Geothermal Energy – Today and Tomorrow

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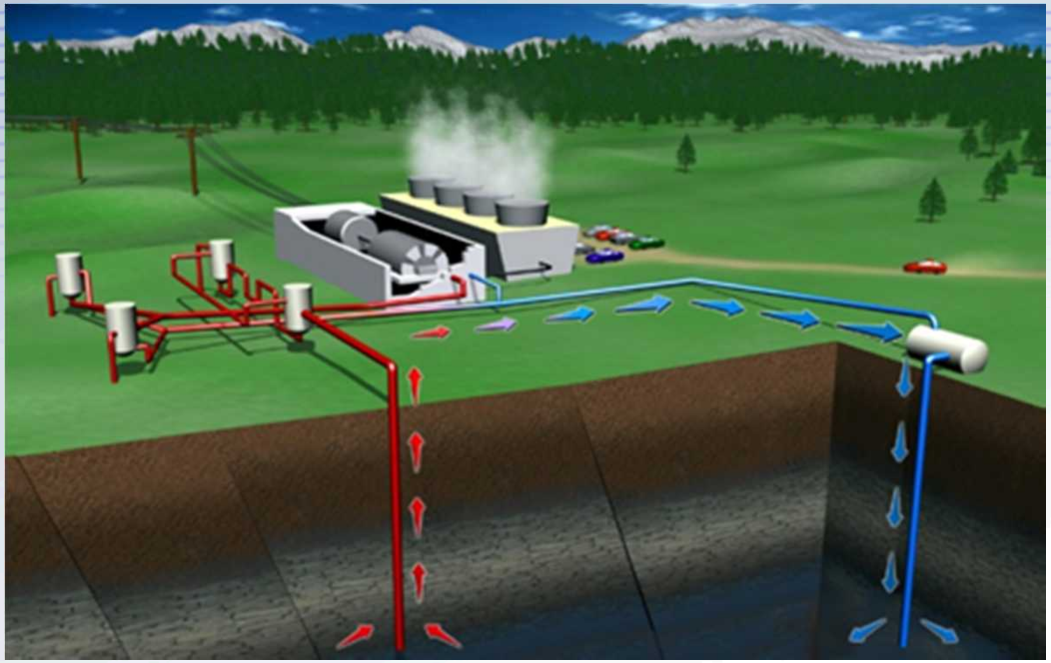
Geothermal Energy

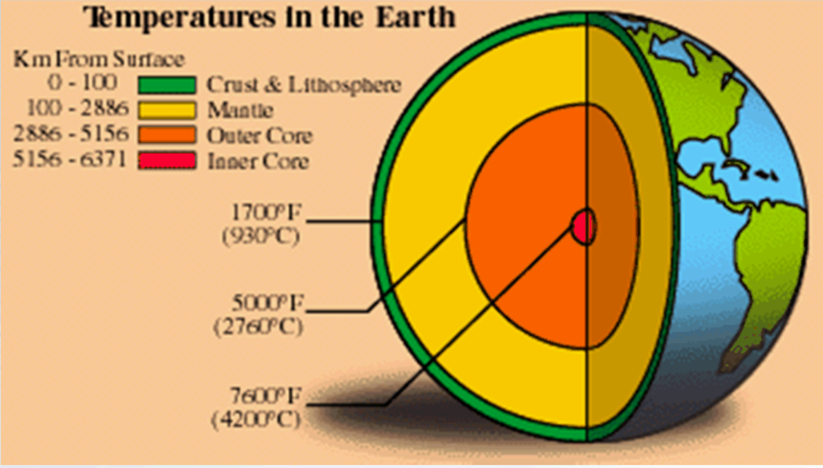


Courtesy: Geothermal Education Office

Using the Earth's heat for electricity production, direct use applications, and as a heat exchange medium for geothermal heat pumps

Exploiting geothermal energy is simple in principle, but the reality is different

- **The heat resource is ubiquitous but the exploitable reserves depend on many interrelated and complex factors**
  - Depth, temperature, geology, stress, mechanical properties, local structure, chemistry, fluids, permeability, ….

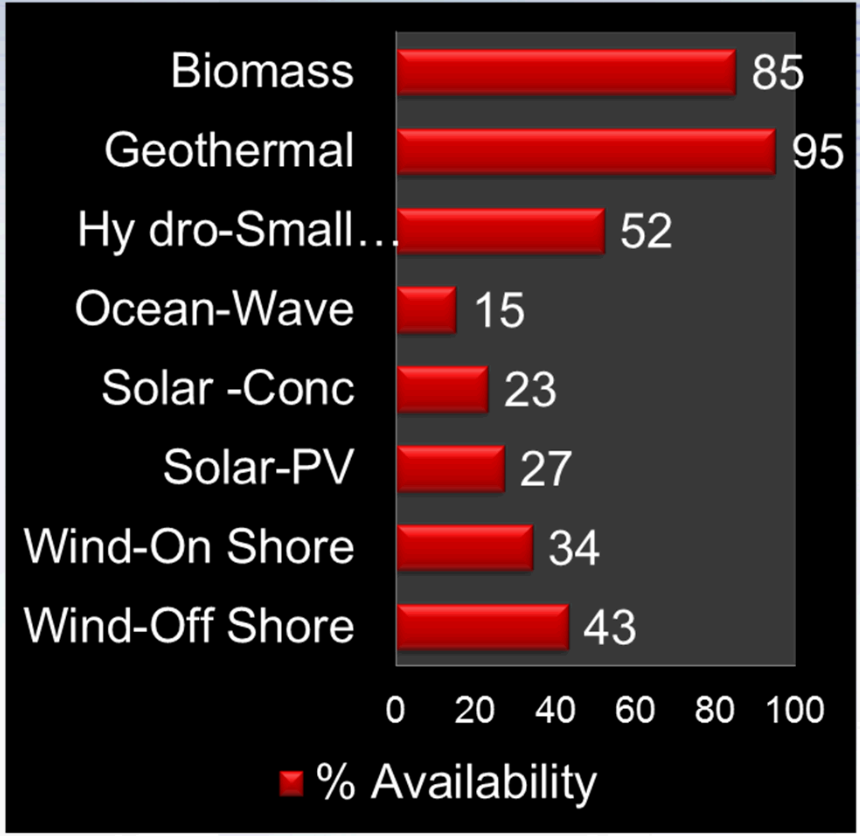


Courtesy: Geothermal Education Office

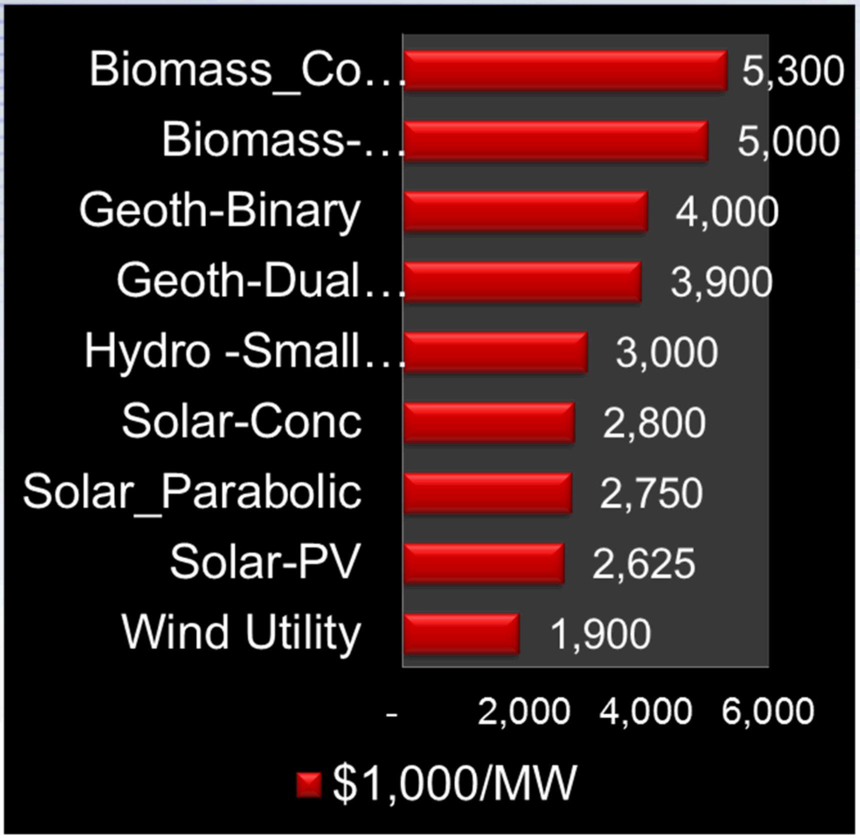
- **Resource is largely hidden**
  - Resource definition and viability depend on factors that are not easily measured and not completely understood
- **In situ conditions are not well constrained and evolve over time**
  - For example, as the resource is exploited stress states evolve which can effect fluid flow, which can affect geochemical interactions
- **Understanding interdependencies of critical parameters is vital to moving geothermal out of its niche status**

Selected Renewable Energy Technologies

Capacity Factors



Investment Cost



Courtesy of Kermit Witherbee, NREL

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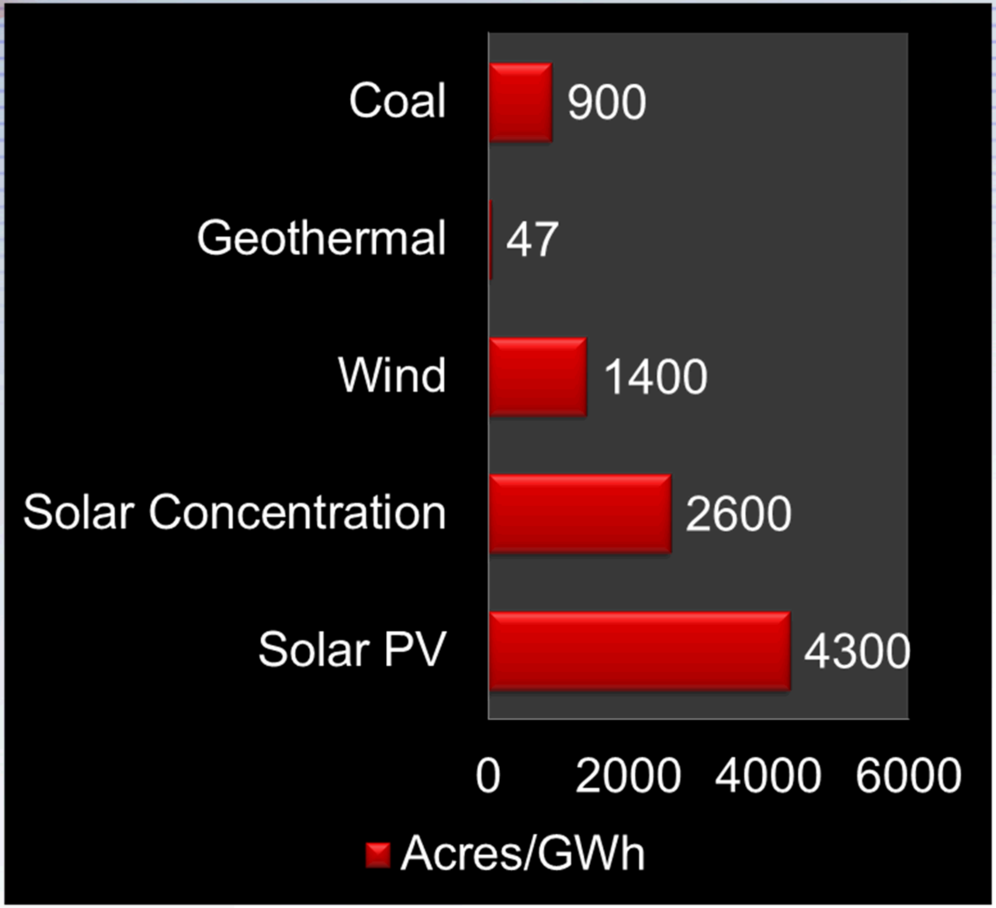
Land Use by Energy Technology



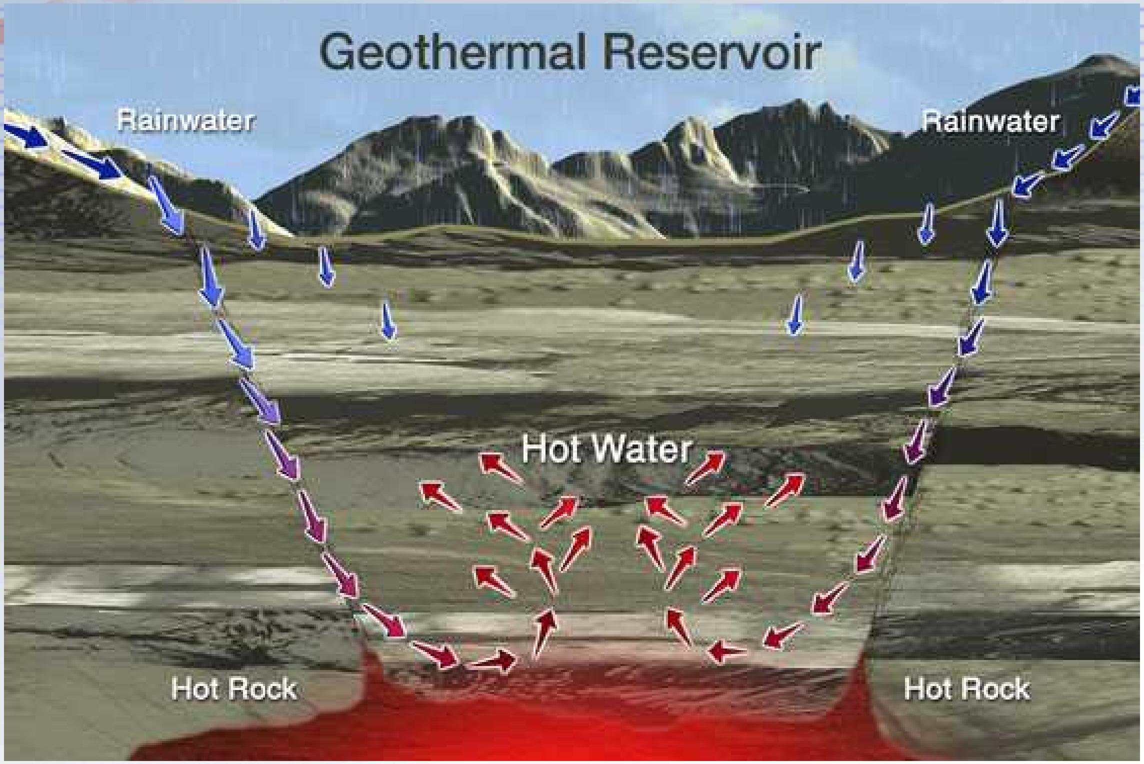
Courtesy of Kermit Witherbee, NREL

Geothermal Reservoir Requirements

- **Temperatures**
  - Greater than 350 C to "warm"
    - Temperatures largely dictate use
      - Power generation to direct use
- **Permeability**
  - Measure of fluid transmission ability of the rock
    - Orders of magnitude variability
      - Tight to open
- **Fluid Availability**

Hydrothermal (current) → Enhanced Geothermal Systems (future)

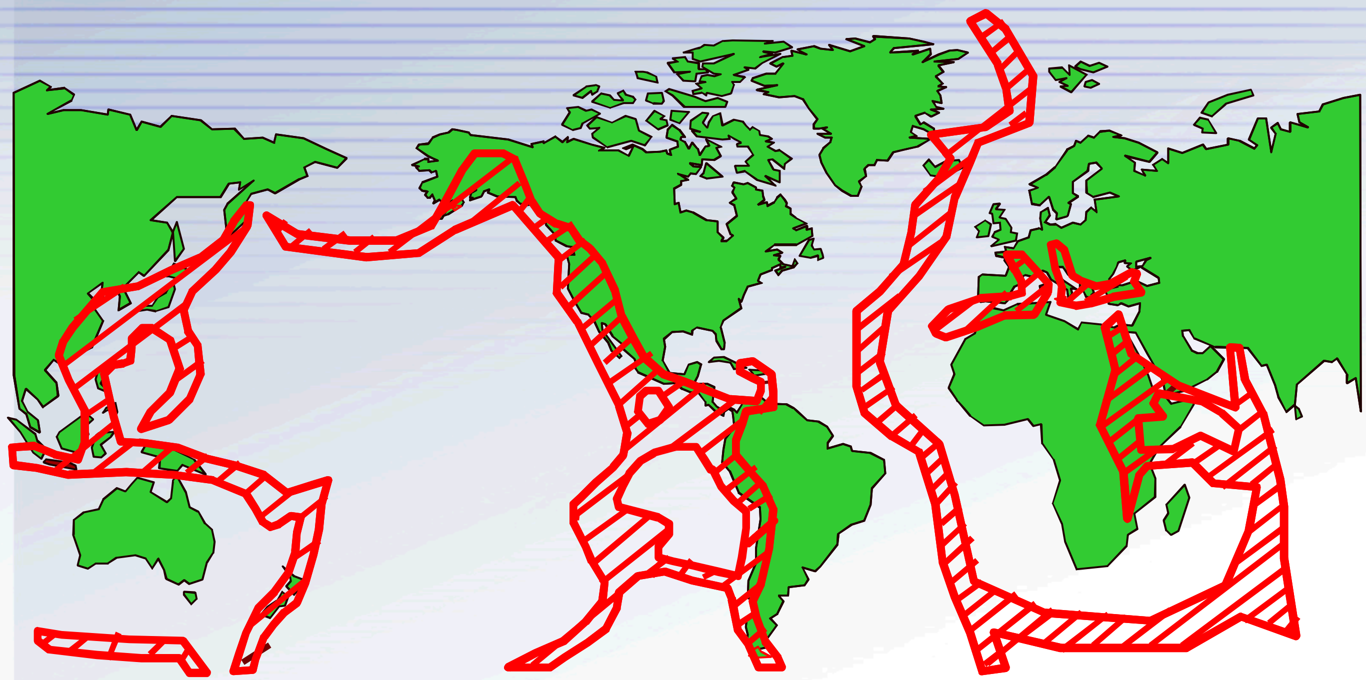
TODAY - Hydrothermal Geothermal Systems



Courtesy: Geothermal Education Office

Hydrothermal Geothermal resources are found where geological activity has brought hot rock near the surface. When hot water and steam is trapped under a layer of low permeability rock, it forms a geothermal reservoir.

World Hydrothermal Resources



Courtesy: Geothermal Education Office

Hydrothermal resources generally found along the plate boundaries.

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Can We Move Beyond "Mining" Hot Water to Mining The Heat?

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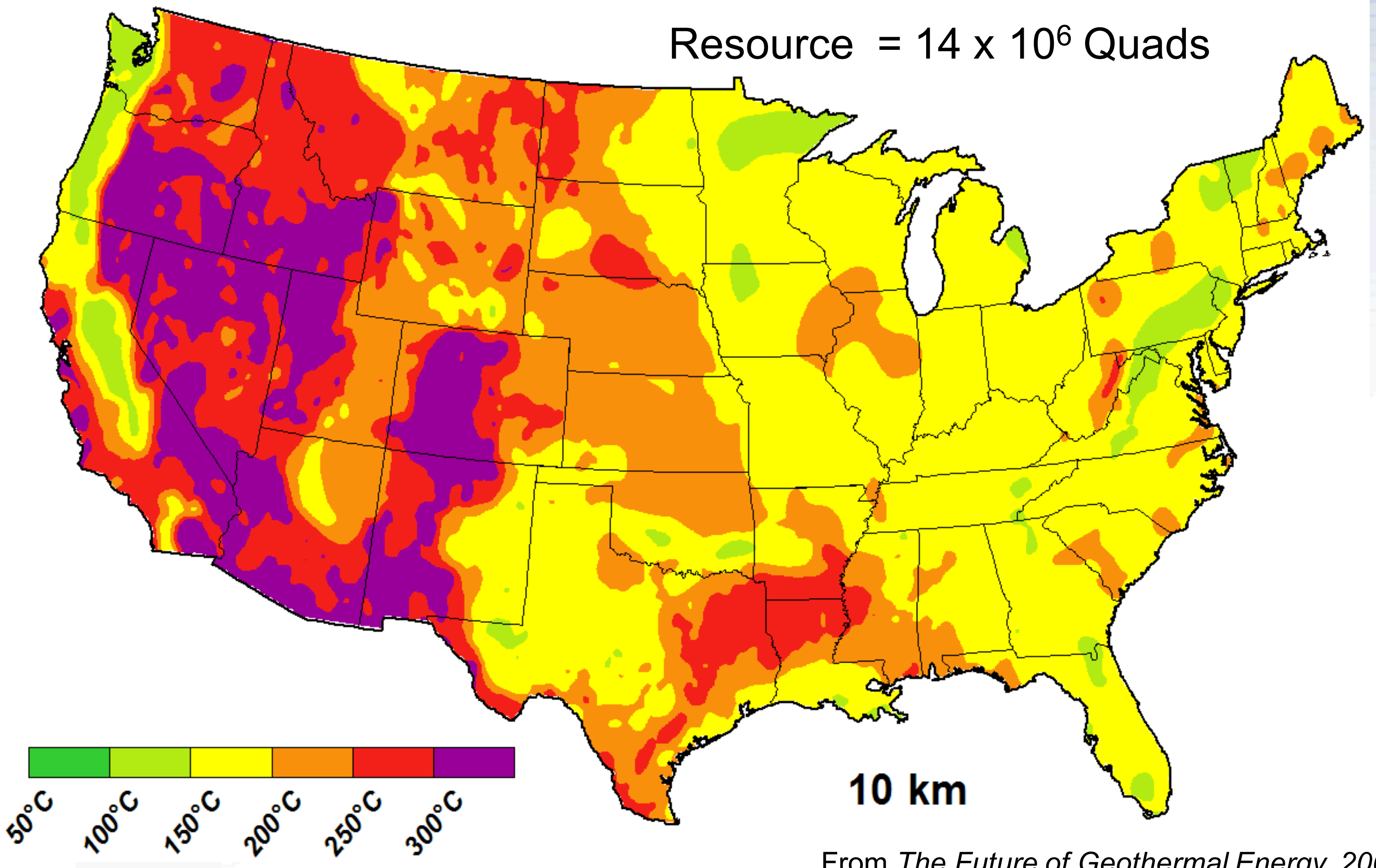
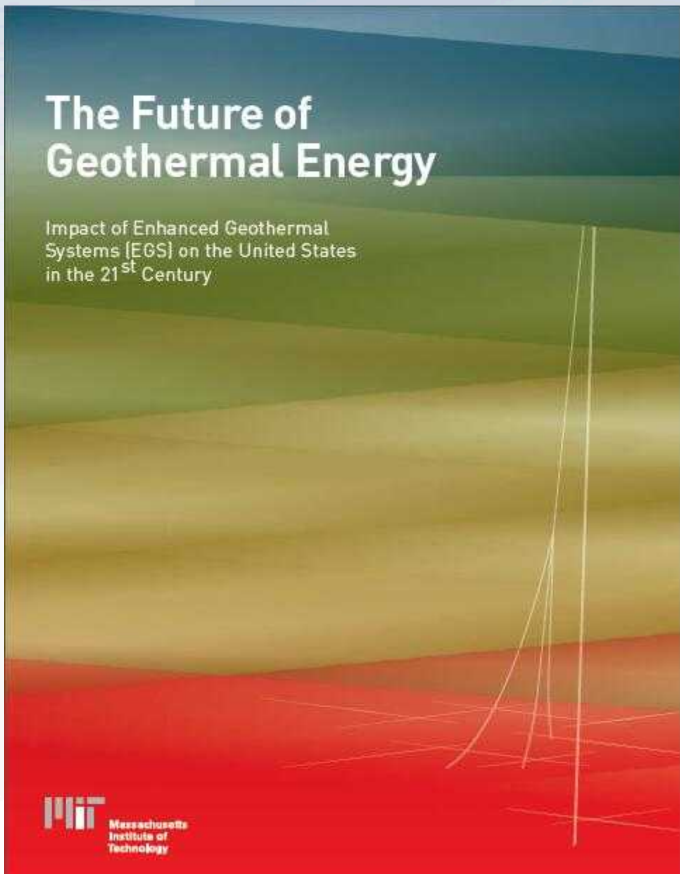
Geothermal Heat Resource in the United States



From *The Future of Geothermal Energy, 2006*

Engineered/Enhanced Geothermal Systems are the Future

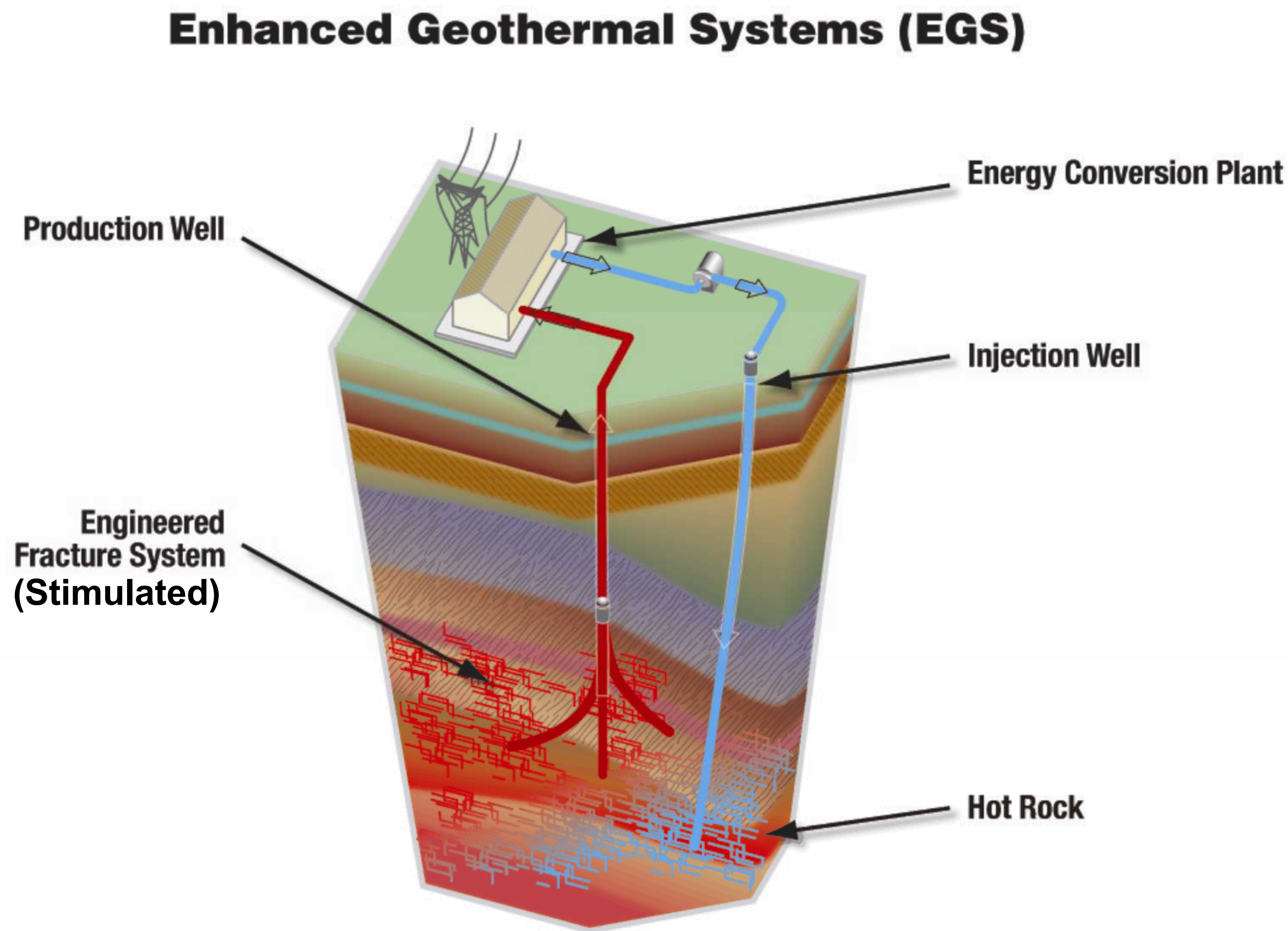
Study of Enhanced Geothermal Systems (EGS) by MIT-Led Panel of Experts



Key Findings/Recommendations

- Extractable geothermal resource exceeds 2000 times the annual energy consumption of the United States
- EGS are versatile, modular, and scalable from 1 to 50 MWe unit sizes
- Technical issues are surmountable – no showstoppers
- Cumulative EGS capacity of 100,000 MWe can be achieved in the United States within 50 years

EGS System Components



Mining the Heat

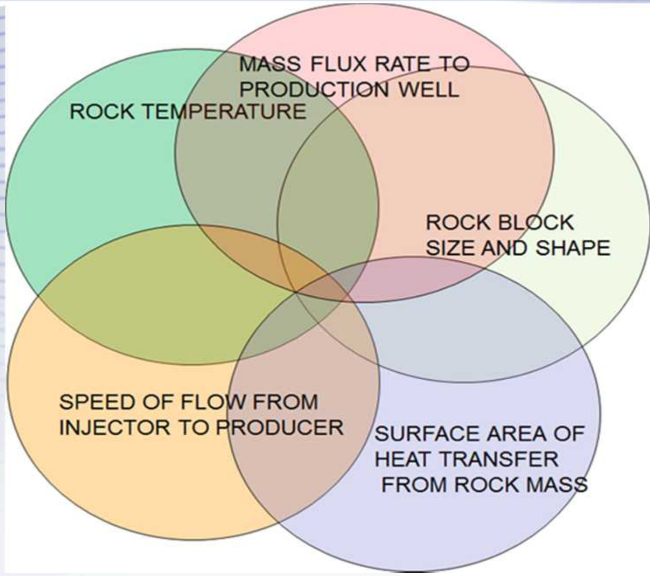
Geothermal Resources(USGS Fact Sheet 2008-3062)

State	Systems	Identified Mean (MWe)	Undiscovered Mean (MWe)	EGS Mean(MWe)
Alaska	53	677	1,788	NA
Arizona	2	26	1,043	54,700
California	45	5,404	11,340	48,100
Colorado	4	30	1,105	52,600
Hawaii	1	181	2,435	NA
Idaho	36	333	1,872	67,900
Montana	7	59	771	16,900
Nevada	56	1,391	4,364	102,800
New Mexico	7	170	1,498	55,700
Oregon	29	540	1,893	62,400
Utah	6	184	1,464	47,200
Washington	1	23	300	6,500
Wyoming	1	39	174	3,000
Total	248	9,057	30,033	517,800

Some Issues to Consider for EGS

- **Needs**
  - High Temperatures
  - High Flow Rates
  - Low Thermal Drawdown

  As well as
  - Low ΔP between injectors and producers
  - Low Fluid Losses
- **EGS relies on the heat transfer from rock matrix blocks to fluids flowing through new or preexisting stimulated fractures**
- **Flow through the system must be enhanced in some manner (e.g., hydraulic stimuation)**

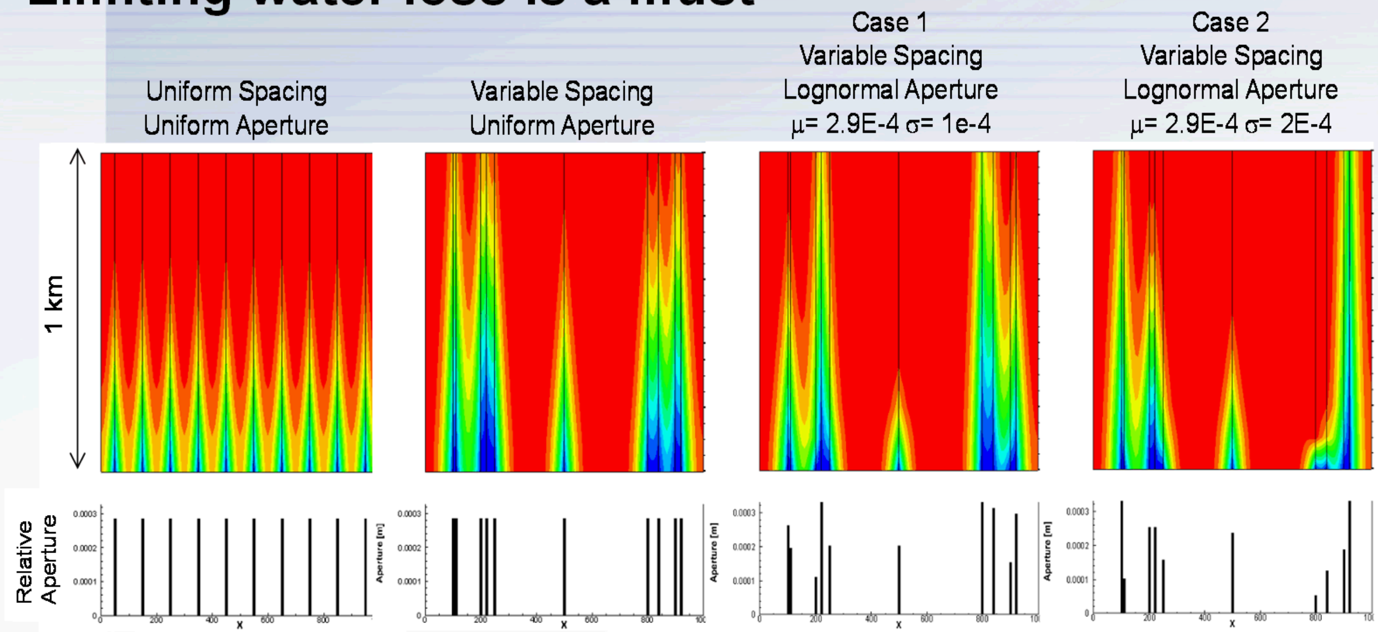


Courtesy of T. Doe, Golder Assoc.

Example – 5 MW (gross) requires ~ 80 kg/s at 200 °C while limiting thermal drawdown and parasitic loads

Fractures and Flow

- **Control of fracture and flow critical**
  - **Controlling fracture evolution and permeability and fluid access to fractures vital to EGS**
  - **Limiting water loss is a must**

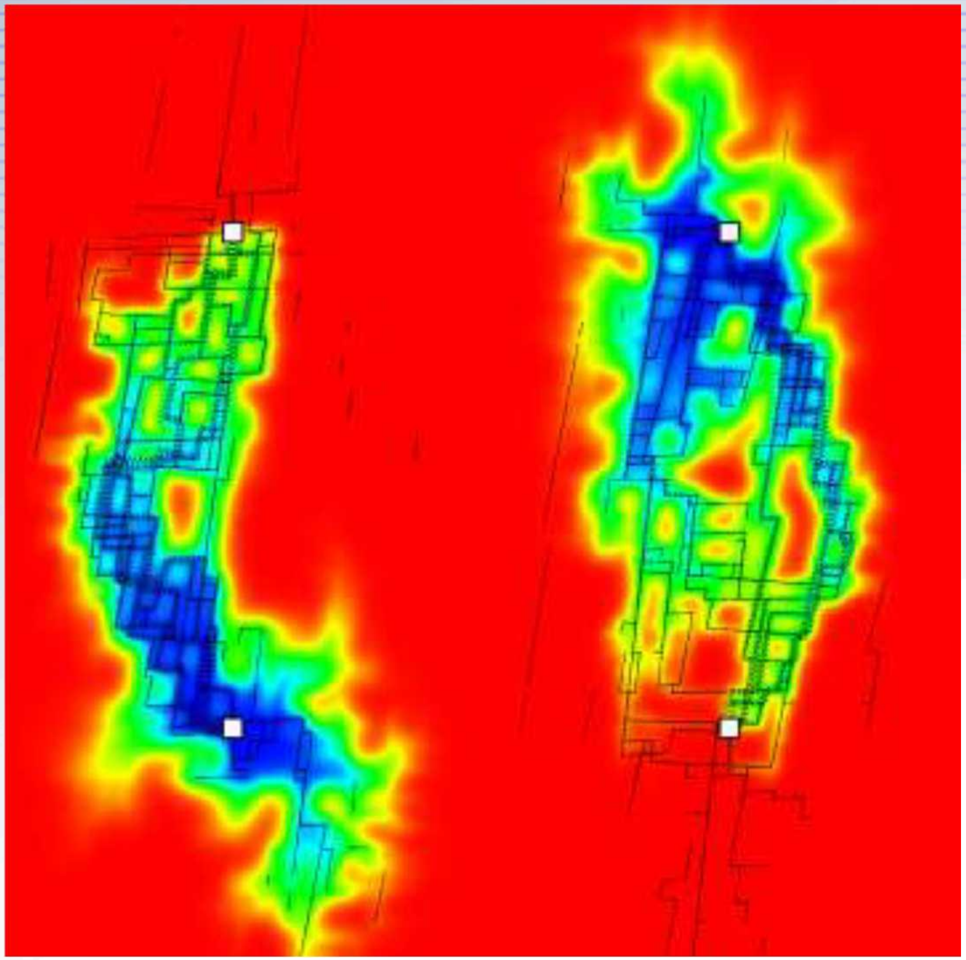


From Doe, et.al, 2013 (Stanford Geothermal Workshop)

Fracture Flow is Complicated

We want uniform flow through the fracture network – but nature wants to take the easiest path.

And it only gets worse with time



Courtesy of C. Carrigan, LLNL

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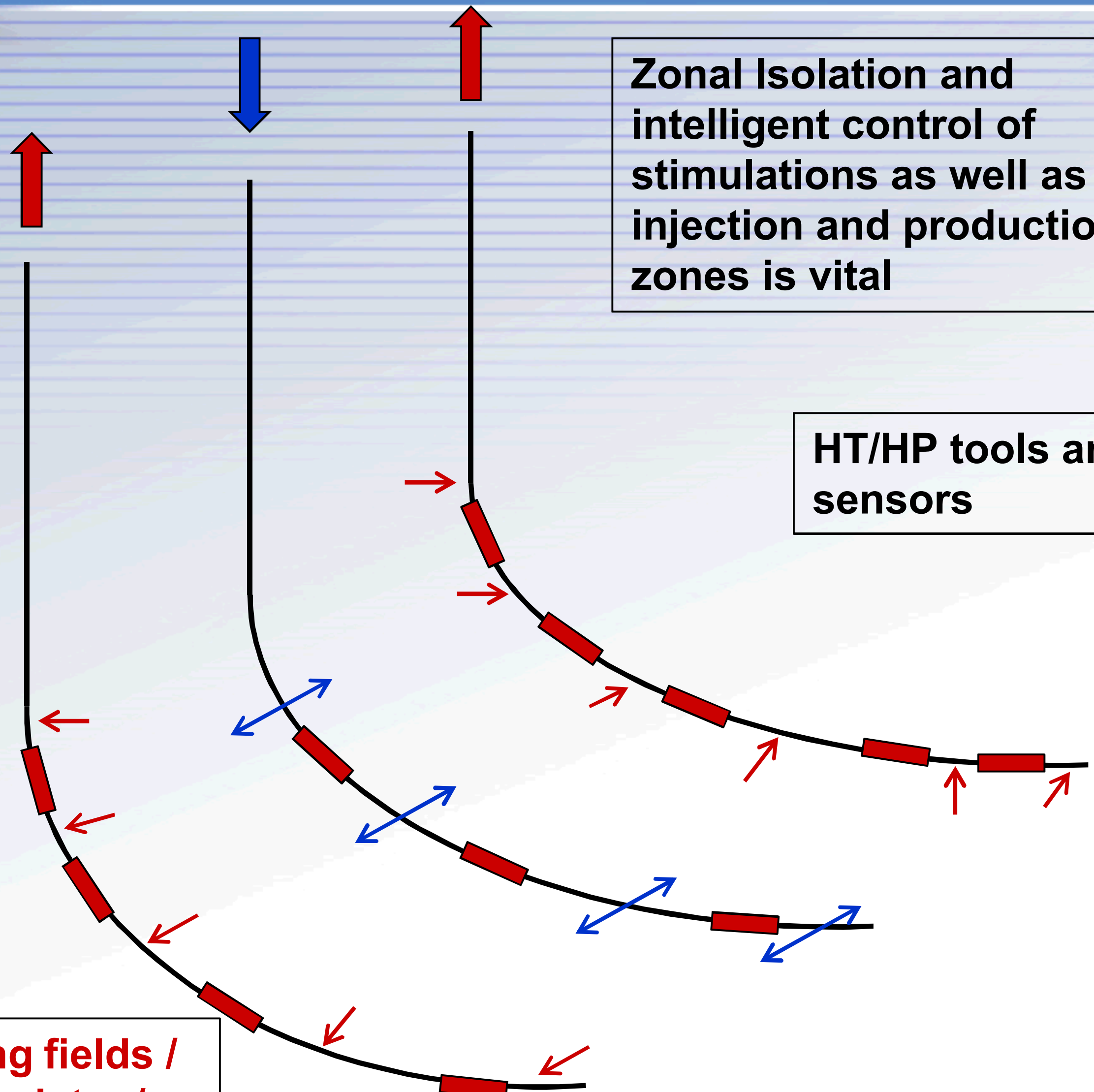
For EGS to Work - An Opinion of <u>Some</u> Critical Needs

Zonal Isolation and intelligent control of stimulations as well as injection and production zones is vital

Directional drilling in most favorable orientation for stimulation and flow



HT/HP tools and sensors

Stimulation technologies to better access existing fracture system

Human talent – All engineering fields / geosciences / materials / chemistry / …

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EGS is a Wicked Hard Problem

But the Prize is Great and Worthy of our Nation's Attention