GreenFire Energy

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IADC

Challenges for the Drilling Industry to Unlock the Enormous Potential of Geothermal Power

November 15, 2017

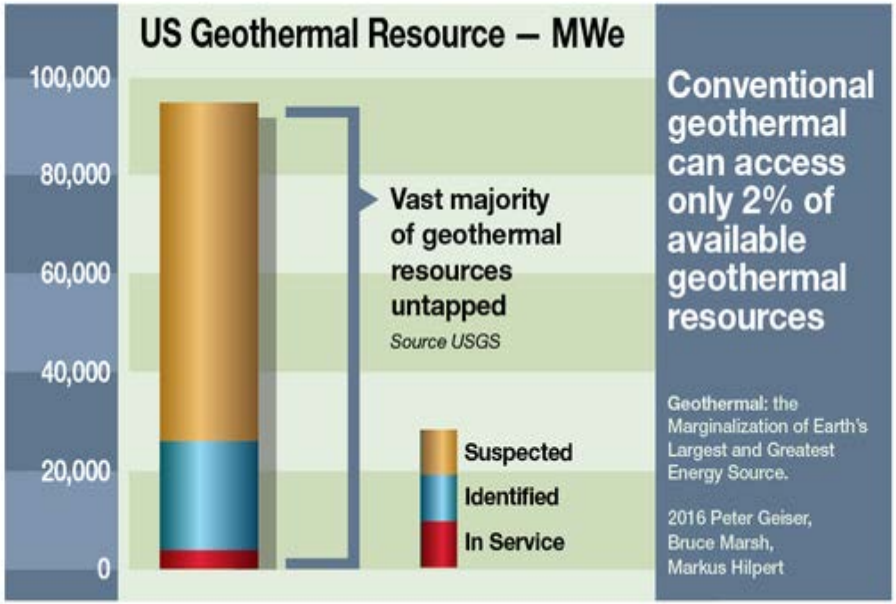
GreenFire Energy Overview

- A “demonstration stage” company
- New generation of geothermal power that uses little or no water and opens up vast, untapped geothermal resources using a closed-loop system to circulate refrigerant fluids: ECO2G™
- Retrofit ECO2G – current business opportunity
  - Make failed or marginal hydrothermal wells productive ~ 1-3 MW
  - Demonstration project at Coso, California in progress with support from California Energy Commission, Shell GameChanger, a utility consortium under the Electric Power Research Institute, Blade Energy and other suppliers
- Full Scale ECO2G – longer term opportunity – today’s topic
  - Hotter and deeper (3-7 km) into hot dry rock
  - BHTs of up to 550°C
  - Very large, profitable projects that each require drilling 100’s of deep wells

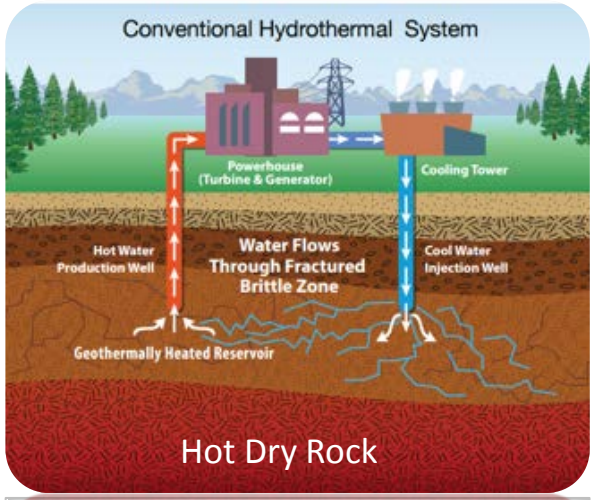
Goal: Solve the drilling challenges of Full Scale ECO2G today, …but how?

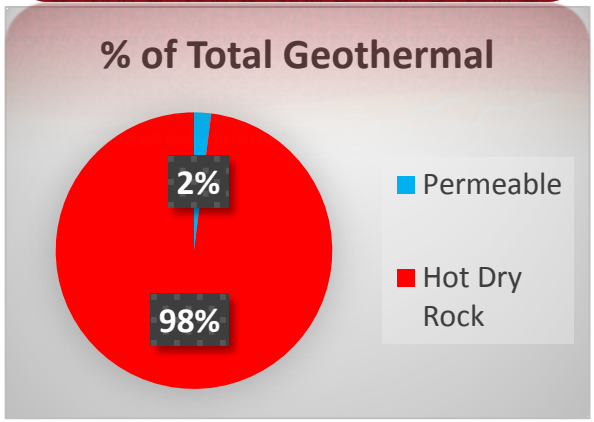
1. Understand the huge potential of full scale ECO2G
2. Understand the specific challenges we've identified
3. Some of the potential solutions that have been offered up
4. Discussion of solutions

Full Scale ECO2G Potential:
Huge geothermal resource is under-utilized; conventional technology is limited to permeable rock and requires water



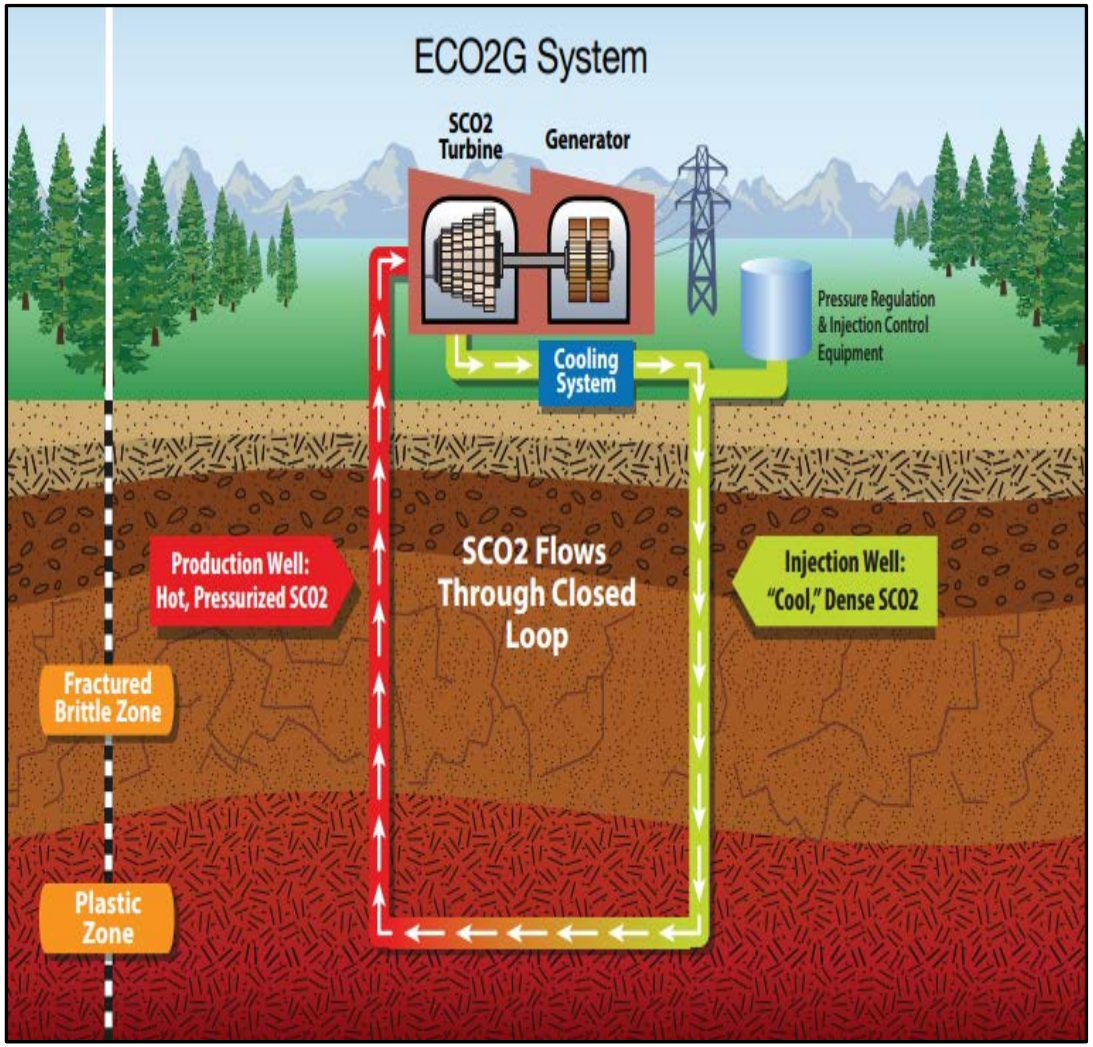
Tester, J. W., Anderson, B., Batchelor, A., Blackwell, D., DiPippo, R., Drake, E., ... & Petty, S. The future of geothermal energy: Impact of enhanced geothermal systems (EGS) on the United States in the 21st century. Massachusetts Institute of Technology (2006).





Geiser, B.,Hilpert, M. Marsh, B., Geothermal: The Marginalization of Earth's Largest and Greenest Energy Source , Stanford Geothermal Workshop, 2016

Full Scale ECO2G: Reaching Hotter and Deeper



ECO2G Attributes:

- Closed Loop
  - Only heat is extracted
- Refrigerants (sCO_2, others)
  - Excellent thermodynamic properties with thermosiphon
- No process water required
- Deep and Hot
  - Brittle or Plastic Zone
  - Hot: 350°- 550°C

ECO2G: superior environmental attributes

ECO2G's closed-loop advantages over hydrothermal

Air & Water Quality

- Zero emissions
- Little or no water consumption
- No contact with subsurface water
- No waste streams

Public Safety

- No waste streams
- No risk of induced seismicity
- No hazardous chemicals
- No risk of fire or explosion

Land Usage

- Very small footprint
- No surface subsidence
- Minimal visual impact
- No noise pollution

Wildlife Preservation

- Not a hazard to birds, animals or fish
- Does not block or restrict migration routes

Lucrative Pacific Rim Project Analysis with Existing Drilling Technology

ASSUMPTIONS:

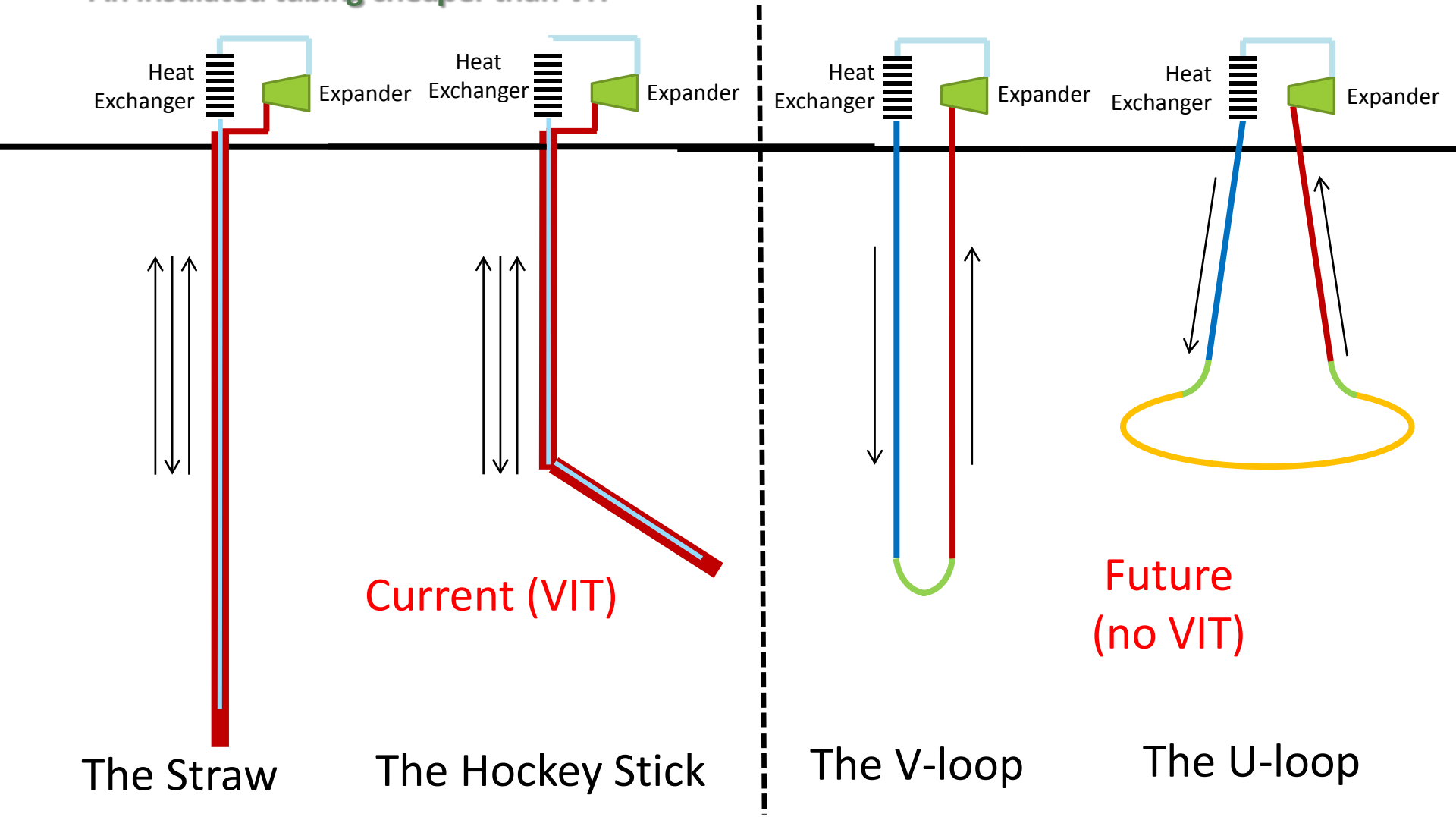
- **200 and 800 MWe Projects**
  (over 200 and 800 wells)
- **Imperial Valley site characteristics**
  - Anchor point @ 350 C & 2600 m
  - Bottom hole **@ 550 C & 4250 m**
  - Hockey Stick - **Well length = 7400 m**
  - **Straw well configuration with VIT**
  - Gross power = 940 kW per well
  - Casing OD 9-5/8”
  - 90% capacity factor
- **Pacific Rim**
  - **$125/MWh PPA**
  - O&M = $4.5/MWh
- **Financial Assumptions**
  - Debt Equity Ratio = 70%:30%
  - Debt Cost = 4.5%
  - 25 Year Project Life

FINANCIAL RESULTS:

	200MWe	800MWe
Levelized Cost of Energy	$60/MWh	$59/MWh
Investment	$1.4 B	$5.5 B
Payback period	4 years	4 years
Net Present Value	$0.68 B	$2.8 B
IRR	39%	42%

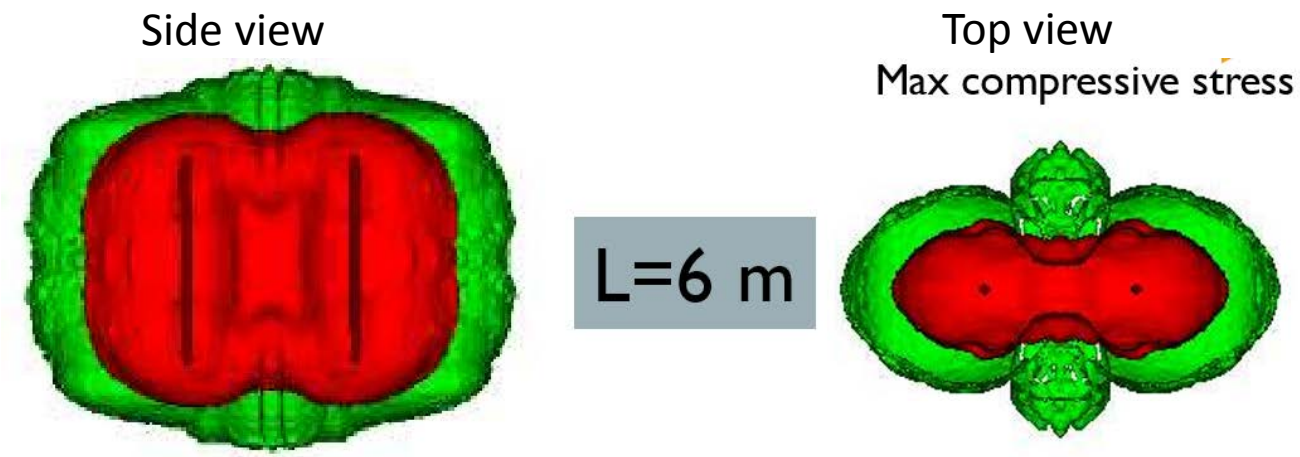
ECO2G: Well Configurations

- Need for secure completion to replace expensive vacuum insulated tubing (VIT), or
- An insulated tubing cheaper than VIT



Challenges for secure completions

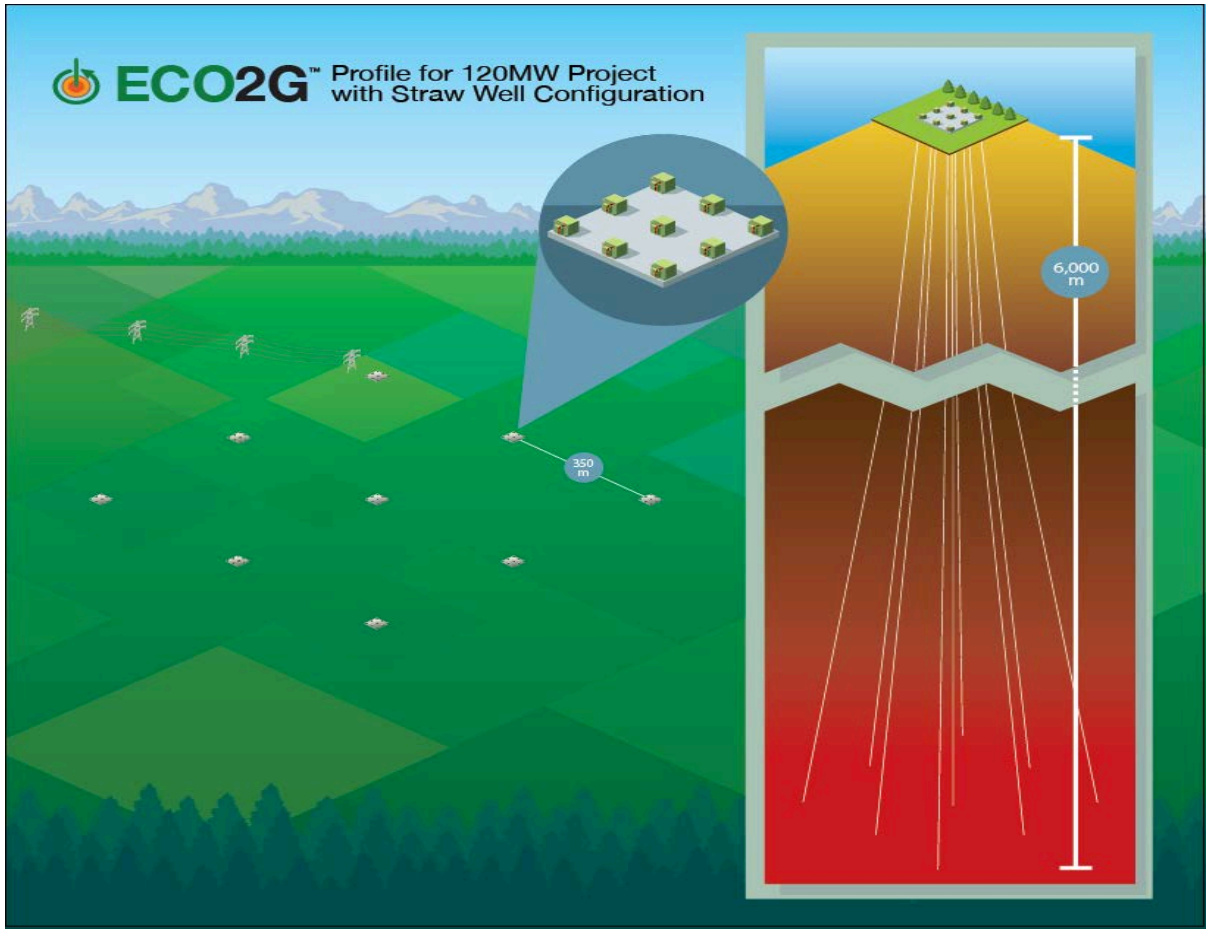
- **Completing V and U shape wells at 3-7 km depths and temperatures up to 550°C**
  - Range finding at high temperatures – chilled circulating mud enough?
  - Well joining/completion at depth with high temperature and pressure with TAML tight (Technology Advancement of MultiLaterals #'s 4, 5 or 6?)
  - Hydraulic flushing to create an open hole completion, maintain flow, and seal to avoid impurities creating corrosion inside the pipe
  - Open hole completions that create a sealed fracture zone to join two boreholes *(Lawrence Livermore National Lab research project)*
    - Energetic stimulation of completion zone feasible
    - Establishing and maintaining sufficient permeability and flow over time at high temperature



Simultaneous explosion in two bores in hot granite

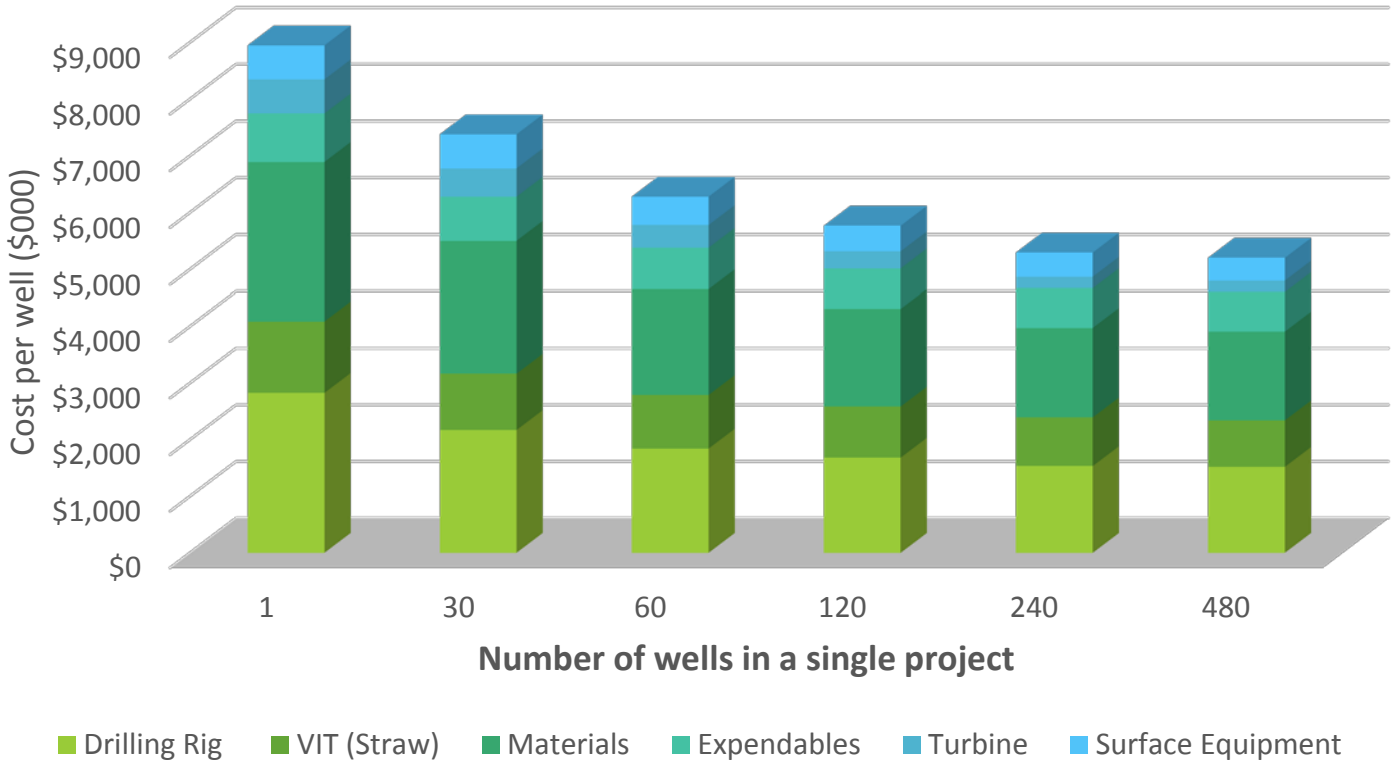
Directional drilling at high temps

Drilling multiple “straw” or “hockey stick” wells while maintaining minimum of 100 meter spacing between wells at depth

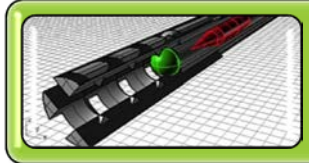


Drilling Campaign Costs – Further Reductions Anticipated

- Surface equipment is low proportion of ECO2G total cost
- Leverage economies of scale (e.g. rigs on tracks)
- Better insulating cement near the surface and conducting cement at depth
- 350°C limit on cement jobs forcing other techniques in bottom hole?
- *ROP is by far the biggest single factor*

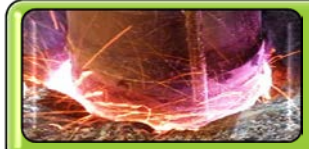


Advanced drilling technologies may cut costs and improve accuracy



Ram Accelerator: ***10 X rate of penetration***

- HyperSciences – Spokane, Washington
- Projectiles accelerated to Mach 5 to smash rock



Plasma Flare

- GA Drilling – Bratislava, Slovakia
- Electric plasma arc thermally breaks rock

Microwave Drilling: ***3 X rate of penetration***

- Impact Technologies - Tulsa OK
- High energy millimeter waves vaporize or melt rock

High Power Laser

- Foro Energy – Littleton, Colorado
- Melts through rock

Electro Pulse Borehole: ***deep, large bores at 5% current cost***

- Alaska Applied Sciences
- High power electric pulses fracture rock

Sonic Drilling

- Los Alamos National Laboratory, New Mexico

Questions & Answers

Solutions

Thank you!

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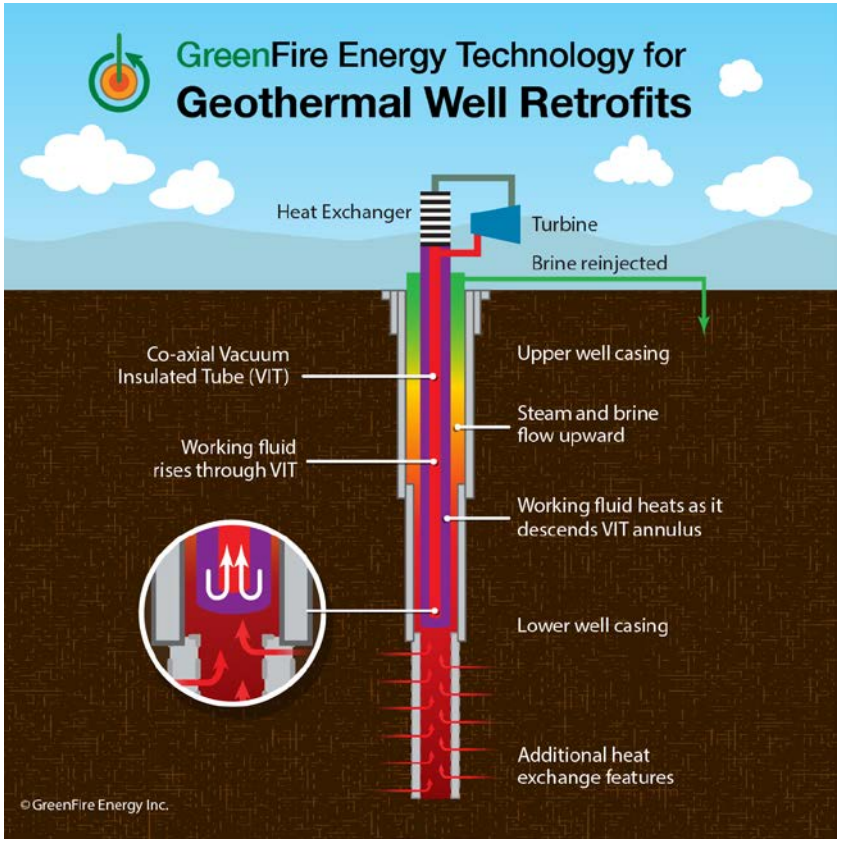
Potential for ECO2G Retrofits: California Example



California wells drilled from 1980

Wells	Active	Idle	Abandoned
1698	829	115	754

Source CA DOGGR database

Types of Wells to Consider

- Decreased hydrothermal flow
- Insufficient hydrothermal flow from inception
- High brine acidity that limits hydrothermal use
- Injection wells with high temperature or flow
- Flash wells releasing toxic or greenhouse gases.