally for geothermal power generation and related capex

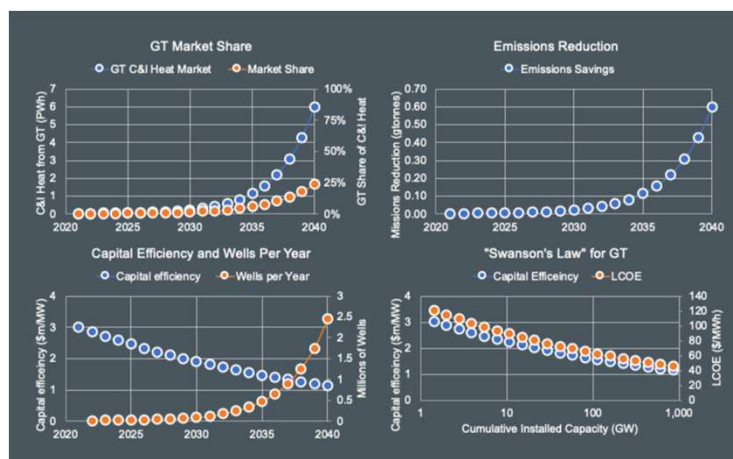


*Unannounced projects contain an estimated number of wells to be drilled to meet government targets on capacity additions towards 2030

Source: Rystad Energy Geothermal Analysis Dashboard

14

...Or Not So Modest?



Causeway GT, 2021

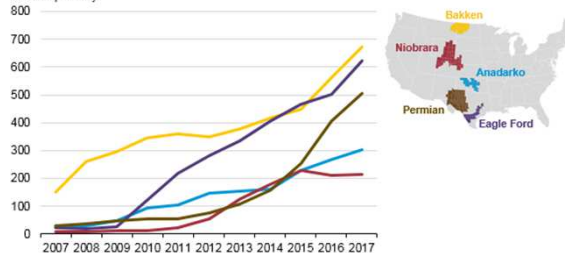
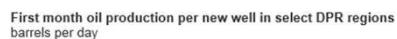
15

Levelized Cost of Energy Comparison—Historical Renewable Energy LCOE Declines

Unsubsidized Wind LCOE



16



17



What do horizontal drilling and hydraulic fracturing have to do with geothermal?



18

Enhanced Geothermal System

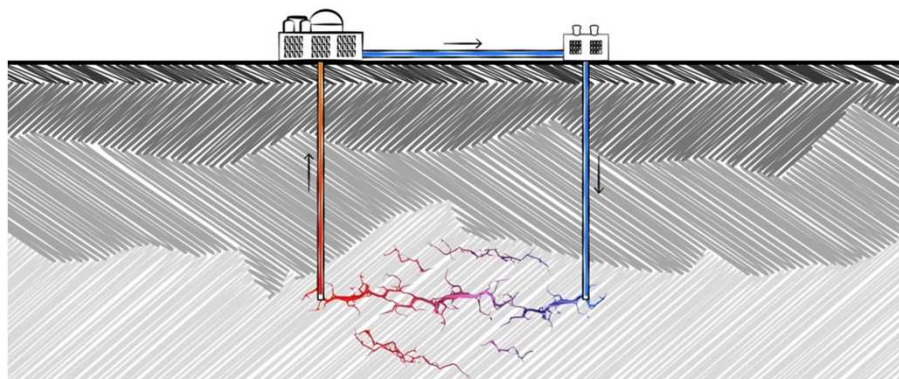


image courtesy J. Beard/Pivot2021: Geothermal Reimagined

19

Advanced Geothermal Systems

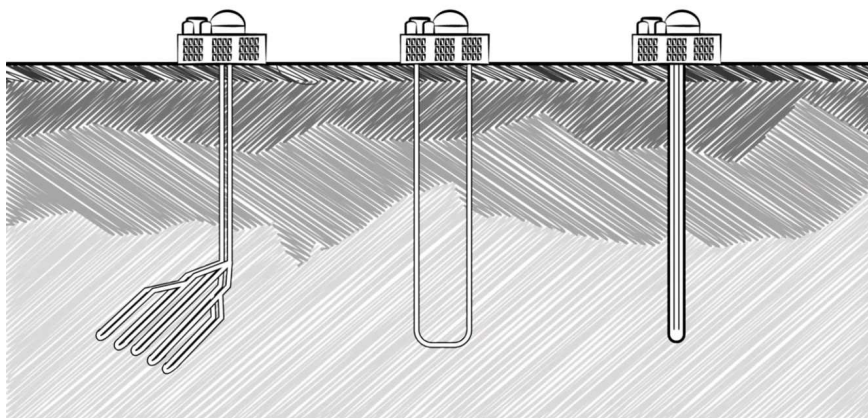


image courtesy J. Beard/Pivot2021: Geothermal Reimagined

20

Hybrid Geothermal System

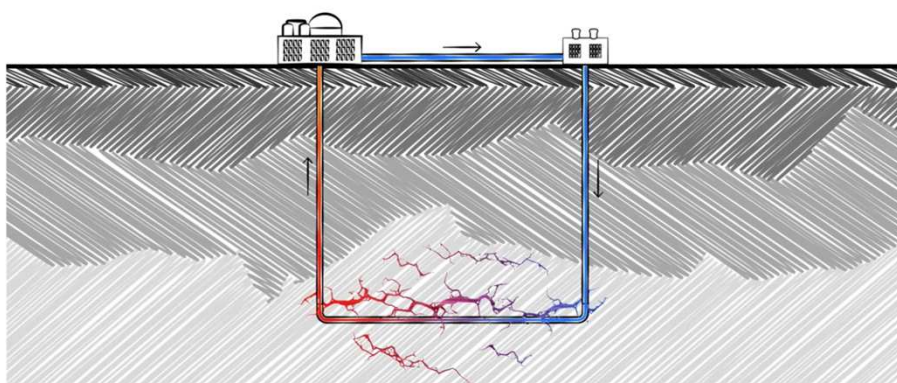


image courtesy J. Beard/Pivot2021: Geothermal Reimagined

21



Don't these just look like oil and gas wells?



22



“... oil and gas service companies who have positioned themselves as leaders in high-temperature and high-pressure drilling are going to own this future”

Vik Rao, Executive Director of the Research Triangle Energy Consortium, former CTO of Halliburton



23



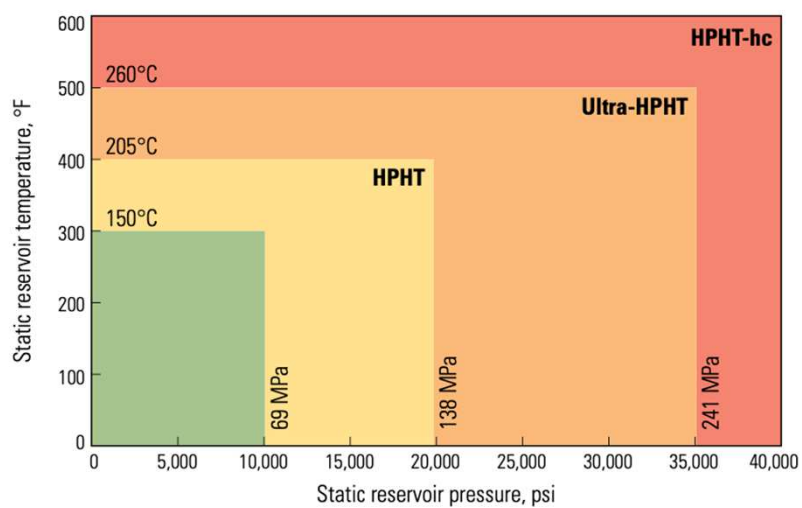
What are the key differences?



24



Temperature and Pressure

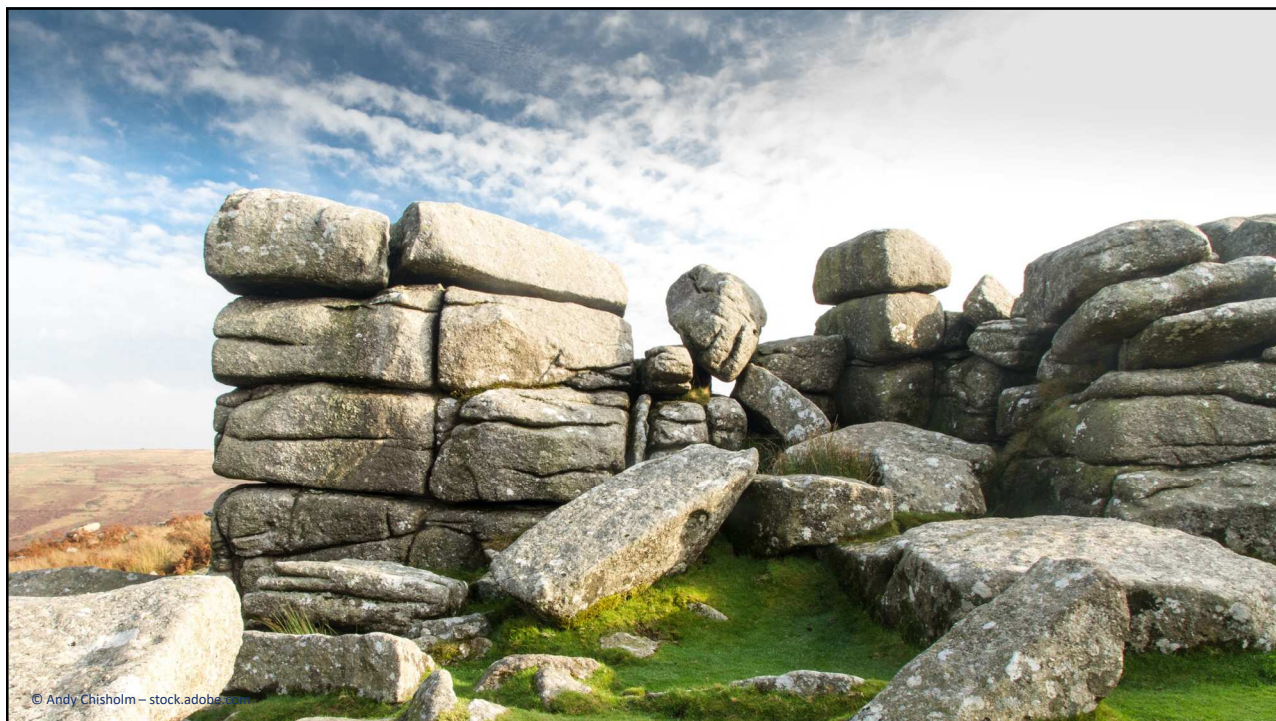


25

List of 200°C+ Commercial O&G MWD/DD Tools



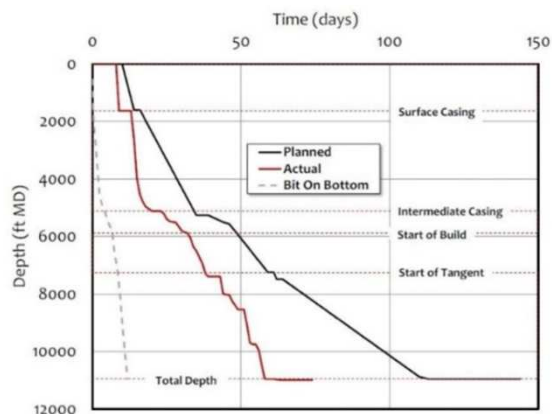
26



Drill Bits



hypersciences.com



Well 16A(78)-32 Planned vs. Actual Depth vs. Days (source: NOV, ReedHycalog)

thinkgeoenergy.com

28

Friction



High coefficient of friction with igneous rocks

- Well bore quality is important
- Continuous rotation is important



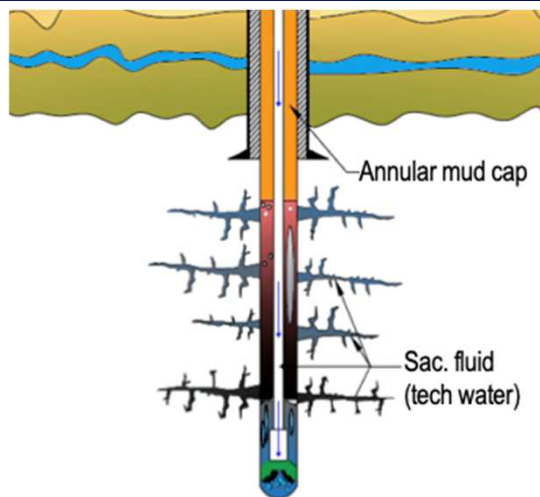
© k_yu - stock.adobe.com

29

Losses



- Highly fractured formations
- Mud losses
- Air or foam drilling
- (Pressurized) mud cap drilling



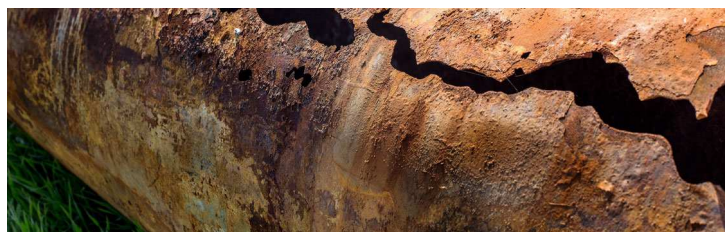
Weatherford

30

Sour Service



- Ca_2+ , Na^+ , CO_2 , H_2S , HCl , NH_3 can all be present in hot geothermal fluids
- Combination with temperature = particular materials challenge



DNV

31

Drilling Mud



- Conventional WBM can lose viscosity at high temperatures
- OBM often preferred
 - Less environmentally friendly
 - Lower heat capacity
- Higher-temperature WBM required



PetGeo

32

Mud Pumps and Chillers



- Mud flow can be used to cool downhole tools
- High flow rates = large pumps, big rigs
- Mud chillers can also help



NOV

33

Continuous Flow



- Continuous circulation systems can prevent rapid temperature increase of downhole tools during connections
- Implications for rig design

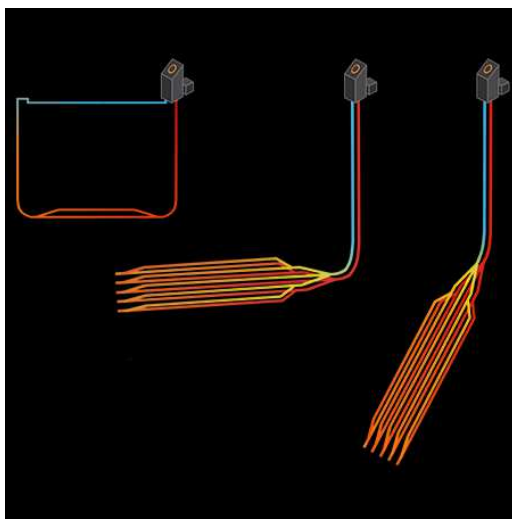


Halliburton



34

Deeper and Hotter



Eavor



35

There is One 200°C LWD Tool



- Required “ground-up redesign”

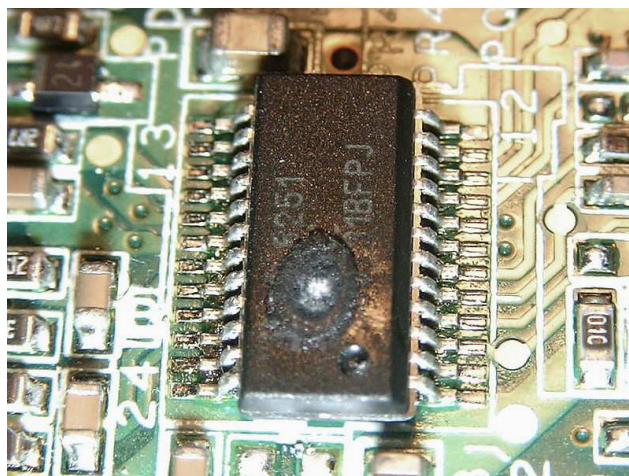


Kleawyothis el at, SPE-191054-MS 2018



36

Plastic Packaged Electronics at 200°C



Wikimedia Commons



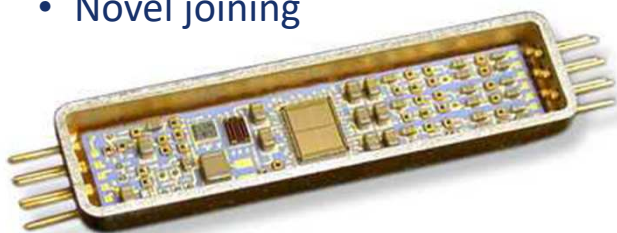
37



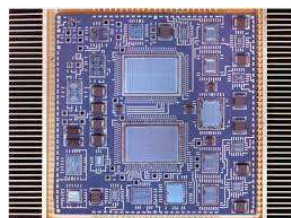
Hotter is Better



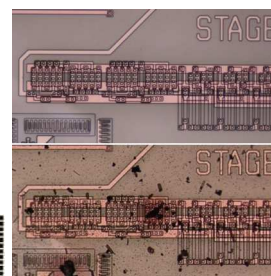
- Novel packaging
- Novel joining



Quartzdyne

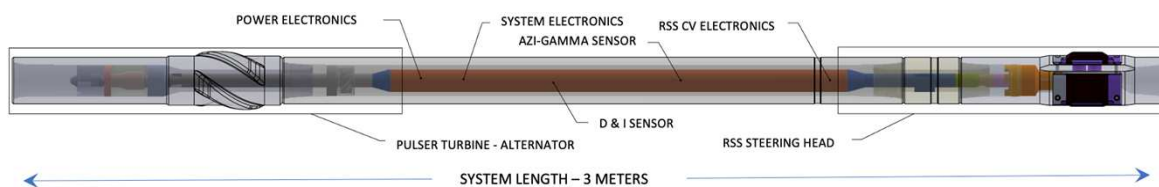


Smithsonian



NASA

HT Integrated Directional Drilling Tool



Hephae Energy Technology



40

Hybrid Geothermal System

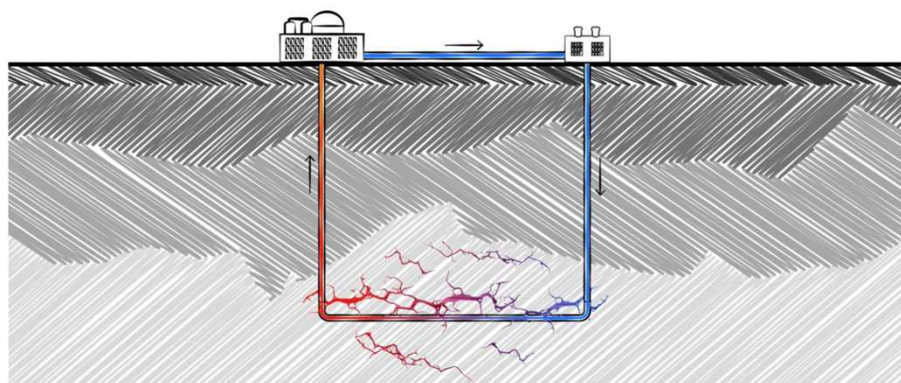


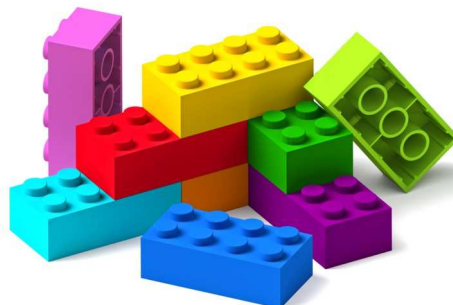
image courtesy J. Beard/Pivot2021: Geothermal Reimagined

41

LEGO



- HT building blocks allow:
 - Drilling and measurements
 - Logging
 - Intelligent completions
 - Production monitoring
 - Production optimization



© Anterovium – stock.adobe.com

42

The Opportunity is There



New technology transformed and scaled
unconventional O/G

Combine new technology + O/G expertise +
decades of Geothermal experience...

...and scale Geothermal to previously
unimagined heights



© meredesign – stock.adobe.com



43



The Technology to Drill High Temperature Geothermal Wells at Scale

John M Clegg
CTO, Hephae Energy Technology



44