# Engineered Geothermal Systems

Presentation to BC Ministry of Energy, Mines and Petroleum Resources

October 17, 2008

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# What is EGS?

- Enhanced or Engineered Geothermal Systems
- A geothermal resource is usually described in terms of stored thermal energy content of the rock and contained fluids underlying land masses that that are accessible by drilling.
- High-grade hydrothermal resources have high average thermal gradients, high rock permeability and porosity, sufficient fluids in place, and an adequate reservoir recharge of fluids; all EGS resources lack at least one of these.
  - For example, reservoir rock may be hot enough but not produce sufficient fluid for viable heat extraction, either because of low formation permeability/connectivity and insufficient reservoir volume, or the absence of naturally contained fluids.

# A Regime of Gradation

Shallow depths
< 100m

Change in Resource Characteristics

Hydrogeothermal Resources
< 4 km (arbitrary)

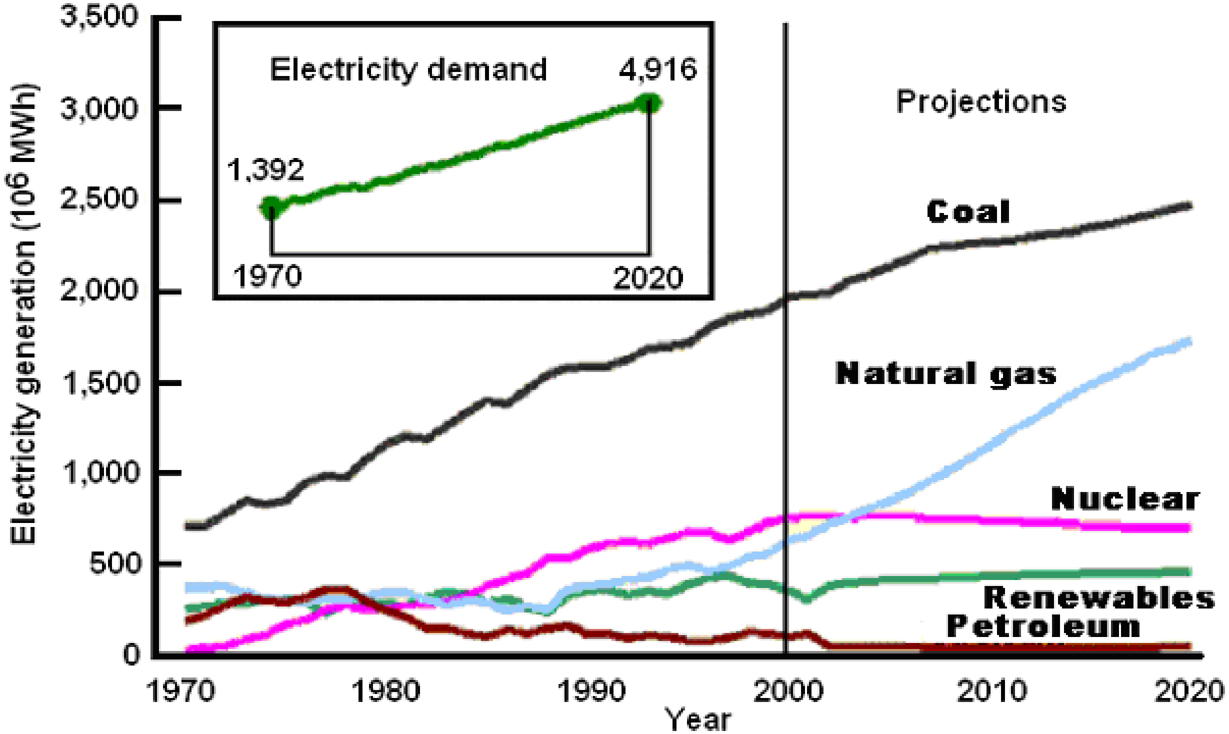
Depth

EGS - Hot Dry Rock
> 200 $^{o}$ C
> 4 km

# Previous Work

- Economic Predictions for Heat Mining: A Review and Analysis of Hot Dry Rock (HDR) Geothermal Energy JW Tester, HJ Herzog - 1990
- Blackwell, D. D. and M. Richards. 2004. *Geothermal Map of North America*
- The Future of Geothermal Power, MIT 2006
- Unpublished work from NRCan
- Majorwicz and Moore, Alberta Survey

# The EGS Driver:Projected growth in US electricity demand and supply



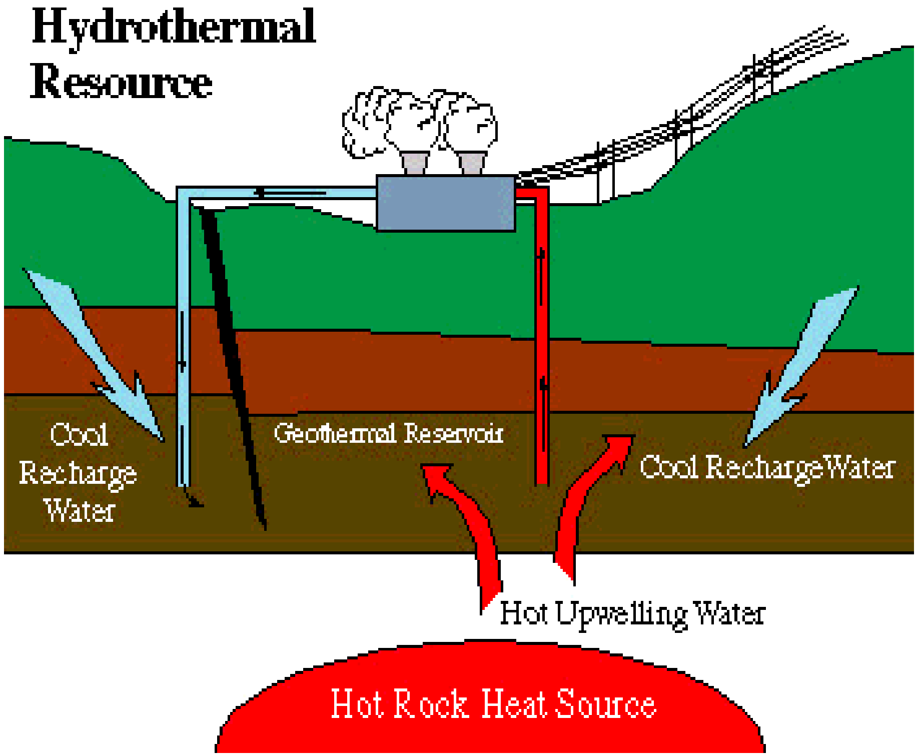

US electricity generation by energy source 1970-2020 in millions of MWe-hr.

Source: EIA (2005)

**Current US generating capacity is now about 1,000,000 MWe or 1 TWe**

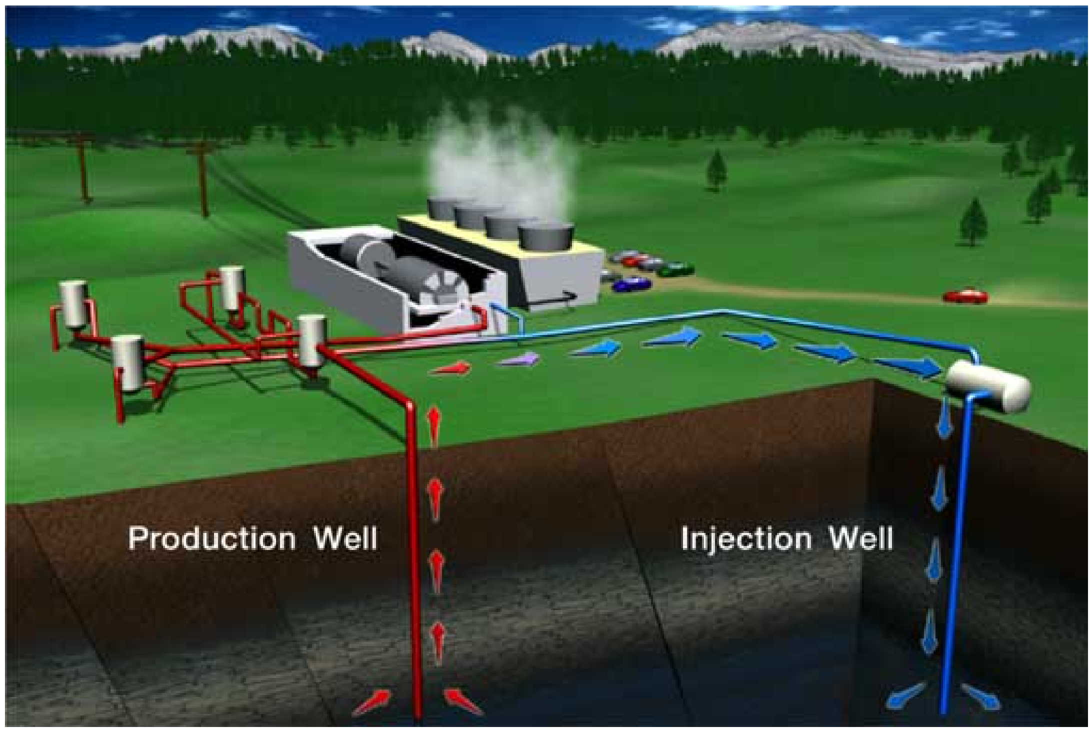
# Geothermal Energy

1.3 GW capacity in 1985

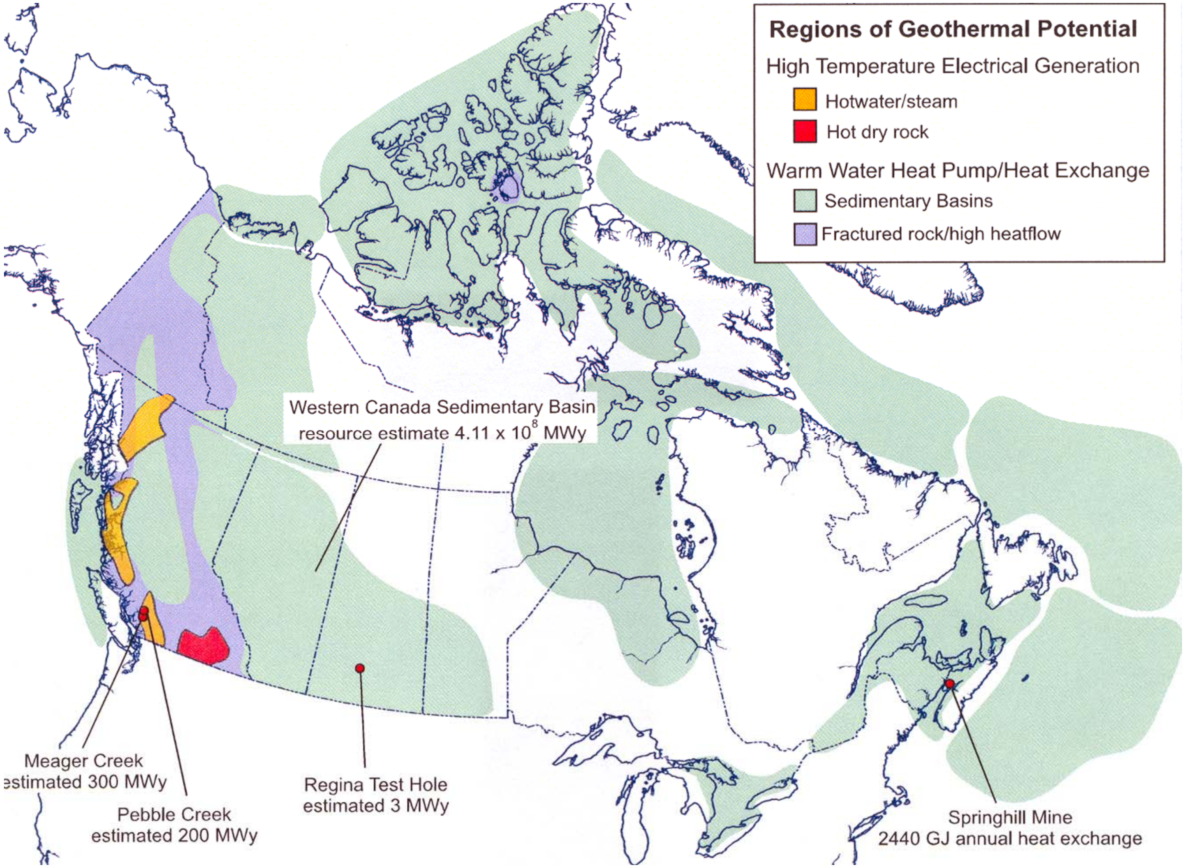



Hydrothermal systems
Hot dry rock (igneous systems)
Normal geothermal heat (200 C at 10 km depth)

# Schematic

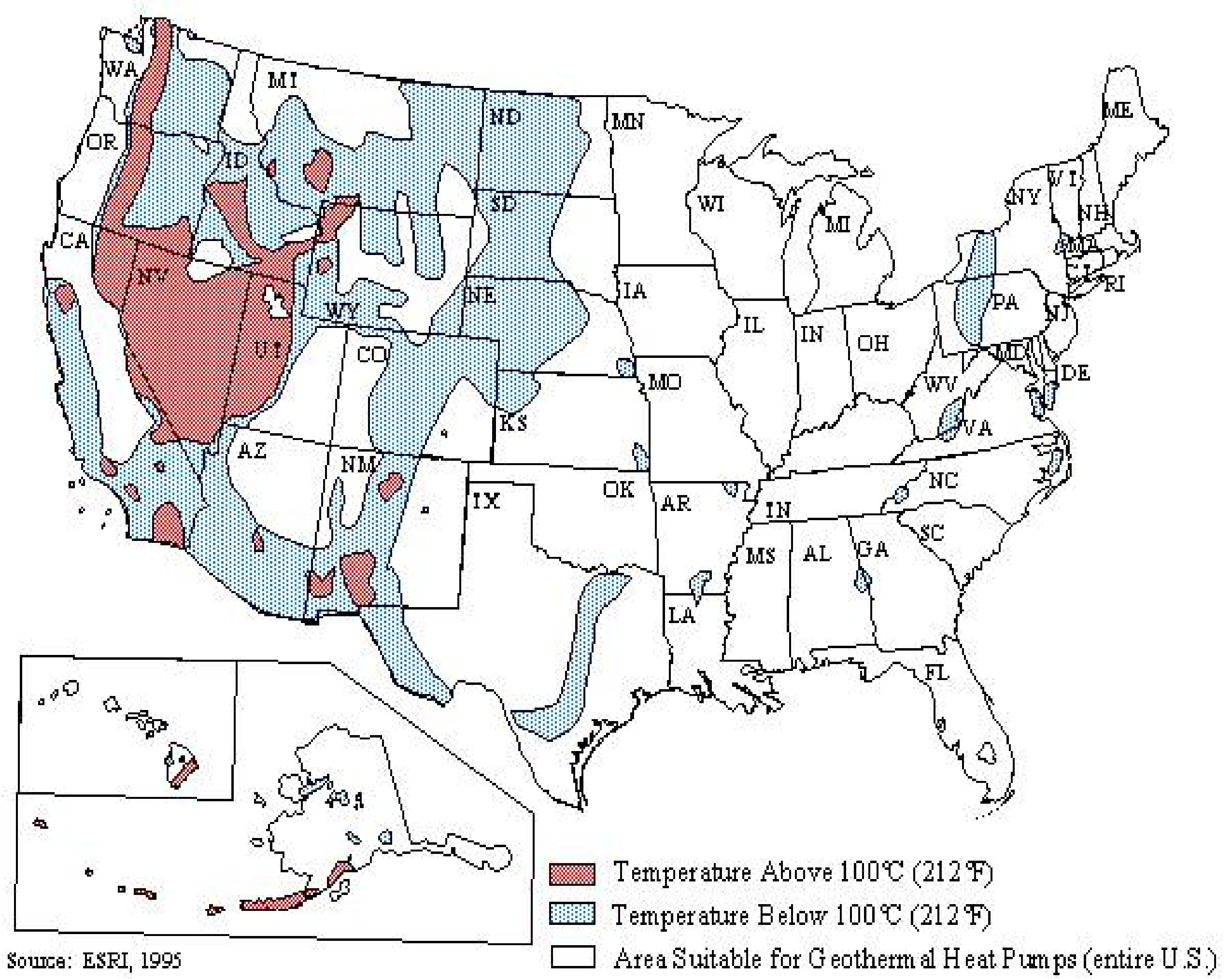


# Canadian Resources




Source: CGS

# US Geothermal Energy Potential



# Geothermal Energy Potential

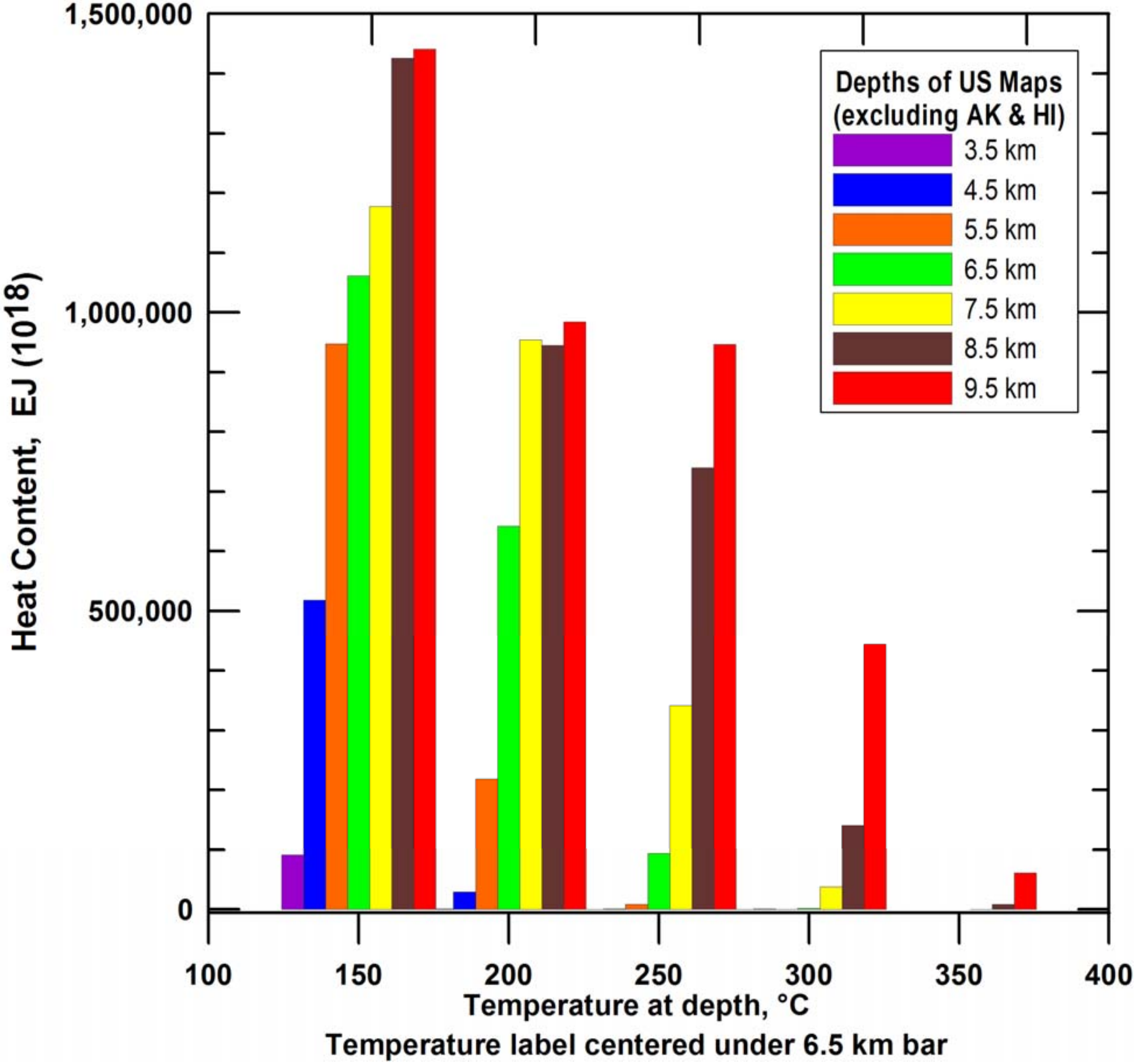
- Mean terrestrial geothermal flux at earth's surface 0.057 W/m$^2$
- Total continental geothermal energy potential 11.6 TW
- Oceanic geothermal energy potential 30 TW

- Wells "run out of steam" in 5 years
- Power from a good geothermal well (pair) 5 MW
- Power from typical Saudi oil well 500 MW
- Needs drilling technology breakthrough

(from exponential $/m to linear $/m) to become economical)

# Histograms of heat content in EJ

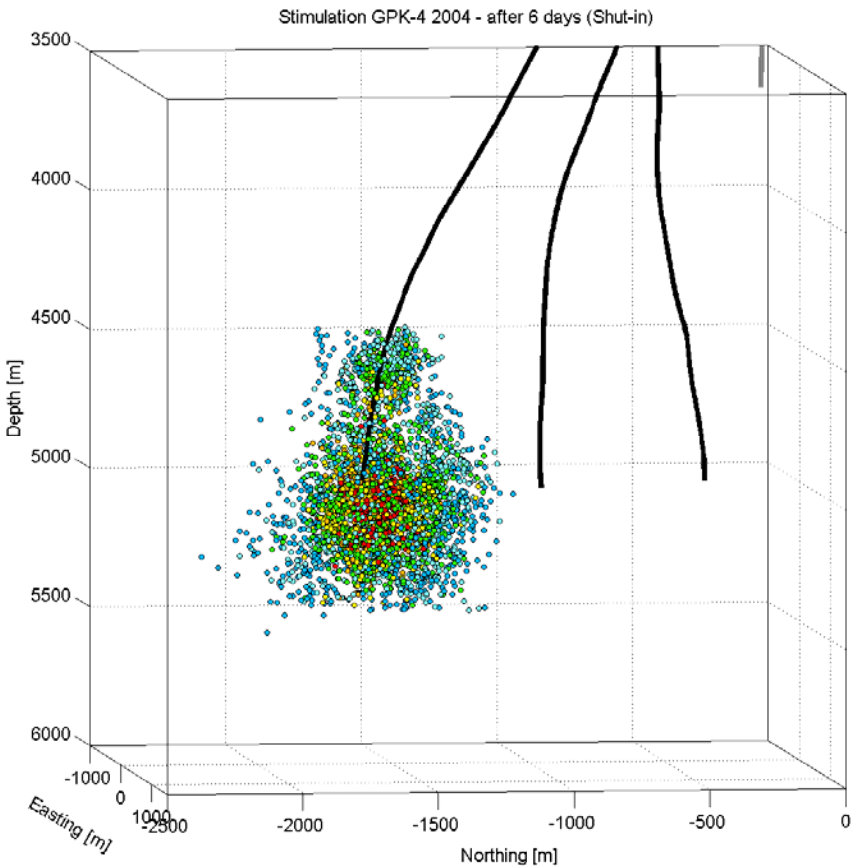
(as a function of depth for 1 km slices)



# Developing stimulation methods to create a well-connected reservoir

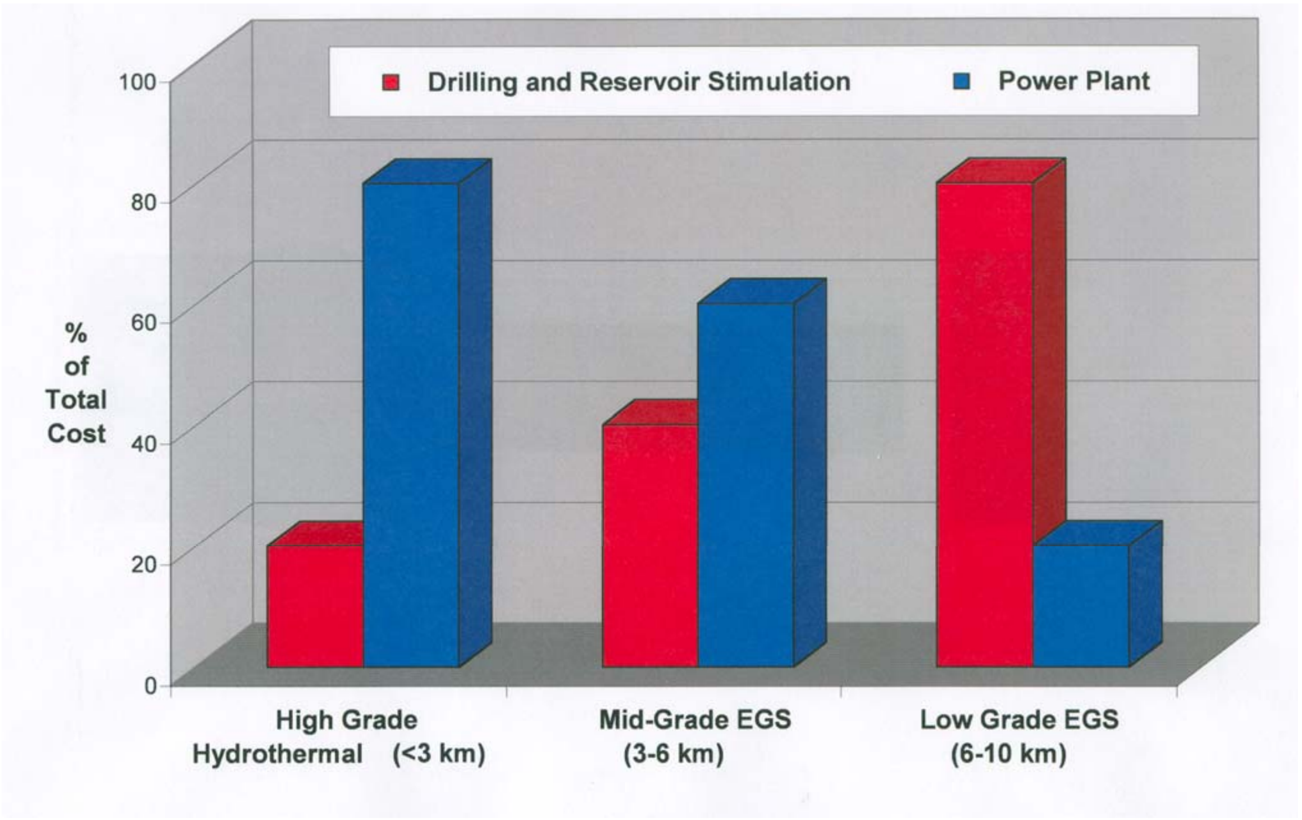
**The critical challenge technically is how to engineer the system to emulate the productivity of a good hydrothermal reservoir**

**Connectivity is achieved between injection and production wells by hydraulic pressurization and fracturing**




"snap shot" of microseismic events during hydraulic fracturing at Soultz Source: Roy Baria

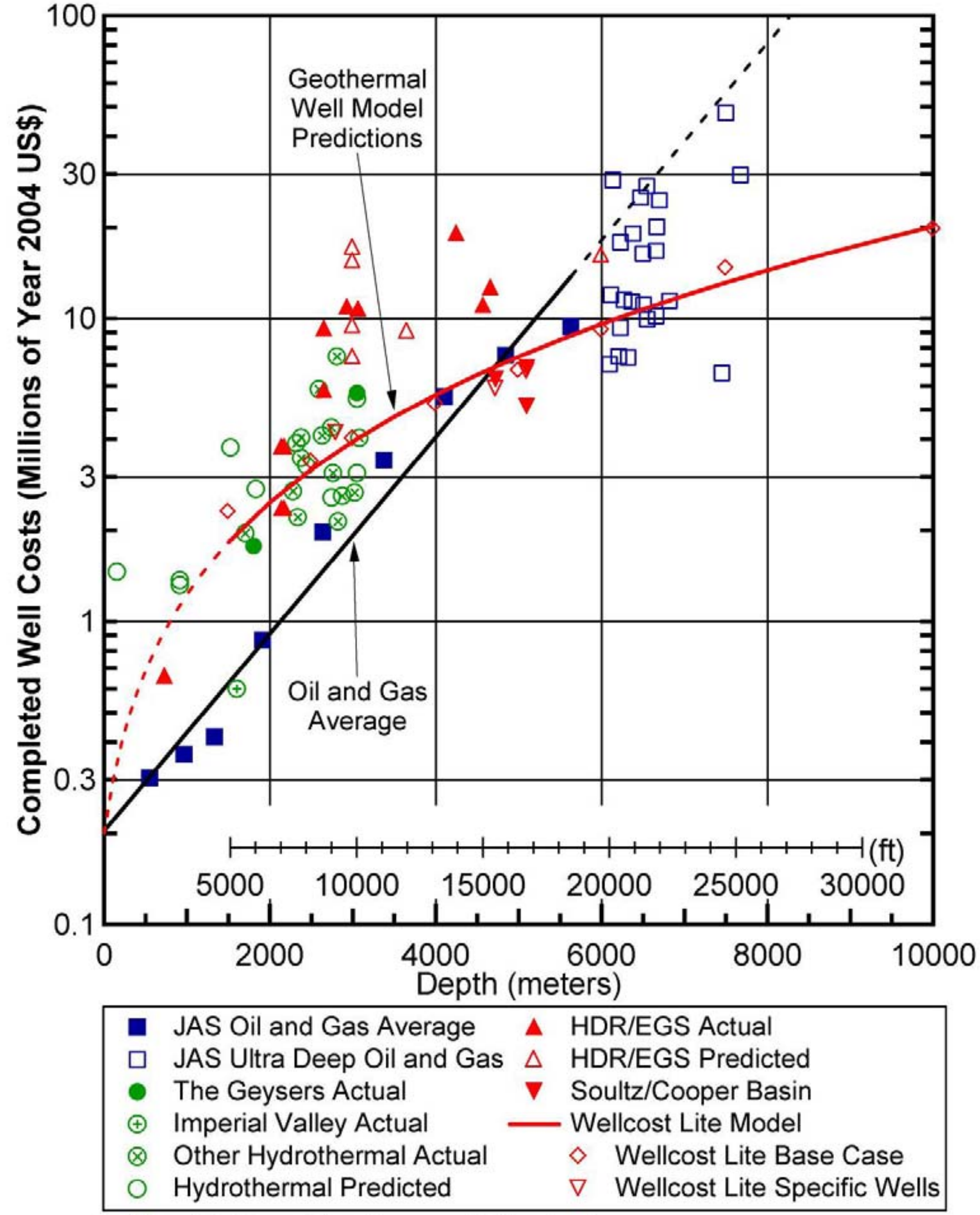
# As EGS resource quality decreases, drilling and stimulation costs dominate



# EGS Drilling

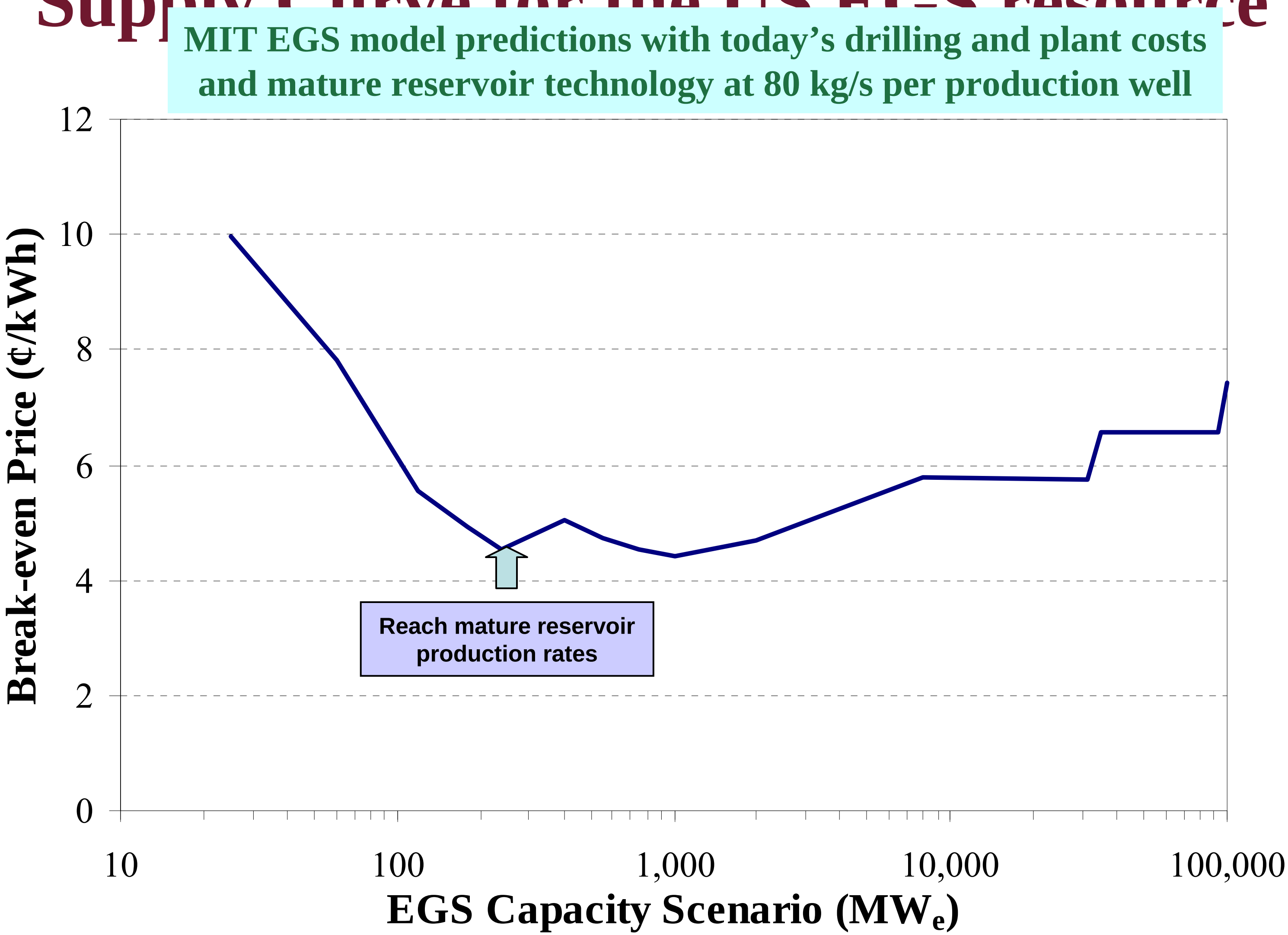
- critical cost component, particularly for low-grade EGS requiring deep wells
- no drilling experience beyond 6 km depths
- Wellcost Lite model was validated to 6 km and used to predict EGS well costs for base case conditions up to 10 km
- multilateral completions and advanced casing designs considered
- actual drilling costs for geothermal and oil and gas wells were normalized to 2004 $ and compared
- sensitivity analysis was used to show relative importance of drilling on LEC
- evolutionary progress of technology and learning play critical and interactive roles in reducing costs

**EGS well costs vary less strongly with depth than oil and gas wells.**




1. JAS = *Joint Association Survey on Drilling Costs.*
2. Well costs updated to US$ (yr. 2004) using index made from 3-year moving average for each depth interval listed in JAS (1976-2004) for onshore, completed US oil and gas wells. A 17% inflation rate was assumed for years pre-1976.
3. Ultra deep well data points for depths greater than 6 km are either individual wells or averages from a small number of wells listed in JAS (1994-2000).
4. "Other Hydrothermal Actual" data include some non-US wells (Mansure 2004).

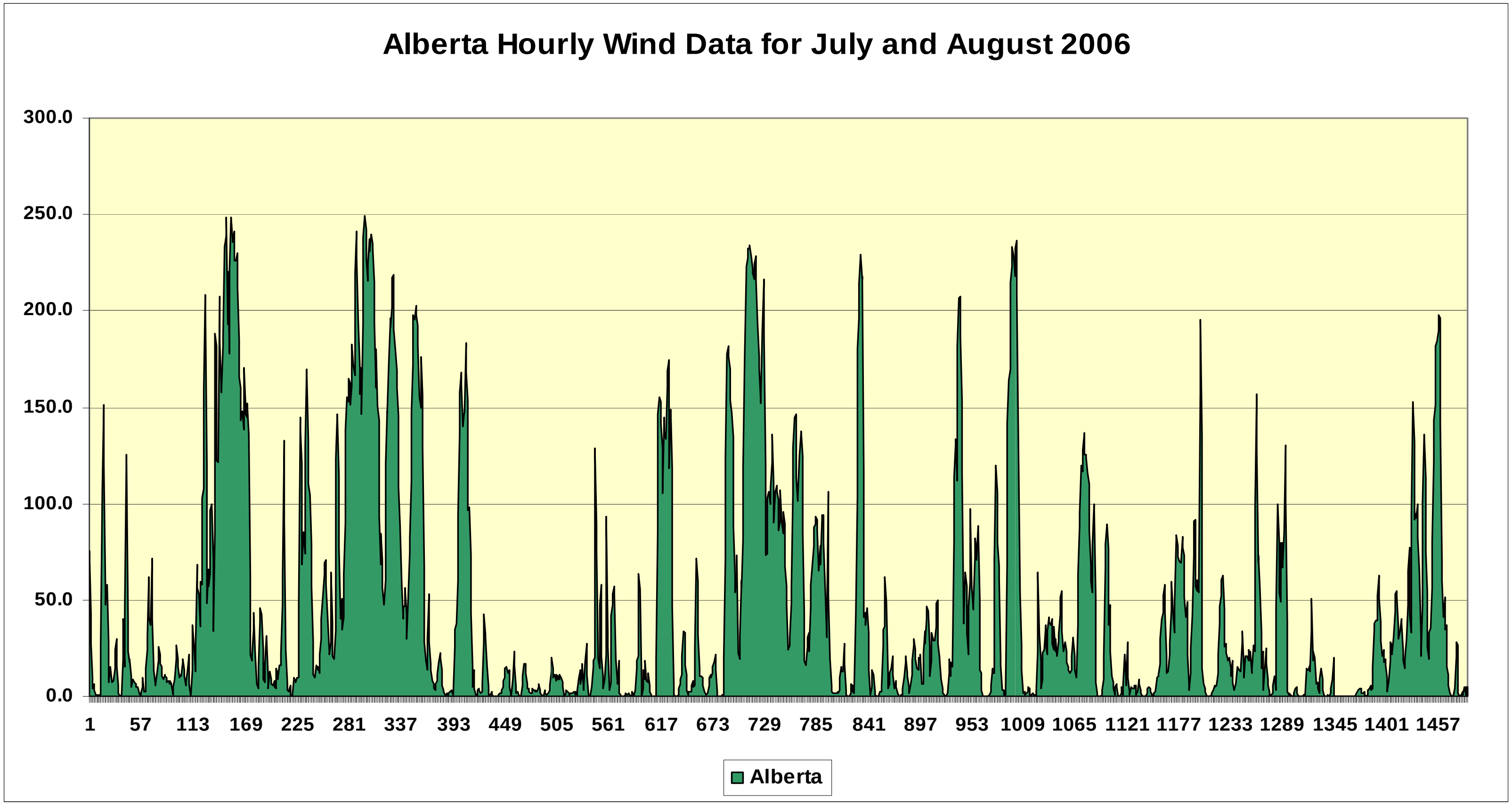
# Supply Curve for the US EGS resource



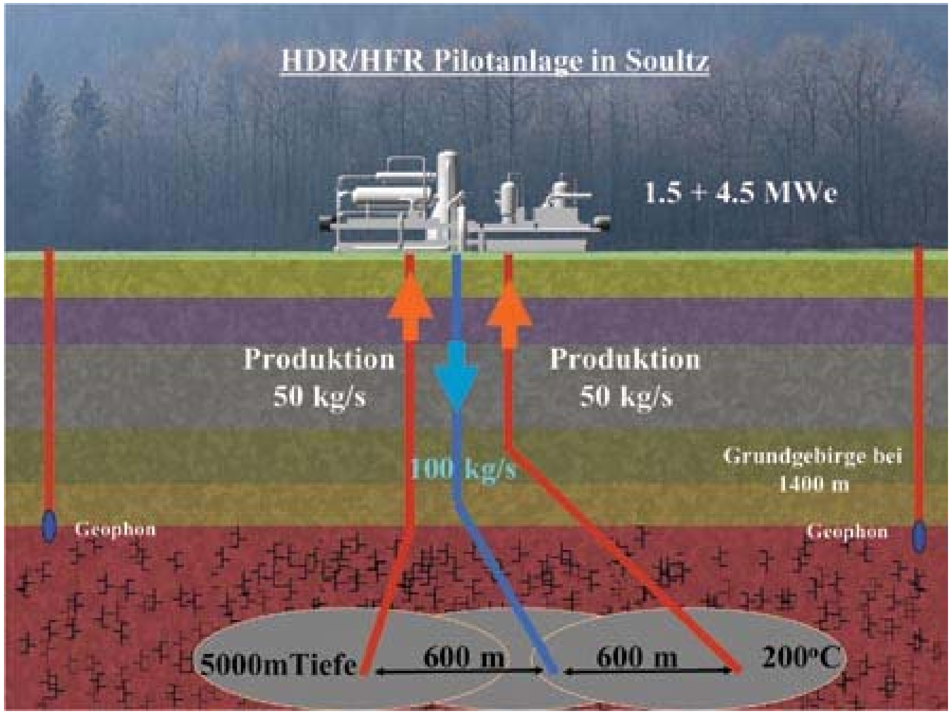
# Key Outcomes of Economic Analysis

- **EGS is a natural but not inevitable extension of hydrothermal technologies**
- **Well configuration and stimulation techniques affect reservoir productivity and lifespan**
- **Highest correlation for costs is effectiveness of stimulation to achieve acceptable reservoir productivity**
- **High sensitivity to early R&D investment**
- **Invested costs are reasonable compared to other alternative energy programs and can yield competitive baseload contribution in under 15 years**
- **Pursuing EGS aggressively does not diminish but extends the role of hydrothermal**

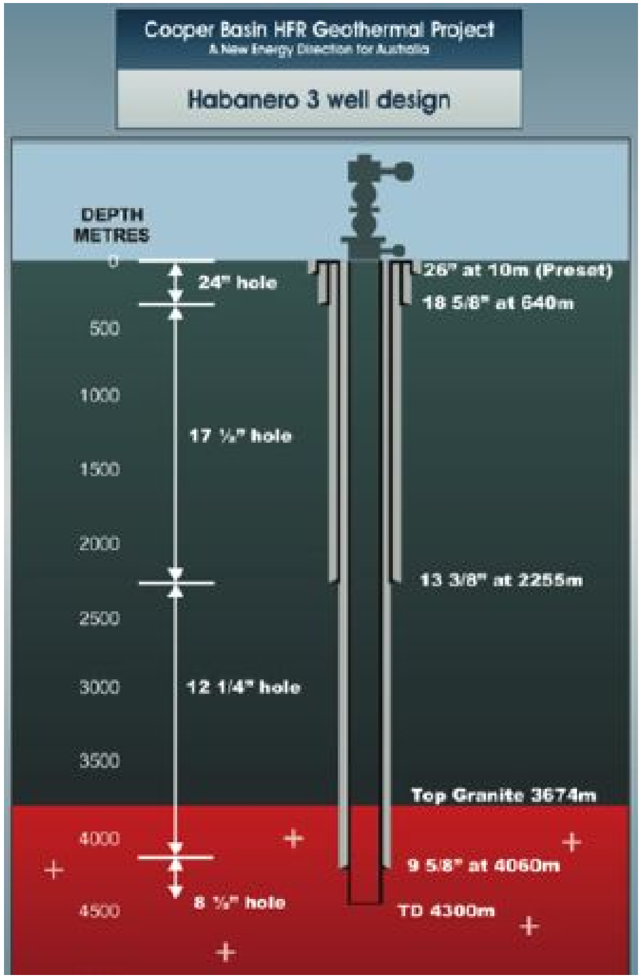
Total Alberta wind output for this period was unusually volatile with a capacity factor of 19.4%  The 2005 full year value was 34.6%



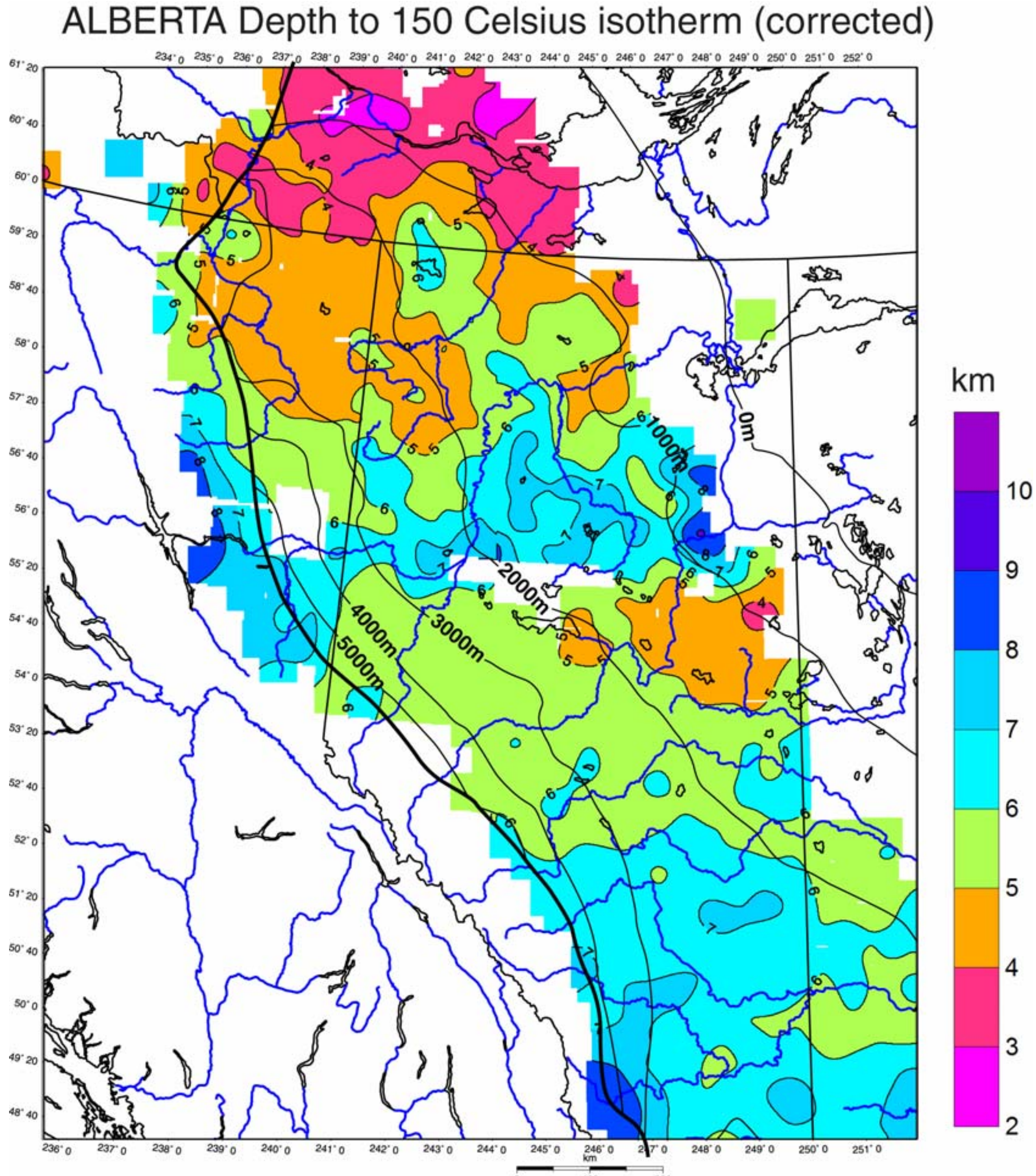
# Soultz, France



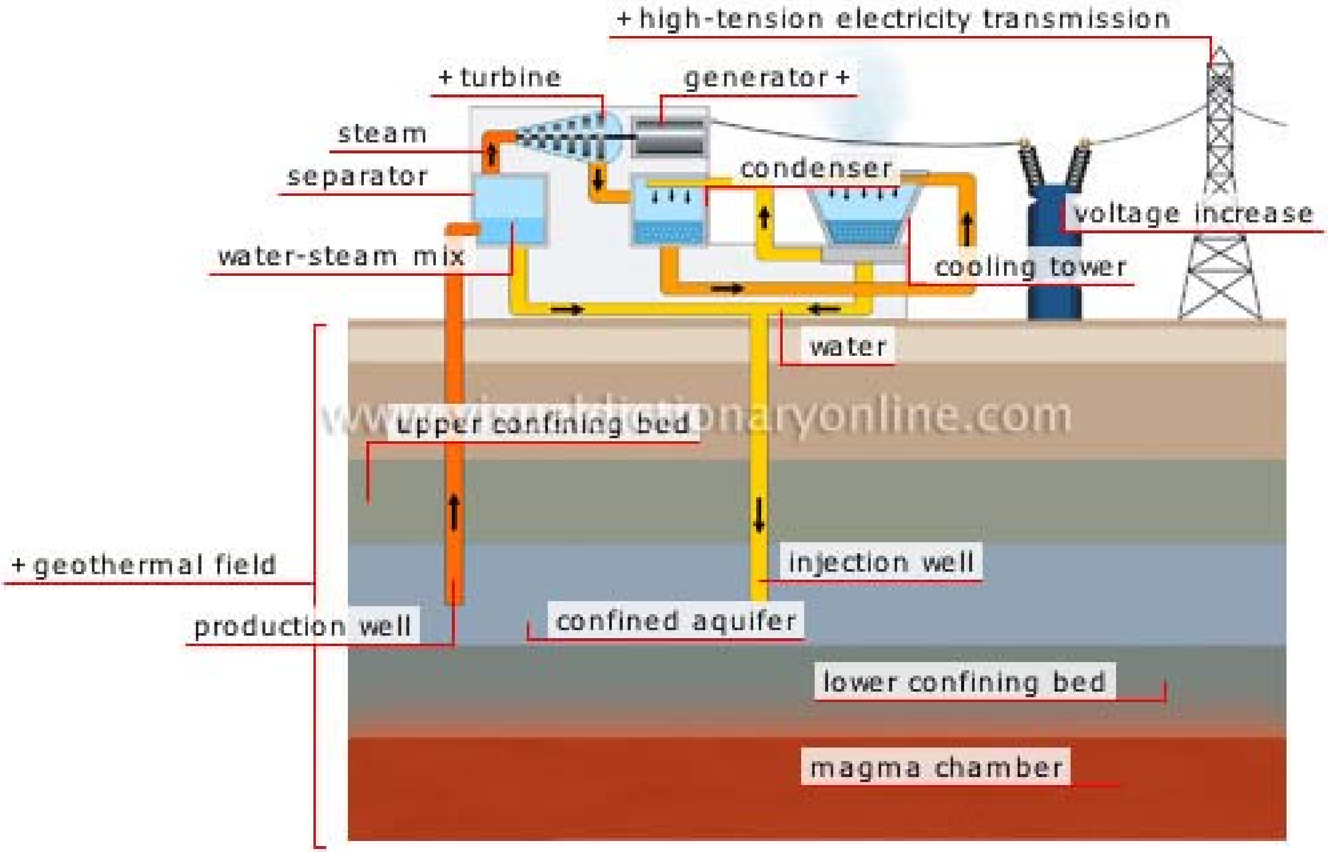
# Cooper Basin



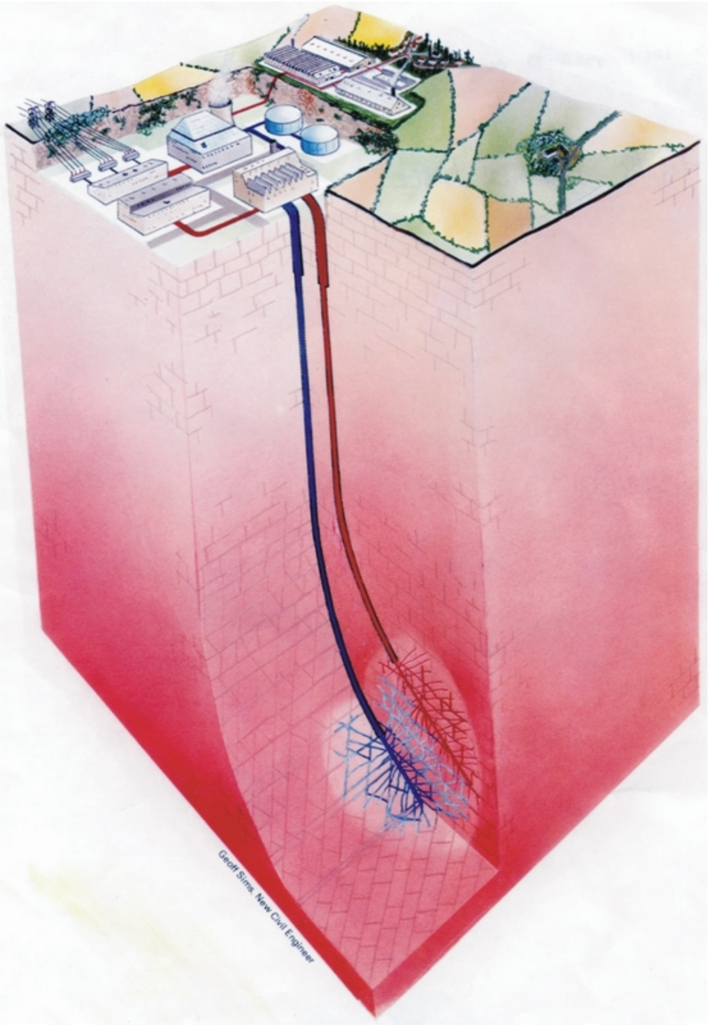

# Alberta


ALBERTA Depth to 150 Celsius isotherm (corrected)
km
10
9
8
7
6
5
4
3
2
0m
1000m
2000m
3000m
4000m
5000m
km
0
100
200

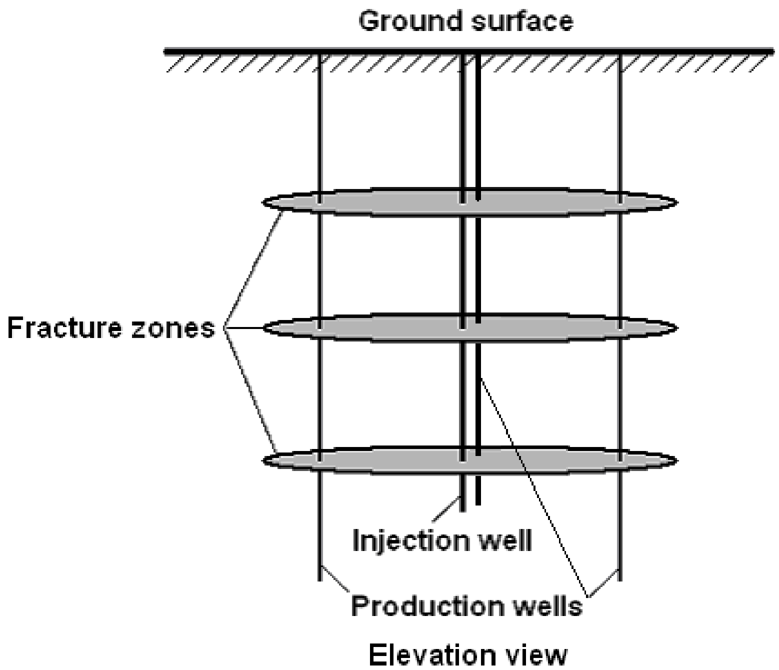
# In the Electric Grid

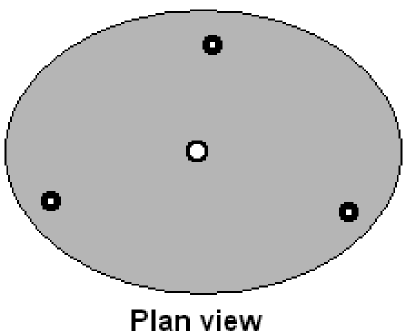


# Well co-location

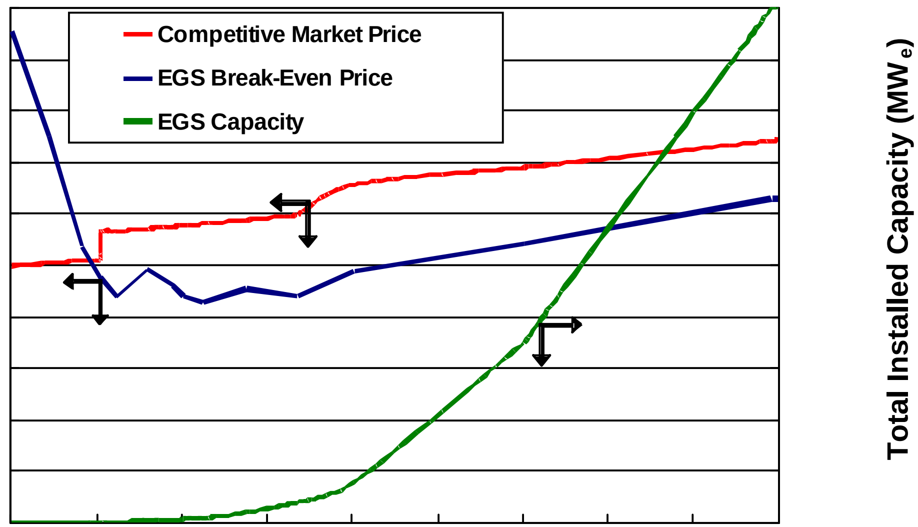


# Flow and Fractures

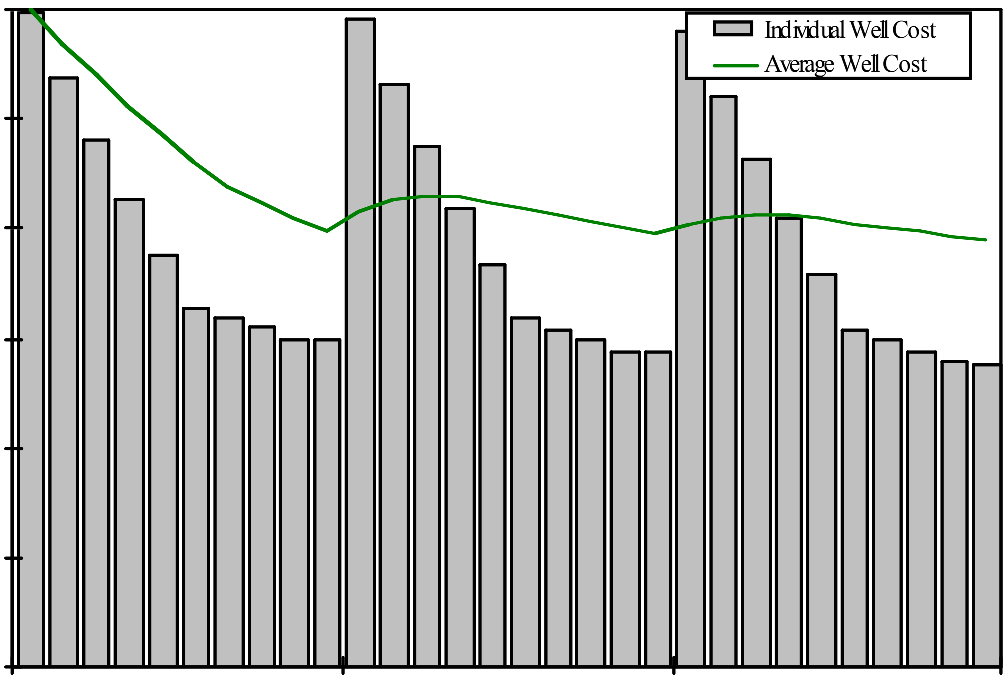


# Price and Learning Curves



# Well Drilling & Learning Curves



# Base case parameters for EGS economic modeling

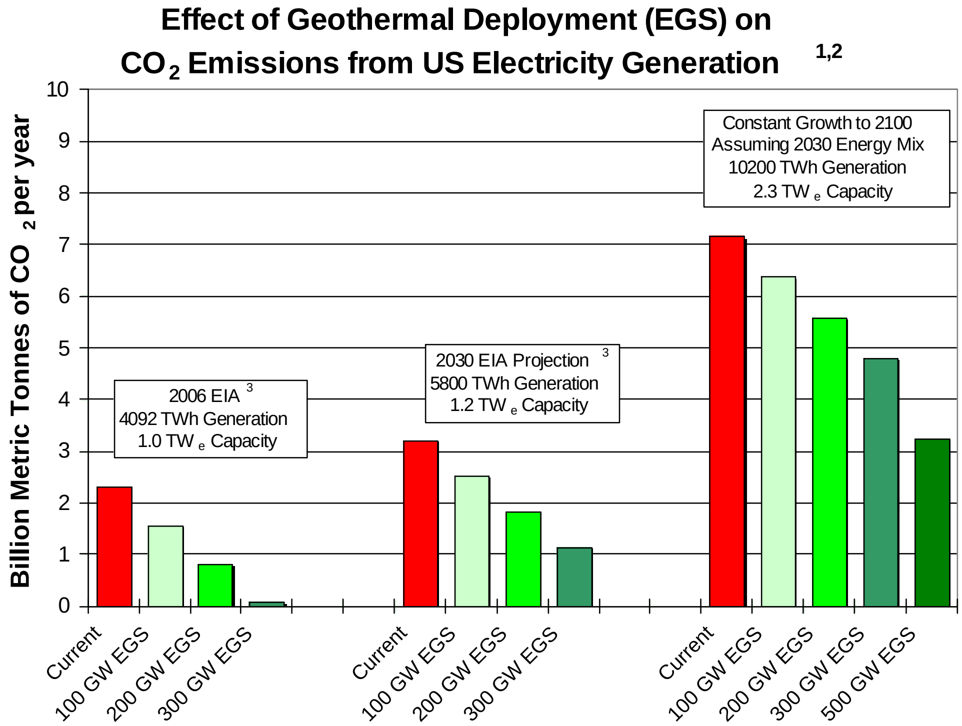
**Major Impact with higher uncertainty and risk --**

- Flow rate per production well (20 to 80 kg/s )
- Thermal drawdown rate / redrilling-rework periods (3% per year / 5-10 years)
- Resource grade – defined by temperature or gradient = f(depth, location)
- Financial parameters
  - Debt/Equity Ratio (variable depends on EGS resource grade)
  - Debt rate of return (5.5 -8.0%)
  - Equity rate of return (17%)
- Drilling costs from model predictions using a 20% contingency factor

**Lesser impact but still important --**

- Surface plant capital costs
- Exploration effectiveness and costs
- Well field configuration
- Flow impedance
- Stimulation costs
- Water losses
- Taxes and other policy treatments

# De-carbonizing Benefits




Notes: 1. 95% capacity factor assumed for EGS
2. Assumes EGS offsets CO2 emissions from Coal and Natural Gas plants only
3. EIA Annual Energy Outlook 2007

# Issues and Limits

- Location
- Mapping
- Drilling cost
- Fracturing Costs
- Transmission Access
- Demonstration projects

# Issues for Future Grid Support

- The NA energy supply system is threatened in the long term by potential supply shortages that will appear in the next 15 to 25 years
  - In that period, 40 GWe of "old" coal-fired capacity will probably need to be retired or updated as a result of failure to meet new emissions standards
  - > 40 GWe of existing nuclear energy will be beyond even generous relicensing procedures
- Projected availability and desirable use of NG may limit generation capacity expansion from this source
- Nuclear power expansion, and even replacement may be problematic in the near term
- Infrastructure improvements needed for interruptible renewable energy resources including storage, inter-connection and new T & D facilities are formidable

# Environmental Attributes and Constraints

- Water use – will require effective control and management, especially in arid regions
- Land use – small "footprint" compared to alternatives
- Induced seismicity must be monitored and managed
- Low emissions, carbon-free base load energy
- No storage or backup generation needed
- Adaptable for district heating and co-gen / CHP applications

# Conclusions

- Shortfalls in base load supplies make alternatives such as EGS attractive
- With caveats for depth limitations, this is a ubiquitous self-sustaining resource
- Refinements in drilling techniques support a wide range of uses
  - Heat products
  - Waste disposal
  - $CO_2$ sequestration
- Ability to dispatch increases the value of the balance of energy portfolio
- Improvements in drilling and fracturing make this tool feasible and cost effective in a reasonable time frame
- Mapping and assessing the resource is the next logical step in planning for a balanced portfolio

# So What?

- Time is of the essence
- Capital is expensive, lead times are long, retirements are imminent
- Fossil energy expansion is problematic, although inevitable
- Base load resources can be supplanted and shifted
- We can firm by changing our paradygm

# Approach to Research

- Estimate the EGS resource within Geothermal continuum
- Determine and estimate the potential costs of technology applications - drilling, reservoir and conversion
- Investigate the environmental attributes and constraints
- Model costs and project potential returns

Thank you and please read our report at
htpp://geothermal.inel.gov

**The Blue Lagoon in Iceland**