Engineering Geothermal Systems

To Impact Global Climate Change

The Energy Under Our Feet

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AltaRock Energy

Mission statement

AltaRock produces clean, renewable baseload geothermal power by developing and commercializing enhanced geothermal systems (EGS) technology.

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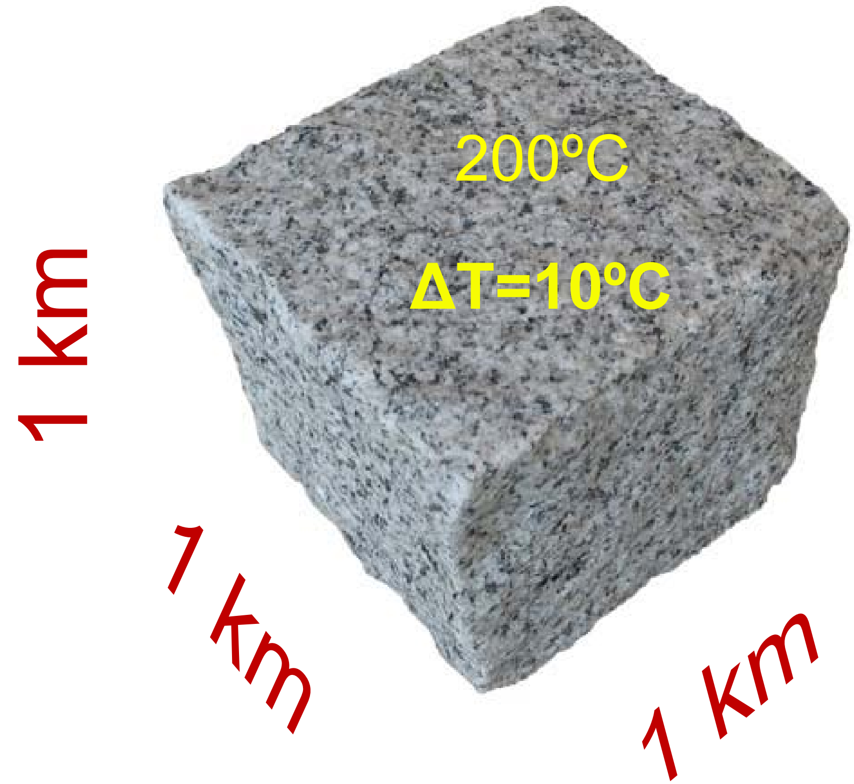
Heat Stored in Rock



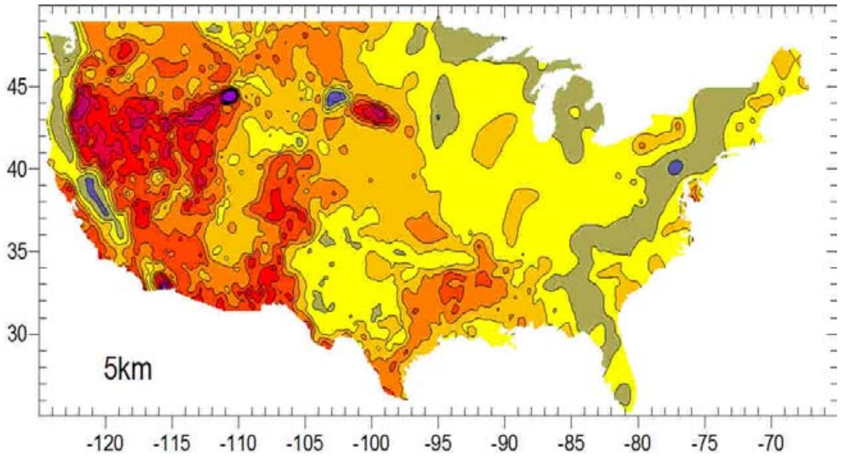
1 km^3 Granite

3,490,000 BBL of Oil Equivalent
or
1,360,000 MWh
as electricity
(155 MW)

The Future of Geothermal Energy

The Future of Geothermal Energy: Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century
http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf

- 12 member panel lead by Dr. Jeff Tester through MIT
- Includes preliminary assessment of US resource

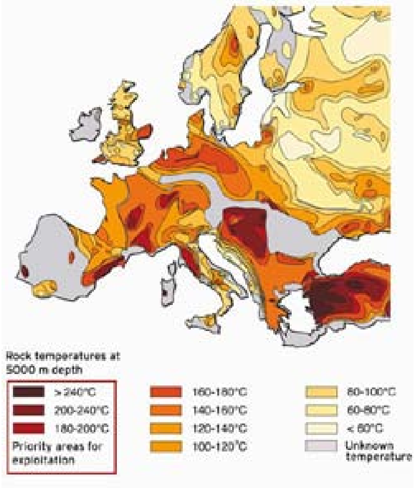


- **Conclusions:**
  - Technically feasible today
  - Best resources economic today
  - Resource extends across US
  - 50,000 MW of EGS power could be on line by 2050 with no federal investment
  - 100,000 MW by 2050 ~$350,000,000 net federal investment

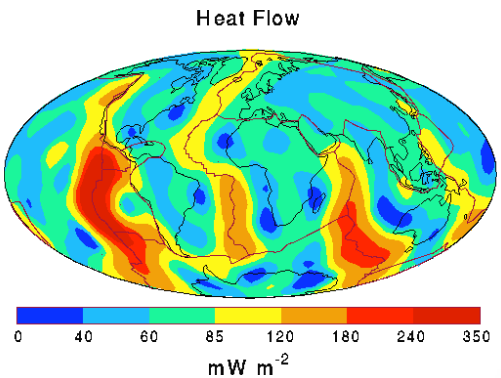
Heat Mining the Geothermal Resource

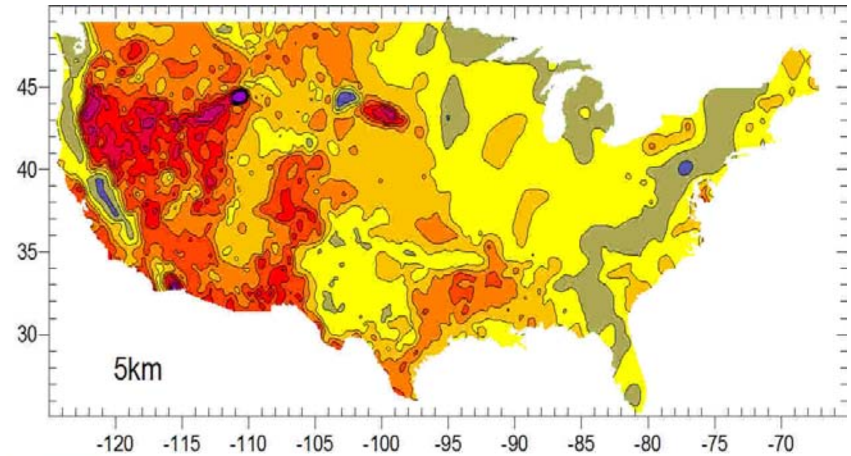
Enhanced Geothermal Systems

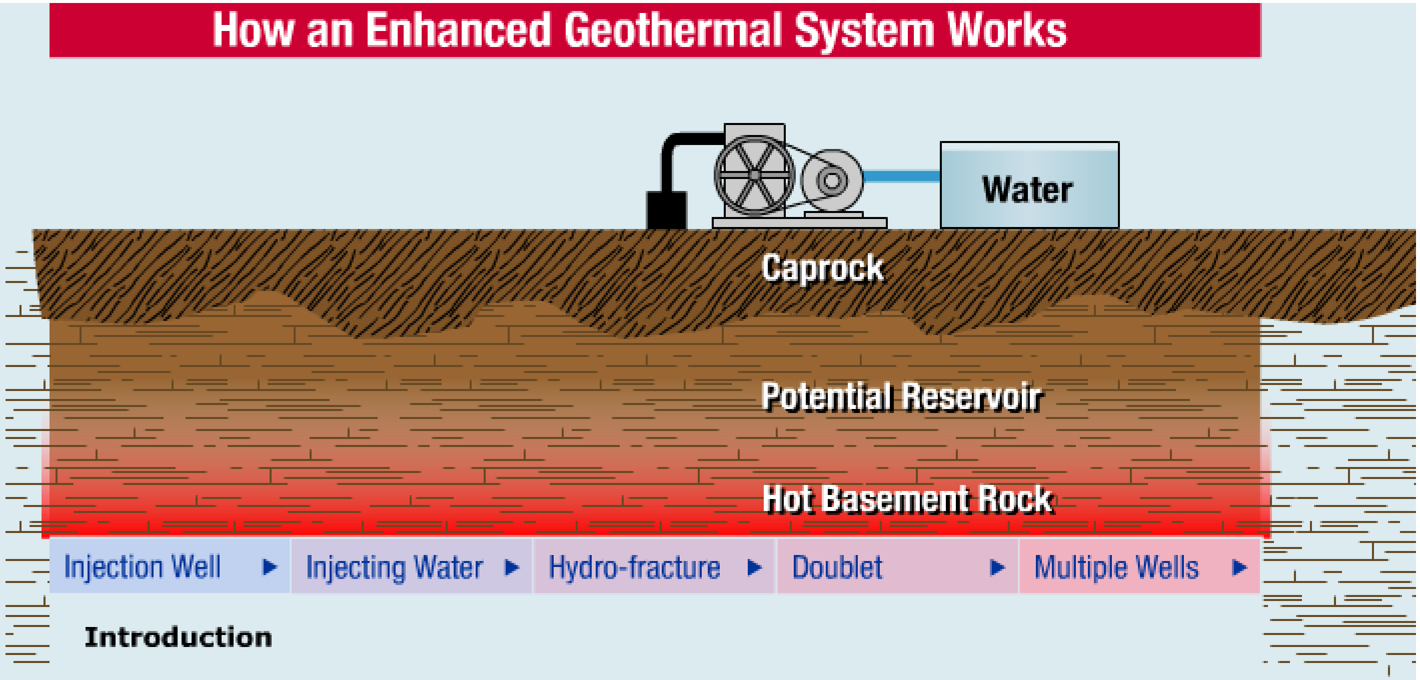
- Enormous resource stored as heat in rock
- Natural heat flow recharges stored heat
- Areas with high heat flow
  - Across the US
  - Around the world



Rock temperatures at 5 km depth







Introduction

Today, geothermal power is produced from geothermal resources that have a combination of three critical factors; 1) high-temperature rock, 2) water saturation of the field, and 3) good permeability to allow water (the heat transfer agent) movement throughout the target geothermal field.

Tapping suitably hot rock that is dry (lacking in fluid saturation due to impermeability) can vastly increase our geothermal energy resource. This diagram shows how all three factors interact, and how a new geothermal field can be realized by increasing permeability through hydro-fracturing stimulation.

Click on the colored buttons above to better understand the process of how enhanced geothermal systems (EGS) are created.

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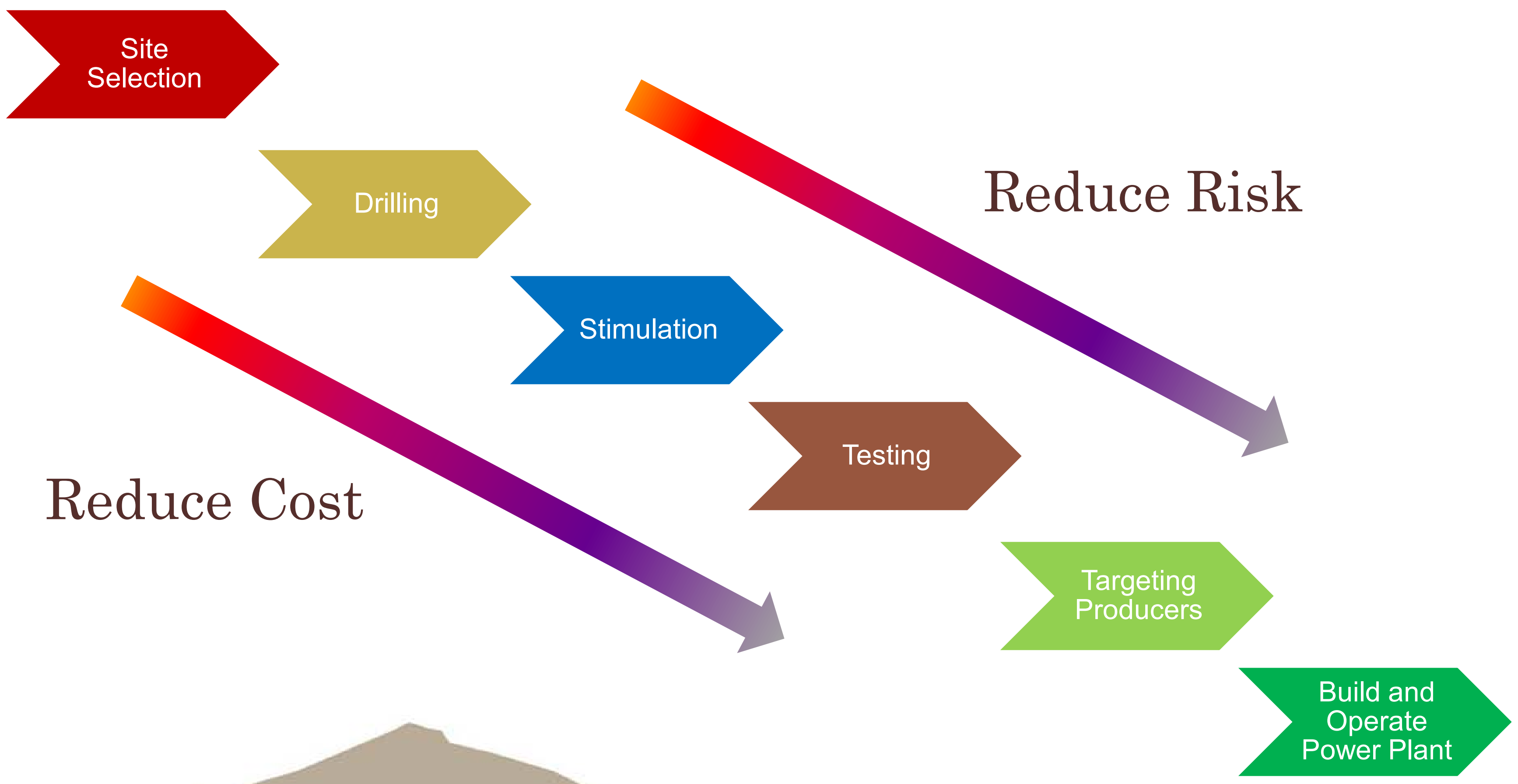
Technology Development Goals



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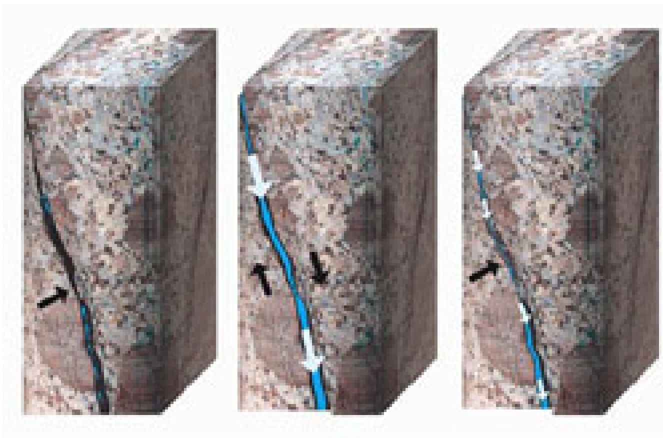
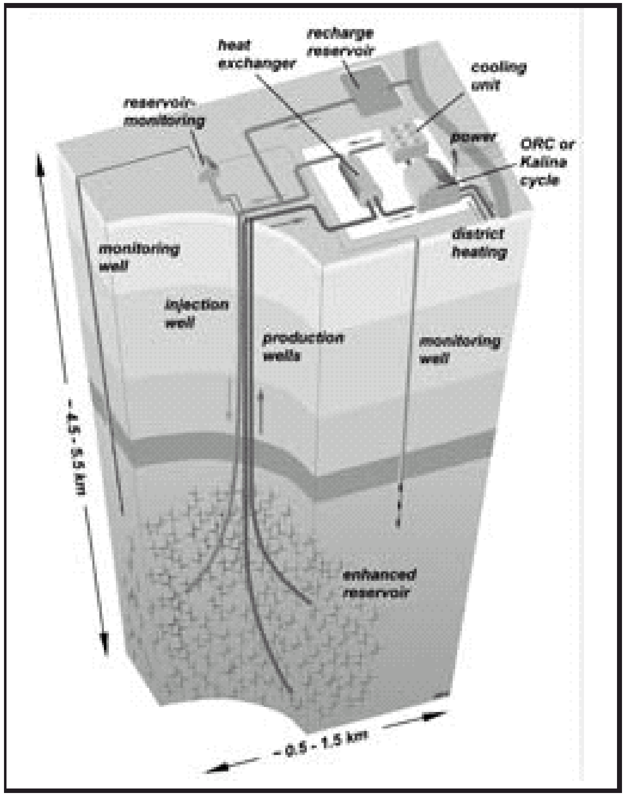
Enhanced Geothermal Systems



Enhancing the rock's permeability. The subsurface at Soultz-sous-Forêts consists of granite containing natural fractures. These fractures have been partially sealed over thousands of years (1). To be able to use these rocks as a heat exchanger, these fractures have to opened up again. This is achieved by injecting water at high pressure. The water expands the fractures, allowing the rocks to move slightly along the fracture planes (2). When the pressure is released, the fractures no longer fit together perfectly, and there is enough space to allow the circulation of water (3). (Courtesy of EEIG "Heat Mining", European Hot Dry Rock Project)



Next Generation Geothermal Technology
Enhanced Geothermal Systems

- Benefits
  - Like hydrothermal – Renewable, baseload, low cost to operate, low cost volatility
  - Uses same plant technology and drilling infrastructure as hydrothermal
  - Scalable – modular development to very large projects
  - Small footprint
  - Less site specific
  - Low to no resource risk – technology based
  - Technically feasible today
- Challenges
  - High up front cost – 75%-80% in wellfield

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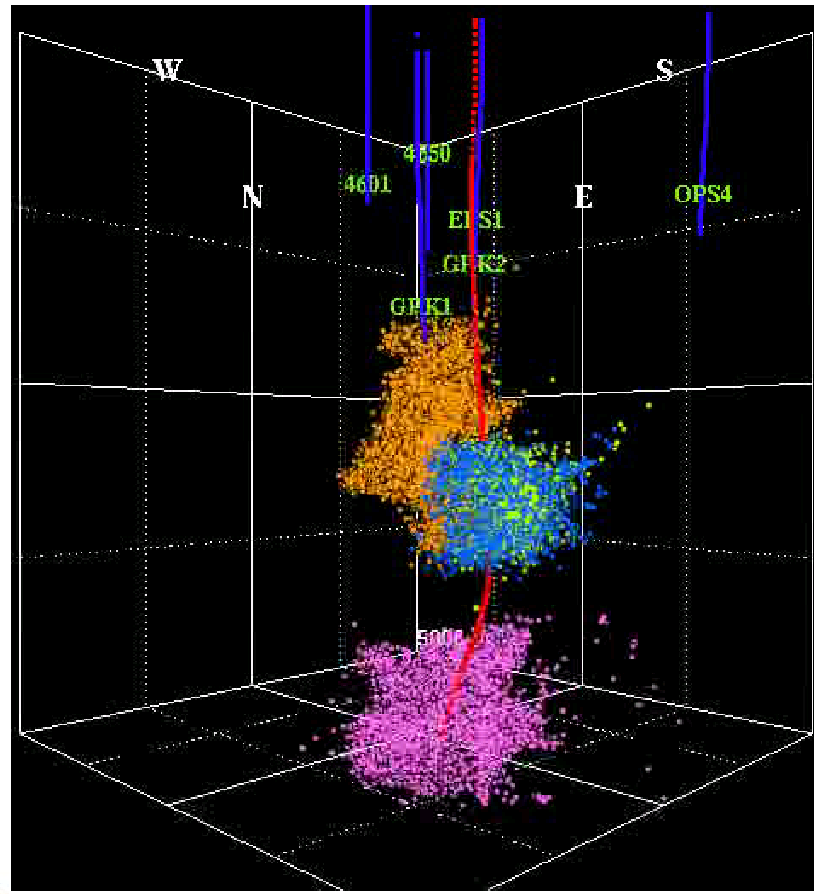
Current Status of EGS Technology

- We can:
  - Drill wells to temperatures suitable for power generation
  - Fracture large volumes of rock > 2.5 km^3
  - Map the fractures we make
  - Drill into the fractured volume
  - Circulate cold water into the injector and retrieve it hot from producers
  - Generate power at economic rates in some areas



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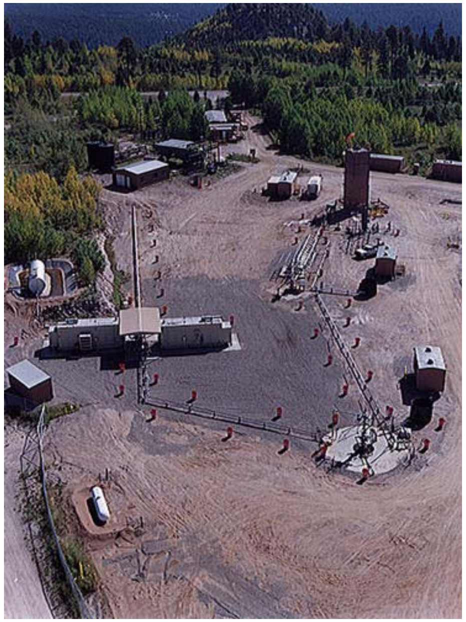
EGS Test Sites

First test of engineered geothermal at Fenton Hill, New Mexico



Binary power plant at Hijiori EGS site, Japan.

Testing at Soultz EGS test site, France.

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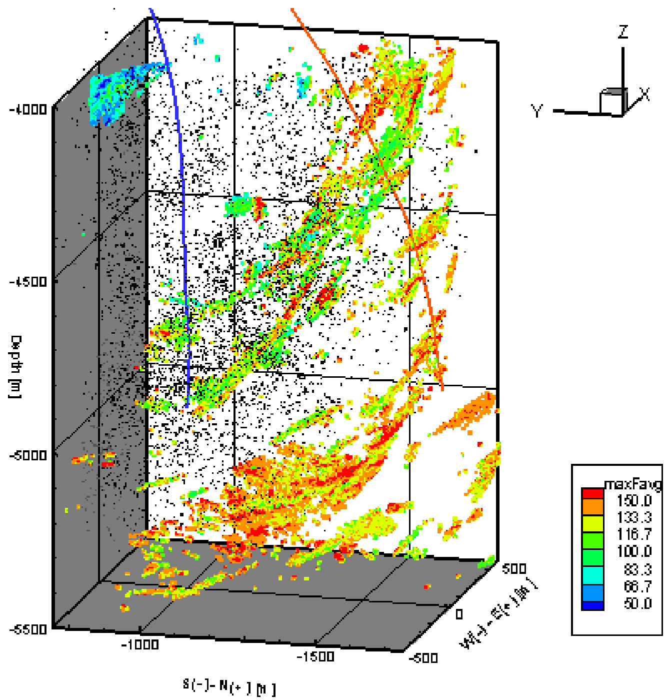
EGS Development Worldwide

Commercializing the EGS resource

Test of EGS well, Cooper Basin, Australia. 30 MW test project planned with expansion to 450 MW.

Pump installation at Landau, Germany. Binary power plant now on line.

What Does a Successful Project Look Like?



- Located near demand
  - Seattle, Bay Area, Los Angeles
  - Beyond the western US - Washington DC?
  - Western New York, Pennsylvania, South Carolina, Arkansas?
  - Worldwide – areas with fast growing demand
- Temperature of over 150ºC
- Close to transmission
- Avoid environmentally sensitive areas
- 7 MW per producer (80 l/s flow rate at 200ºC
- Up to 6 km deep to reach target temperature
- ~3 km^3 of fractured rock in 2 – 3 separate fracture zones
- System life 30 yrs

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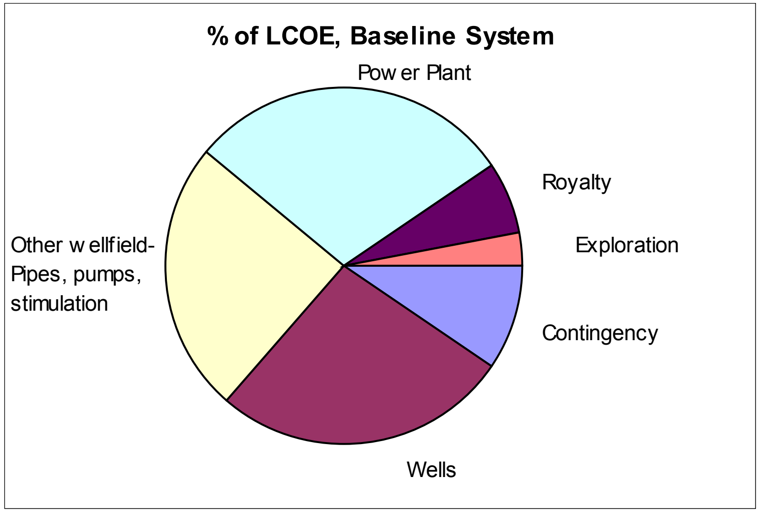
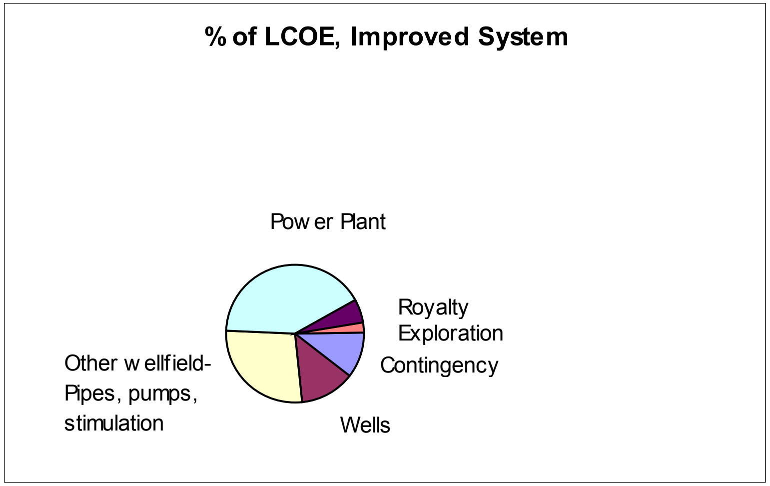
Economics

High Temperature System

300°C at 4 km

- With current technology ~7.8¢/kWh
- With improved technology 5.4¢/kWh
- Areas for technology improvement
  - Conversion cycle efficiency
  - Drilling cost reduction/risk reduction
    - Fewer casing strings
    - Higher hard rock ROP
    - Better measurement while drilling for HT (risk↓)
  - Improved stimulation technology
    - Better zone isolation
    - Better reservoir understanding
      - Stress measurement
      - Fracture ID
      - Higher flow per producer
      - Single well test methods



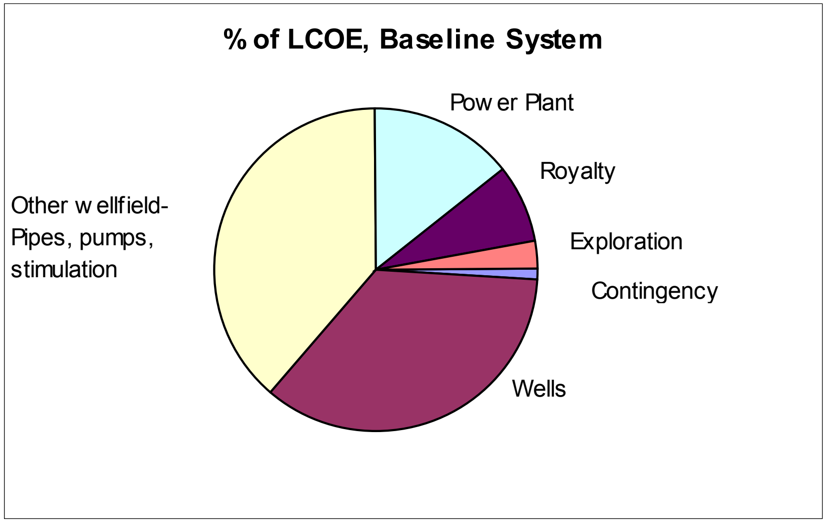


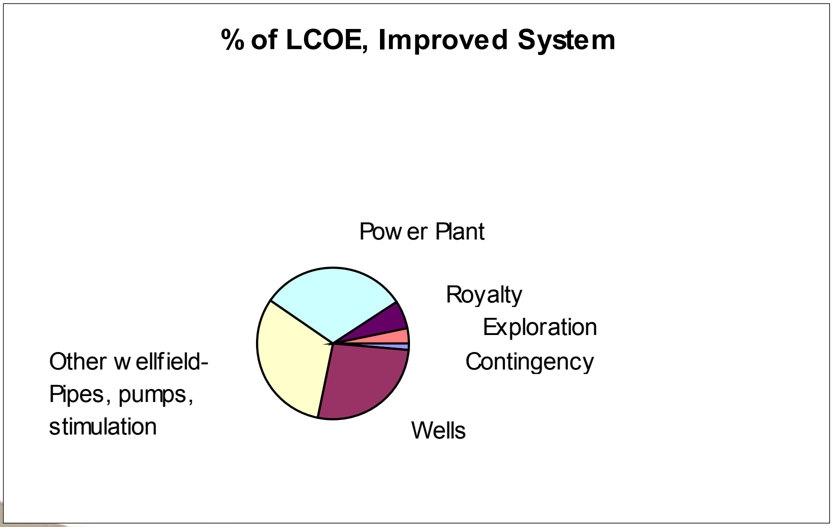
Economics

Low Temperature System

150°C at 5 km

- With current technology ~19.2¢/kWh
- With improved technology 7.4¢/kWh
- Areas for technology improvement
  - Conversion cycle efficiency
    - Improved HT pumping
    - More efficiency binary cycle
  - Drilling reduction/risk reduction
    - Fewer casing strings
    - Higher hard rock ROP
    - Better measurement while drilling for HT (risk↓)
  - Improved stimulation technology
    - Higher flow per producer!
    - Better zone isolation
    - Better reservoir understanding
      - Stress measurement
      - Fracture ID
      - Single well test methods





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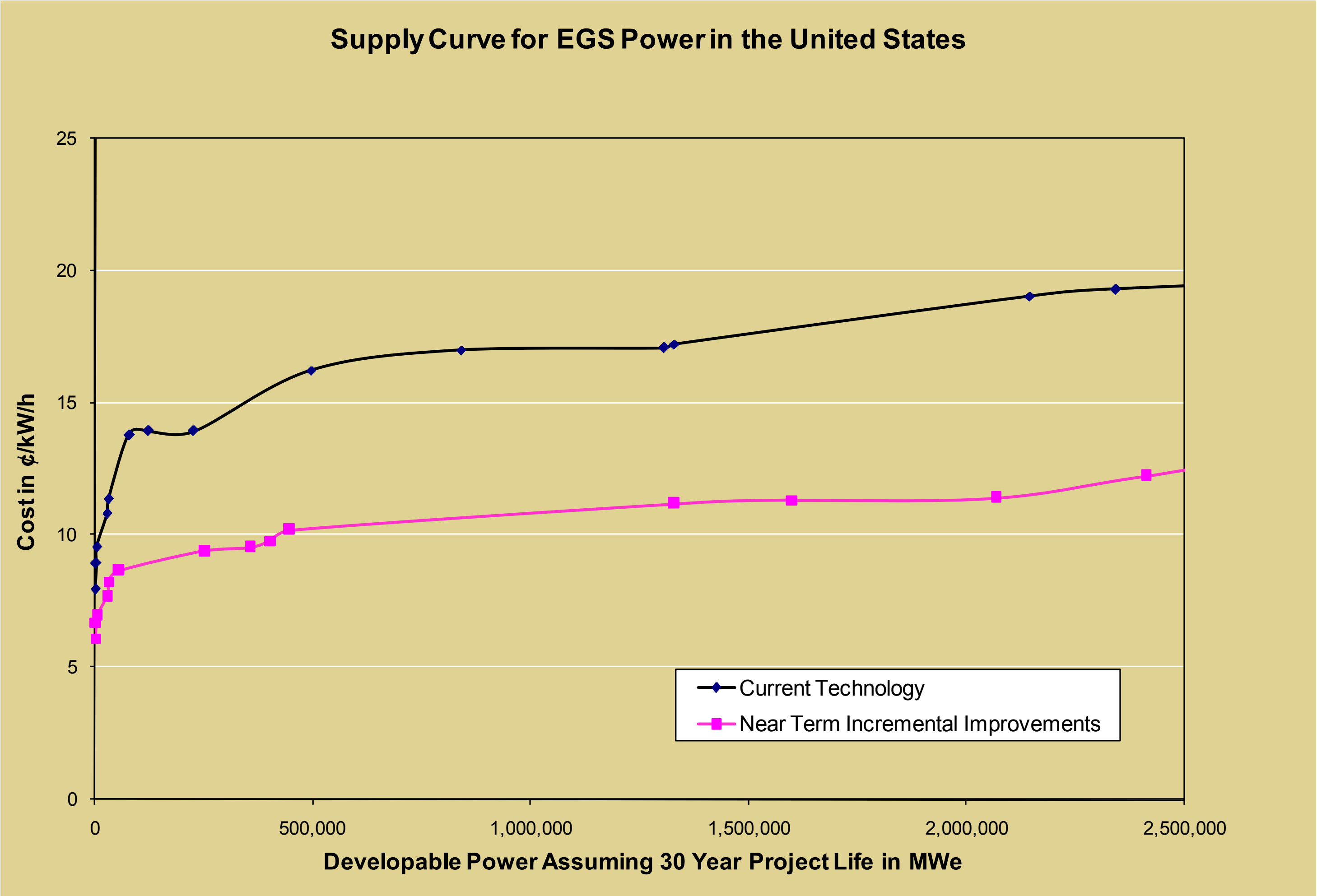
US Available EGS Power at Cost



What Technology Improvements Will Reduce Cost?

- Cost of drilling
  - 20% reduction in cost of drilling
  - Fewer casing strings
  - Better rate of penetration
- Reservoir Stimulation
  - Double the flow per well from 40 l/s to 80 l/s without thermal breakthrough
  - Reduce the stimulation cost by better stimulation design (do it once, do it right)
- Power Plant
  - 20% improvement in conversion efficiency

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What Technology Improvements Will Reduce Risk?

- Exploration/Information gathering-Cost of Risk Reduction
  - 50% reduction in cost of risk
  - Better information
  - Reduces drilling risk and resource risk as well as cost risk on depth to resource
- Reduce Drilling Risk
  - Better information while drilling
  - Improved cementing systems for long strings, high temperatures
  - Improved casing designs
- Reservoir Stimulation
  - Understanding of induced seismicity
  - Improved instrumentation
  - Link between fracturing and stress
- Reservoir Management
  - Reduce risk of scale or short circuit through rock/water, rock/CO_2 interaction