GEOTHERMAL ELECTRICAL PRODUCTION
FROM OIL & GAS DEVELOPMENTS
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The Future of Geothermal Energy

Synopsis of a 15-month study of the potential of geothermal energy as a major provider of electric power for the US

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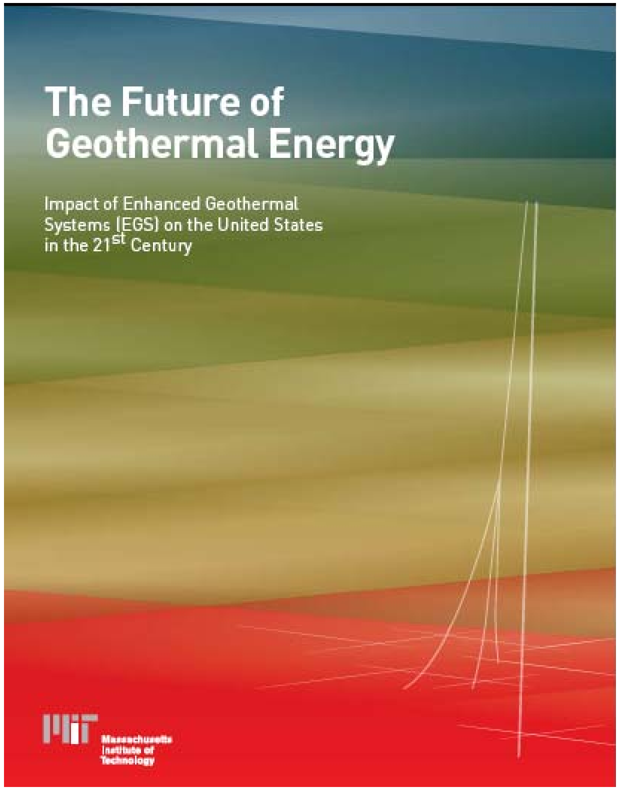
The Future of Geothermal Energy

Energy Recovery from Enhanced/Engineered Geothermal Systems (EGS) – Assessment of Impact for the US by 2050



An MIT– led study by an 18- member international panel

Primary goal – to provide an independent and comprehensive evaluation of EGS as a major US primary energy supplier

Secondary goal – to provide a framework for informing policy makers of what R&D support and policies are needed for EGS to have a major impact

Multidisciplinary EGS Assessment Team

Panel Members

- Jefferson Tester, chair, MIT, energy systems specialist, chemical engineer
- Brian Anderson, University of West Virginia, chemical engineer
- Anthony S. Batchelor, GeoScience, Ltd, rock mechanics and geotechical engineer
- David Blackwell, Southern Methodist University, geophysicist
- Ronald DiPippo, power conversion consultant, mechanical engineer
- Elisabeth Drake, MIT, energy systems specialist, chemical engineer
- John Garnish, physical chemist, EU Energy Commission (retired)
- Bill Livesay, Drilling engineer and consultant
- Michal Moore, University of Calgary, resource economist
- Kenneth Nichols, Barber-Nichols, CEO (retired), power conversion specialist
- Susan Petty, Black Mountain Technology, reservoir engineer
- Nafi Toksoz, MIT, seismologist
- Ralph Veatch, reservoir stimulation consultant, petroleum engineer

Associate Panel Members

- Roy Baria, former Project Director of the EU EGS Soultz Project , geophysicist
- Enda Murphy and Chad Augustine, MIT chemical engineering research staff
- Maria Richards and Petru Negraru, geophysists, SMU Research Staff

Support Staff

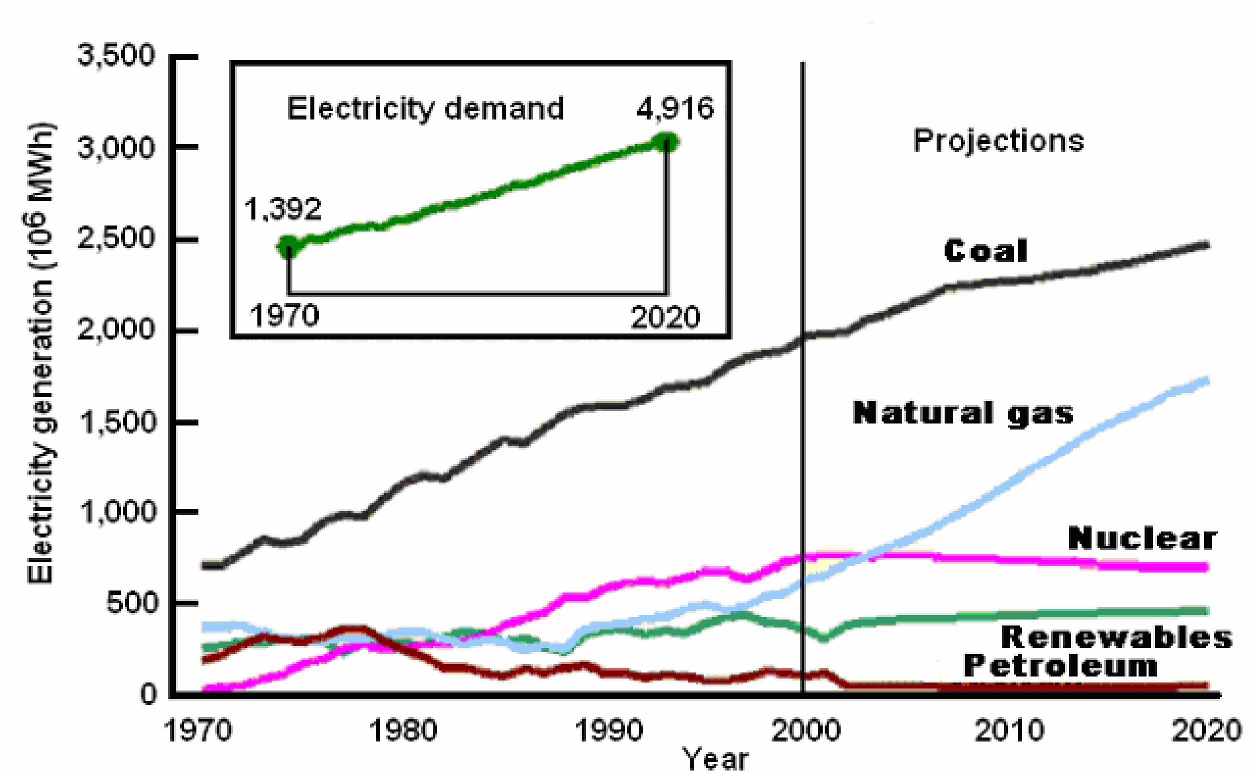
- Gwen Wilcox, MIT

Energy Recovery from Enhanced/Engineered Geothermal Systems (EGS) – Assessment of Impact for the US by 2050

1. Scope and approach
2. Resource base assessment
3. Estimating the recoverable resource
3. Lessons learned from 30 years of field testing
4. Drilling technology and estimated costs
5. Surface plant options and costs
6. Environmental impacts and attributes
7. Economic assessment
8. Summary -- findings and recommendations

A 60-page summary report and a 400+ page full report are available at http://geothermal.inel.gov/publications/future_of_geothermal_energy.pdf

Projected growth in US electricity demand and supply



US electricity generation by energy source 1970-2020 in millions of MWe-hr. Source: EIA (2005)

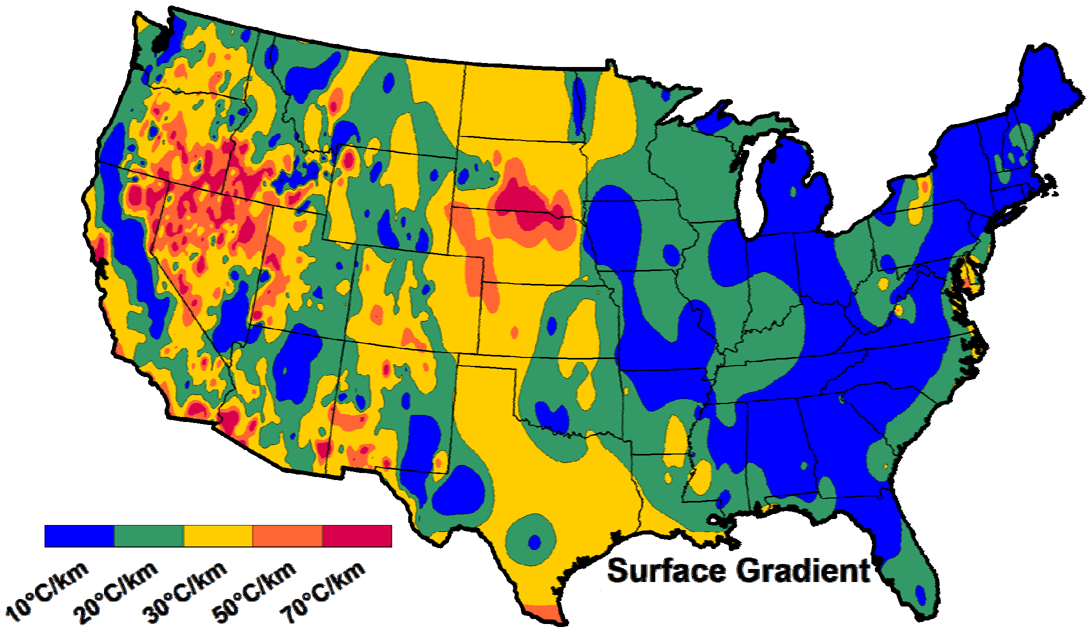
Current US generating capacity is now about 1,000,000 MWe or 1 TWe

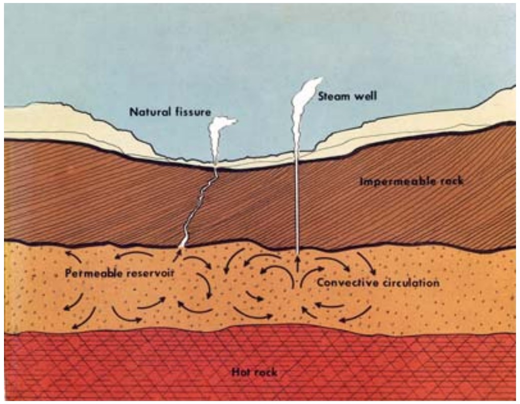
A key motivation – sustainable options for supplying US electricity for the long term

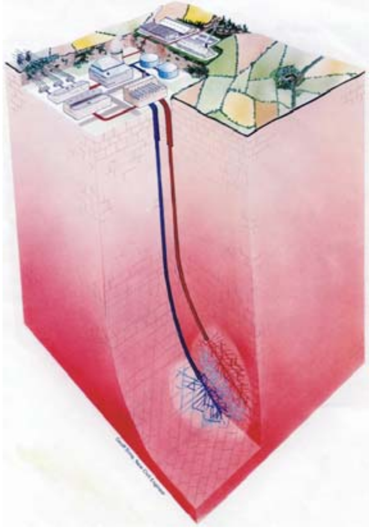
1. **The US energy supply system is threatened** for the long term with demand for electricity outstripping supplies in the next 15 to 25 years
   - In the next 15 to 20 years 40 GWe of “old” coal-fired capacity will need to be retired or updated because of a failure to meet emissions standards
   - In the next 25 years, over 40 GWe of existing nuclear capacity will be beyond even generous re-licensing procedures
2. **Projected availability limitations and increasing prices for natural gas** are not favorable for large increases in electric generation capacity for the foreseeable future
3. **Public resistance to expanding nuclear power** is not likely to change in the foreseeable future due to concerns about waste and proliferation. Other environmental concerns will limit hydropower growth as well
4. **High costs of new clean coal plants** as they have to meet tightening emission standards and may have to deal with carbon sequestration.
5. **Infrastructure improvements needed** for interruptible renewables including storage, inter-connections, and new T&D are large

The Geothermal Option – A missed opportunity for the US ?

Is there a feasible path from today's hydrothermal systems with 3000 MWe capacity to tomorrow's Enhanced Geothermal Systems (EGS) with 100,000 MWe or more capacity by 2050 ?

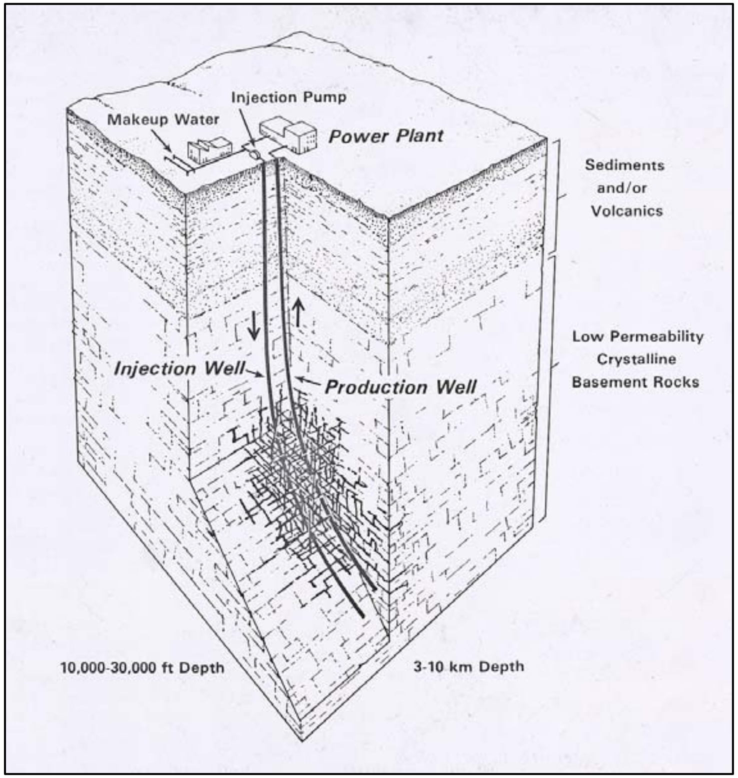


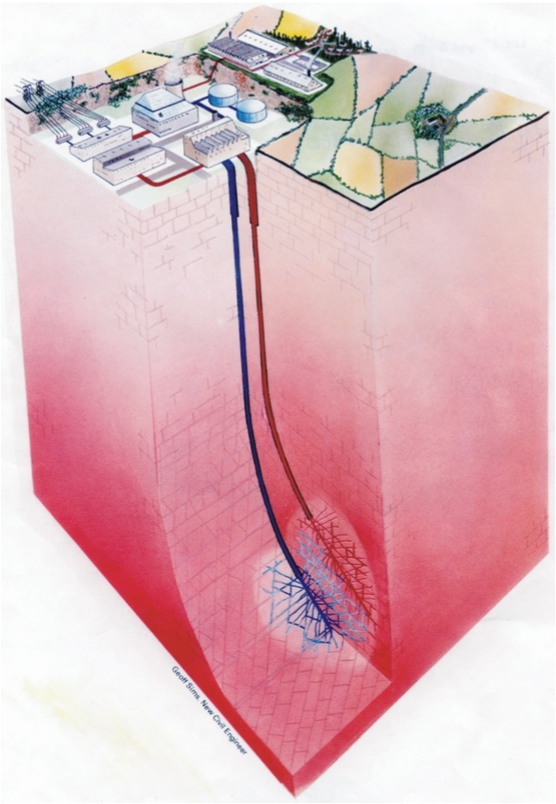




Geothermal resources within a continuum from high-grade hydrothermal to high and low grades of EGS

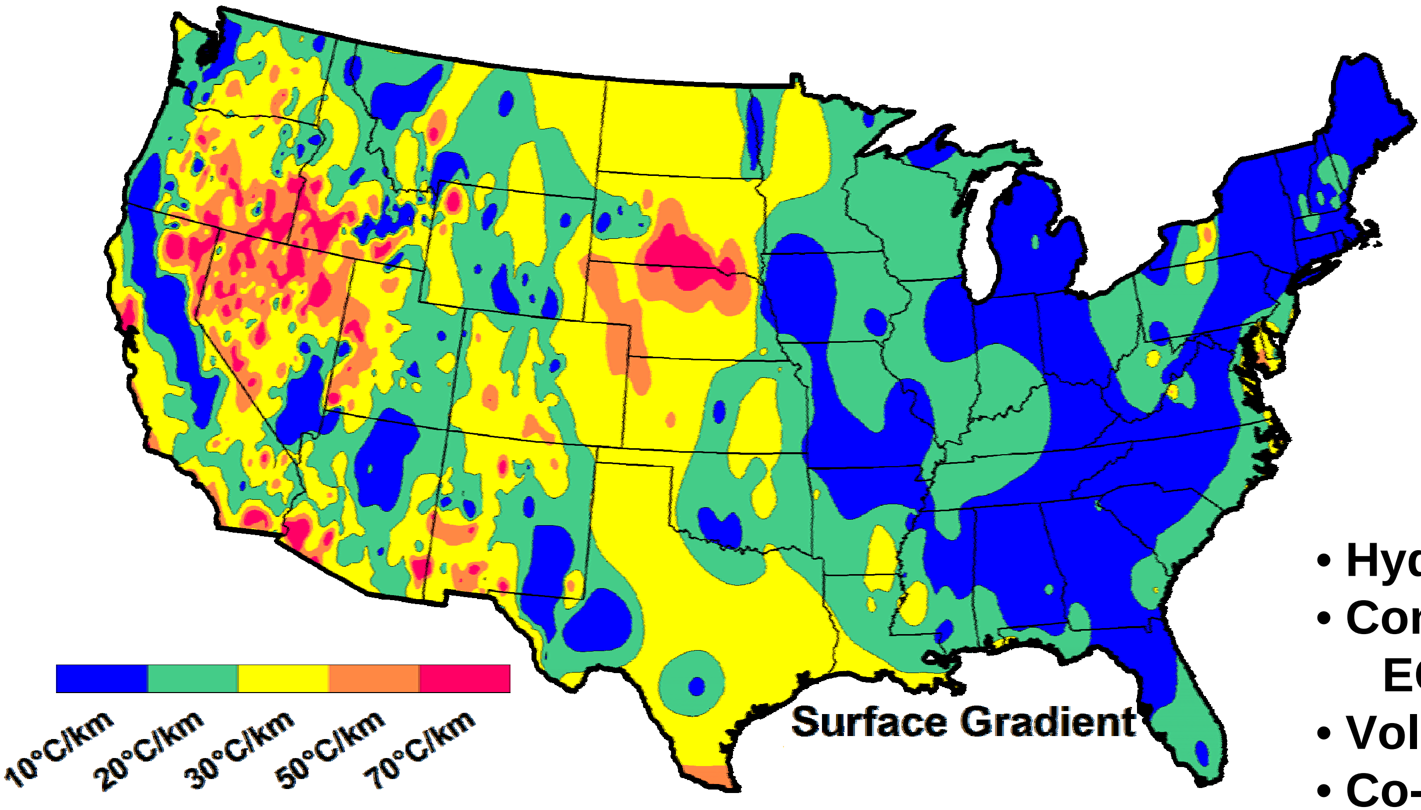
Enhanced/Engineered Geothermal Systems (EGS)





EGS defined broadly as engineered reservoirs that have been stimulated to emulate the production properties of high grade commercial hydrothermal resources.

A range of resource types and grades within the geothermal continuum

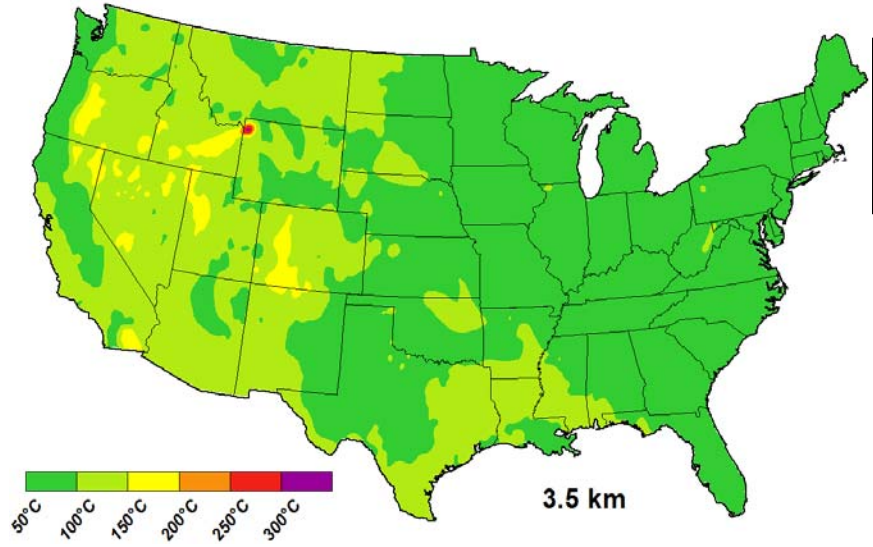


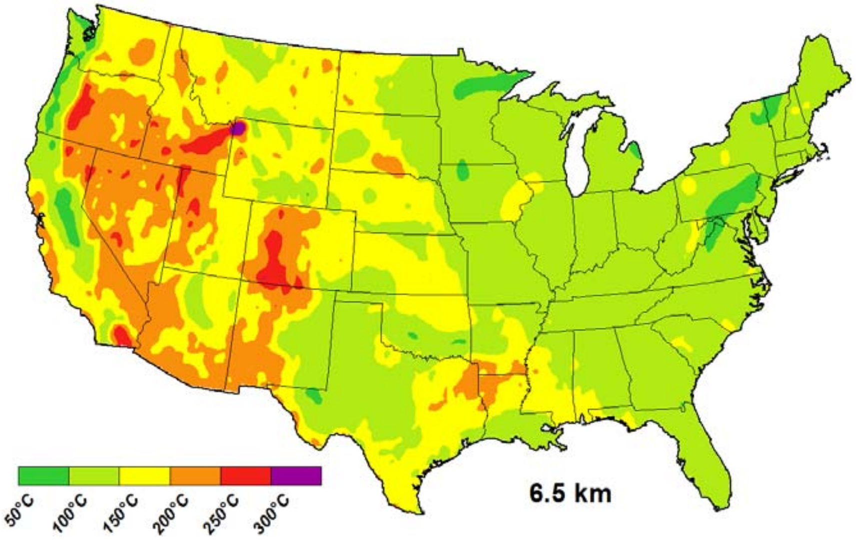
- **Hydrothermal**
- **Conduction-dominated EGS**
- **Volcanic EGS**
- **Co-produced fluids**
- **Geopressured**

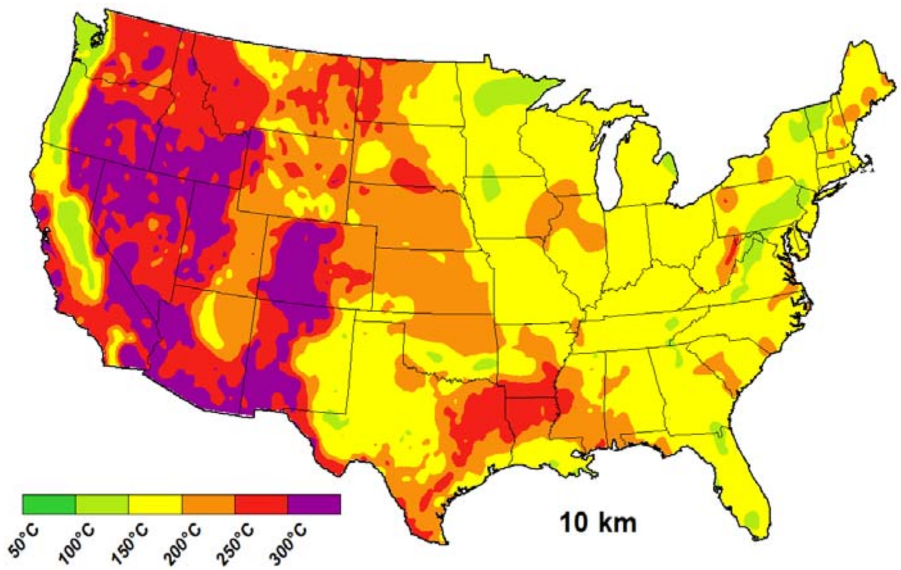
Average surface geothermal gradient

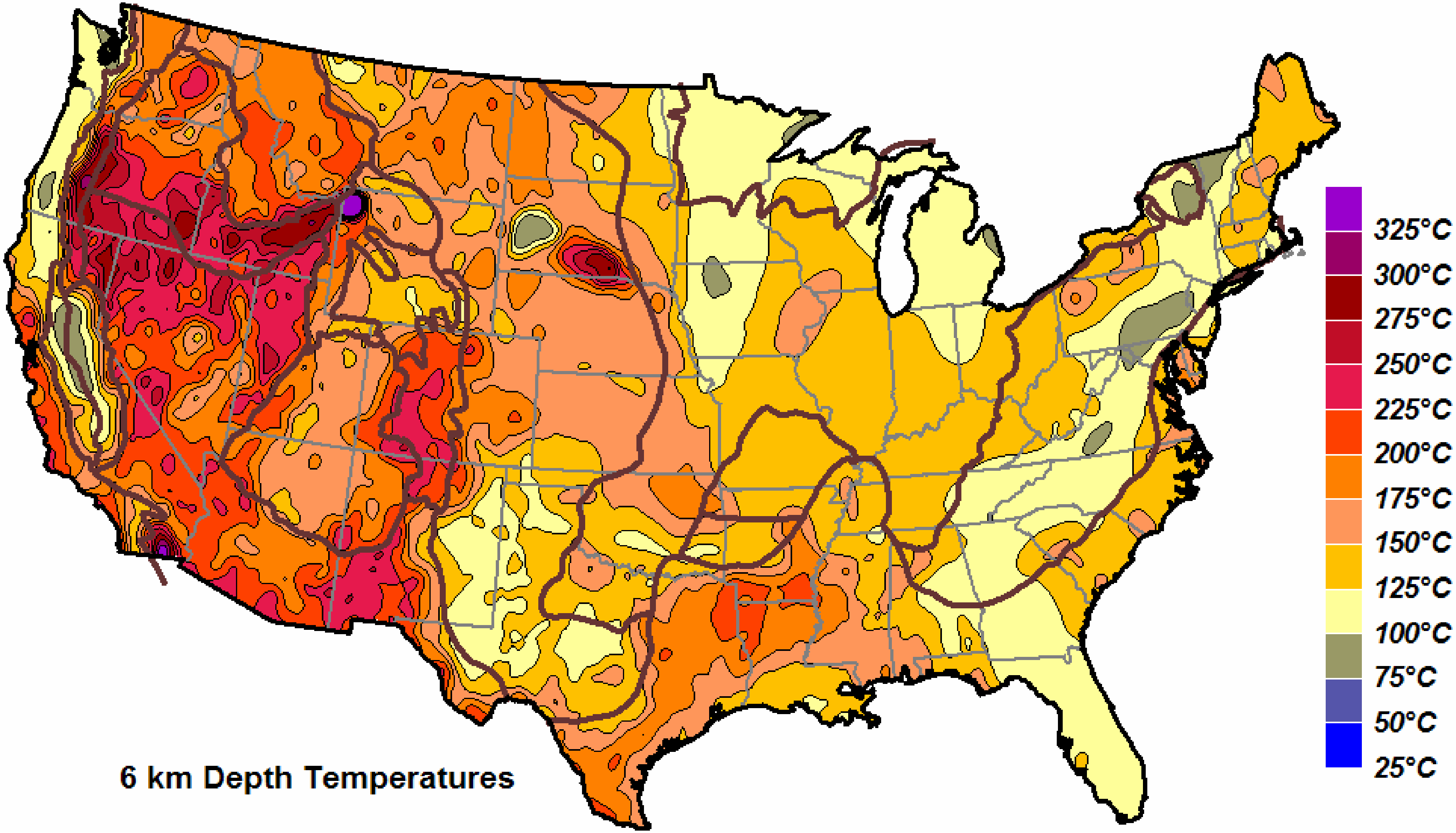
from Blackwell and Richards, SMU (2006)

Estimated Temperatures at Specific Depths

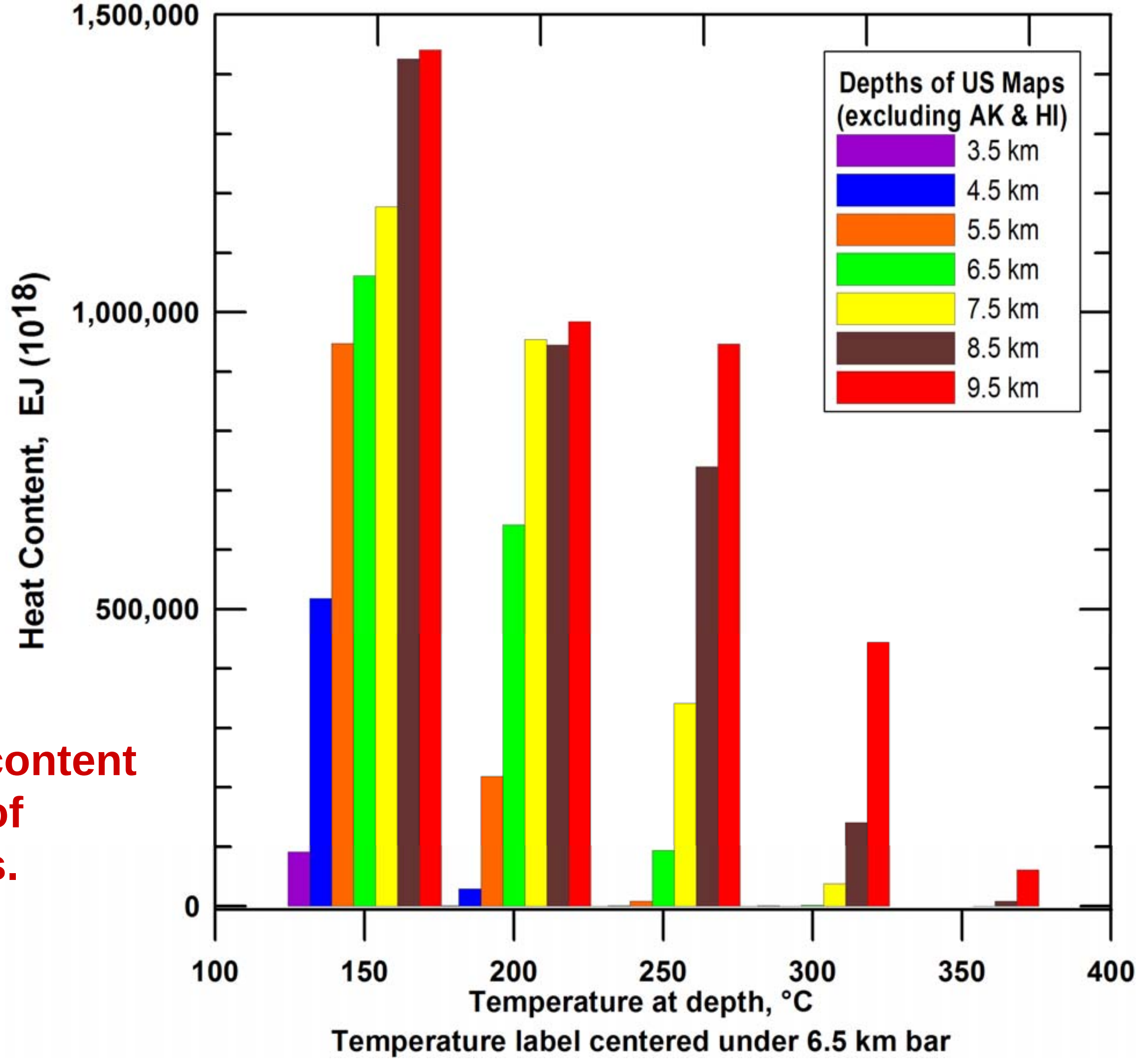




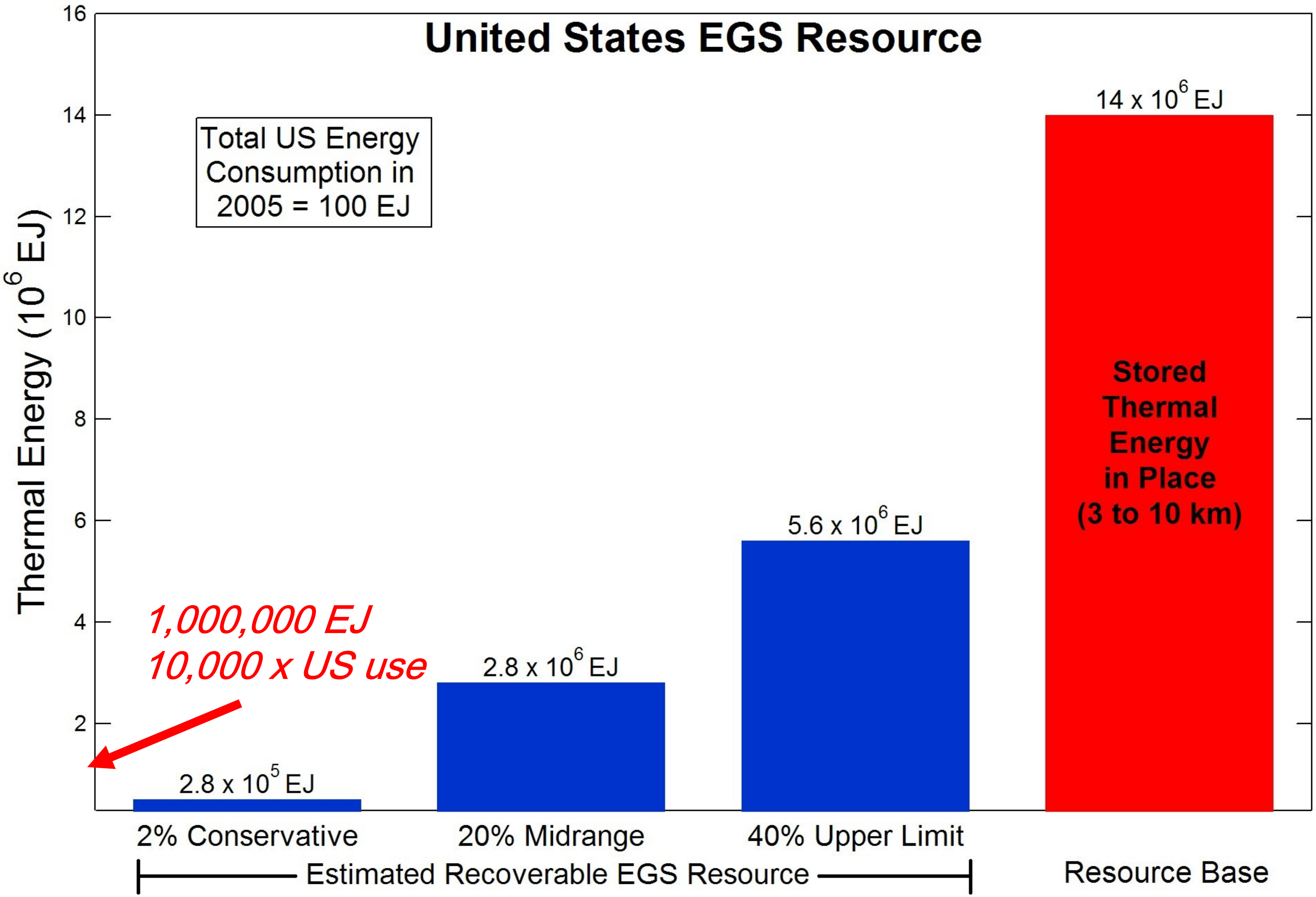




From Blackwell and Richards (June, 2007)

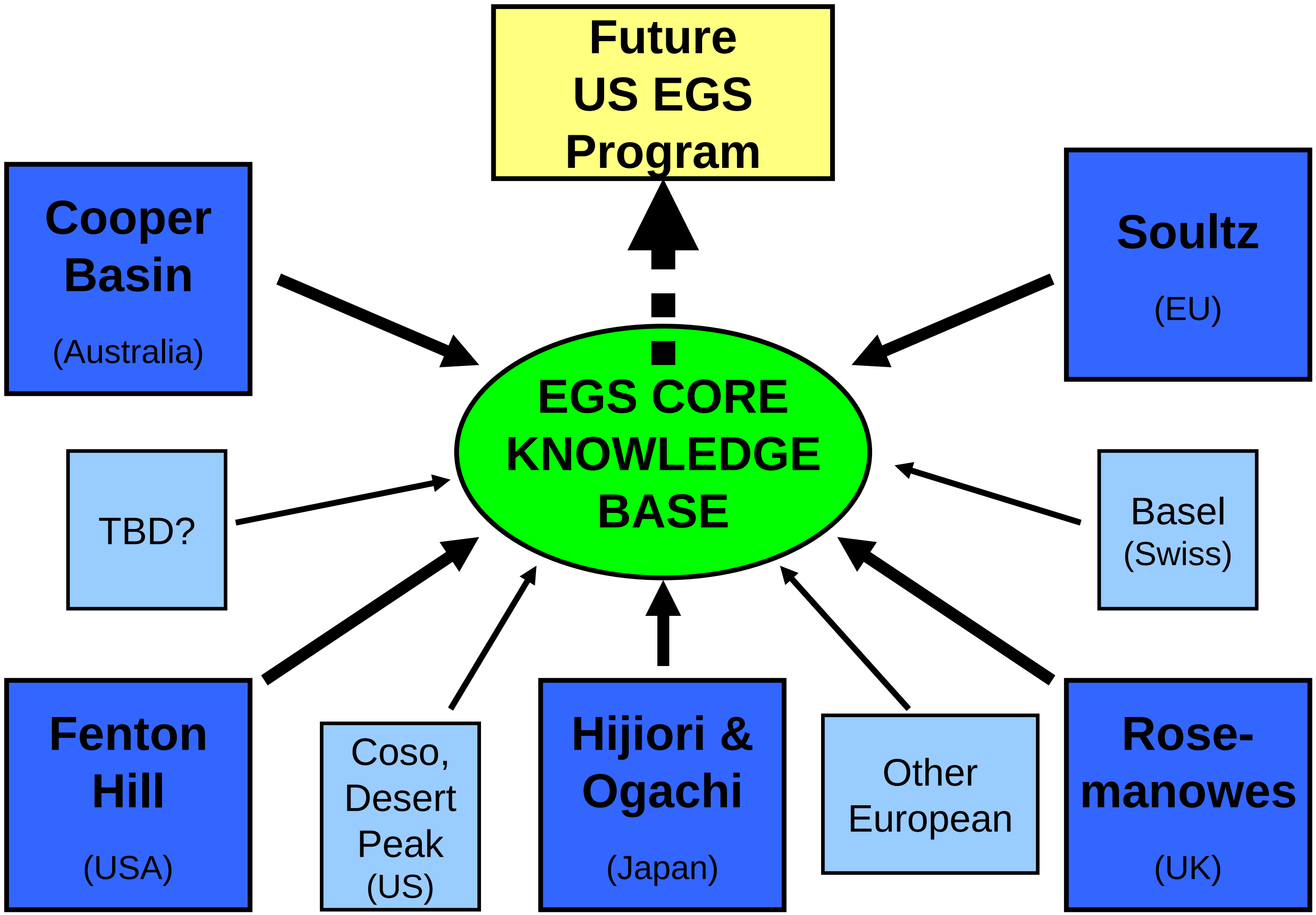


Histograms of heat content in EJ, as a function of depth for 1 km slices.



Estimated total geothermal resource base and recoverable resource given in EJ or 10^{+18} Joules.

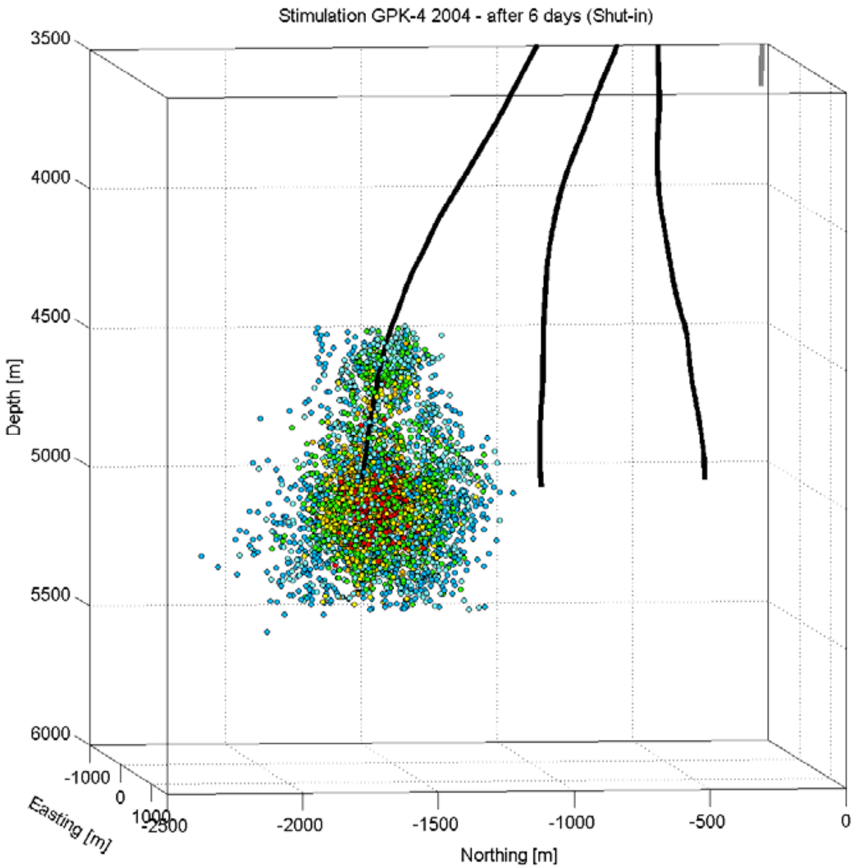
30+ Year History of EGS Research



Developing stimulation methods to create a well-connected reservoir

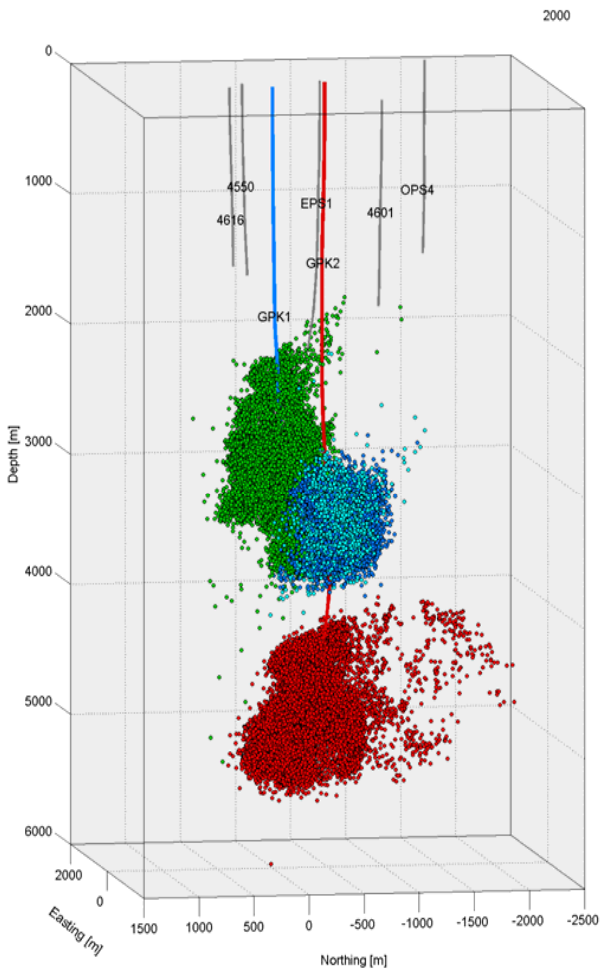
The critical challenge technically is how to engineer the system to emulate the productivity of a good hydrothermal reservoir

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



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

R&D focused on developing technology to create reservoirs That emulate high-grade, hydrothermal systems



Soultz, France from Baria, et al.

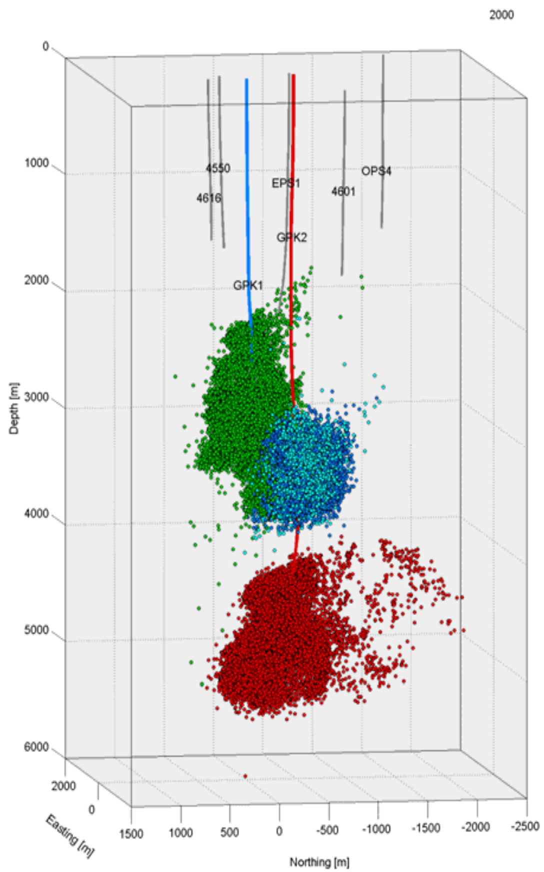
30+ years of field testing at

- Fenton Hill, Los Alamos US project
- Rosemanowes, Cornwall, UK Project
- Hijori, et al , Japanese Project
- Soultz, France EU Project
- Cooper Basin, Australia Project, et al.

has resulted in much progress and many lessons learned

- directional drilling to depths of 5+ km & 300+ºC
- diagnostics and models for characterizing size and thermal hydraulic behavior of EGS reservoirs
- hydraulically stimulate large >1km^3 regions of rock
- established injection/production well connectivity within a factor of 2 to 3 of commercial levels
- controlled/manageable water losses
- manageable induced seismic and subsidence effects
- net heat extraction achieved

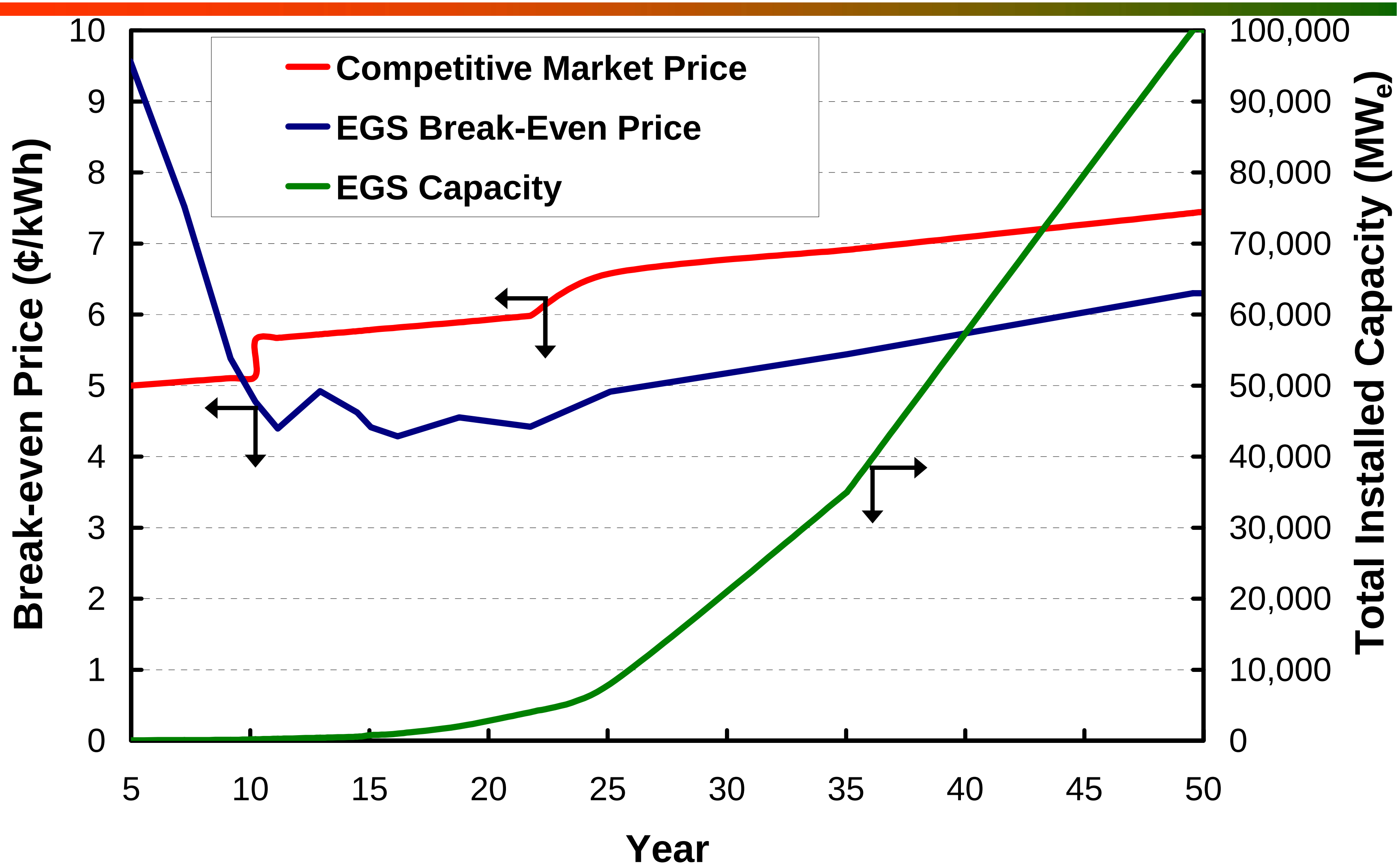
Although much has been accomplished there are a few things left to do



1. Commercial level of fluid production with an acceptable flow impedance thru the reservoir
2. Establish modularity and repeatability of the technology over a range of US sites
3. Lower development costs for low grade EGS systems

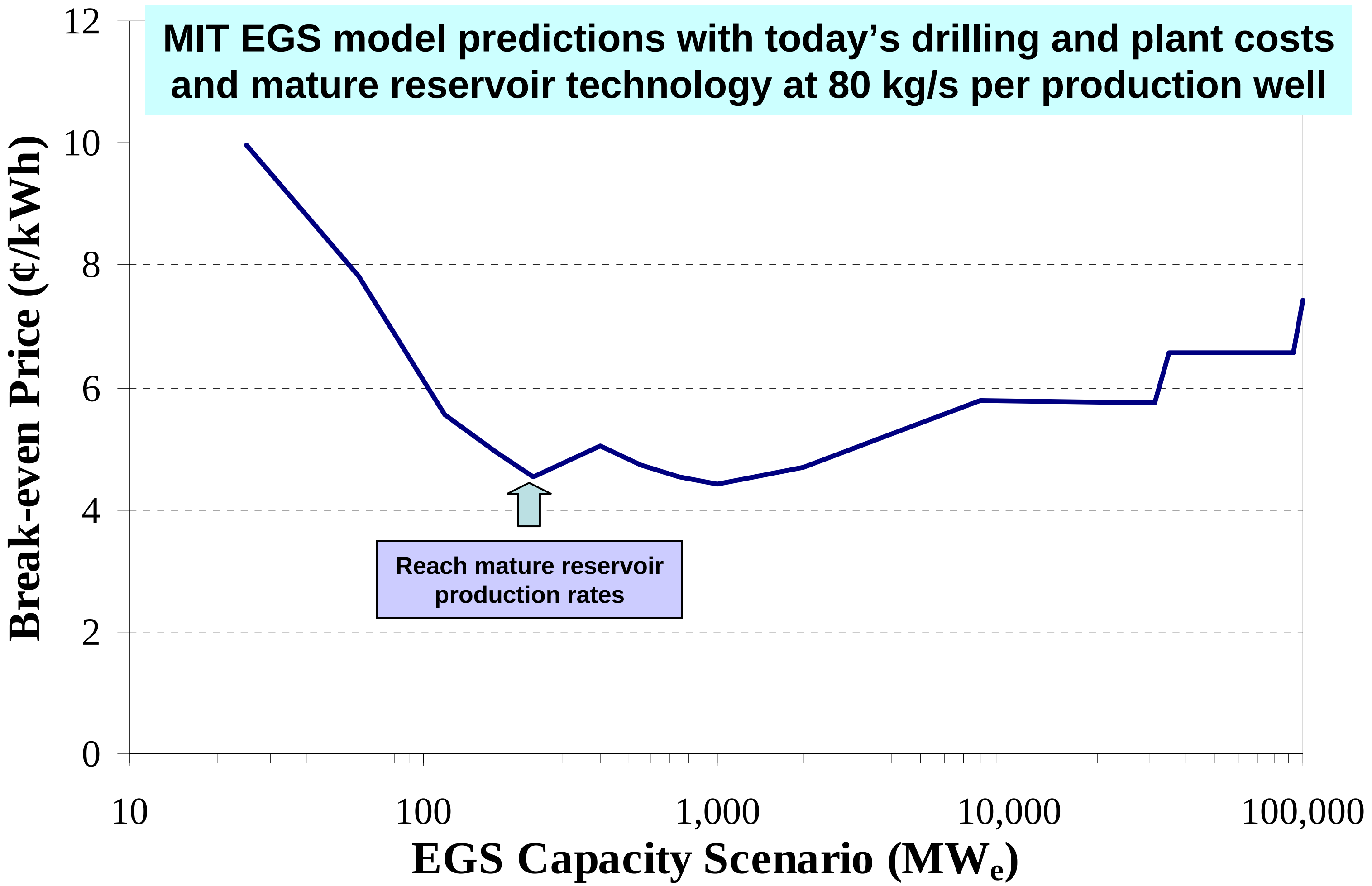
Our analysis evaluated the lowering of risks and costs as a result of investments in research, development and demonstration

Projected Supply of EGS Electricity

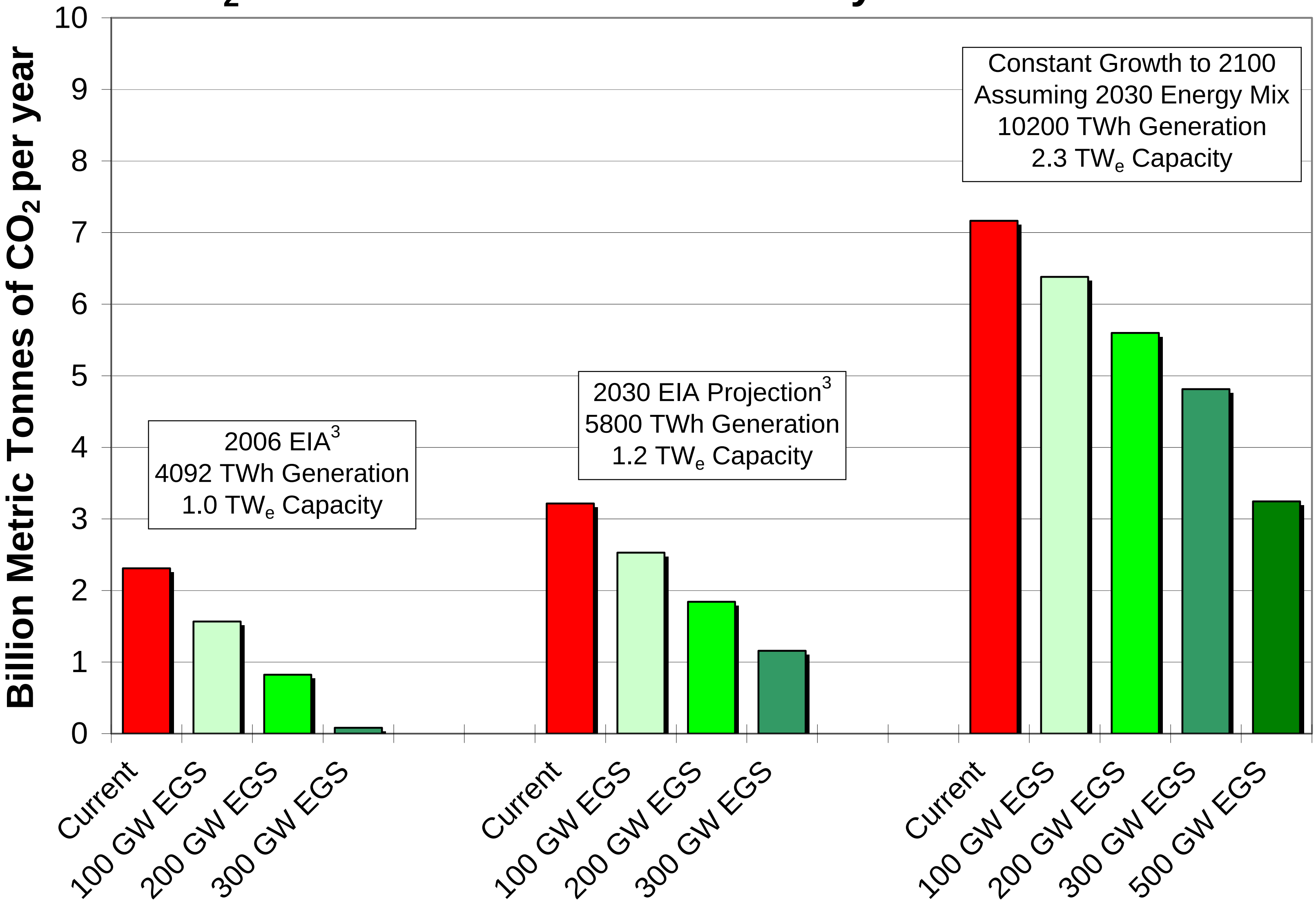


High impact levels for EGS are estimated with a modest investment for research, development and deployment of a 15 year period

Supply Curve for the US EGS resource



Effect of Geothermal Deployment (EGS) on CO_2 Emissions from US Electricity Generation[1,2]



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

Summary of major findings

1. **Large, indigenous, accessible base load power resource** – 14,000,000 EJ of stored thermal energy accessible with today's technologies. Key point -- extractable amount of energy that could be recovered is not limited by resource size or availability
2. **Fits portfolio of sustainable renewable energy options** - EGS complements the existing portfolio and does not hamper the growth of solar, biomass, and wind in their most appropriate domains.
3. **Scalable and environmentally friendly** – EGS plants have small foot prints and low emissions – carbon free and their modularity makes them easily scalable from large size plants.
4. **Technically feasible** -- Major elements of the technology to capture and extract EGS are in place. Key remaining issue is to establish inter-well connectivity at commercial production rates – only a factor of 2 to 3 greater than current levels.
5. **Economic projections favorable** for high grade areas now with a credible learning path to provide competitive energy from mid- and low-grade resources
6. **Deployment costs modest** -- an investment of $200-400 million over 15 years would demonstrate EGS technology at a commercial scale at several US field sites to reduce risks for private investment and enable the development of 100,000 MWe.
7. **Supporting research costs reasonable** – about $40 million/yr needed for 15 years -- low in comparison to what other large impact US alternative energy programs will need to have the same impact on supply.

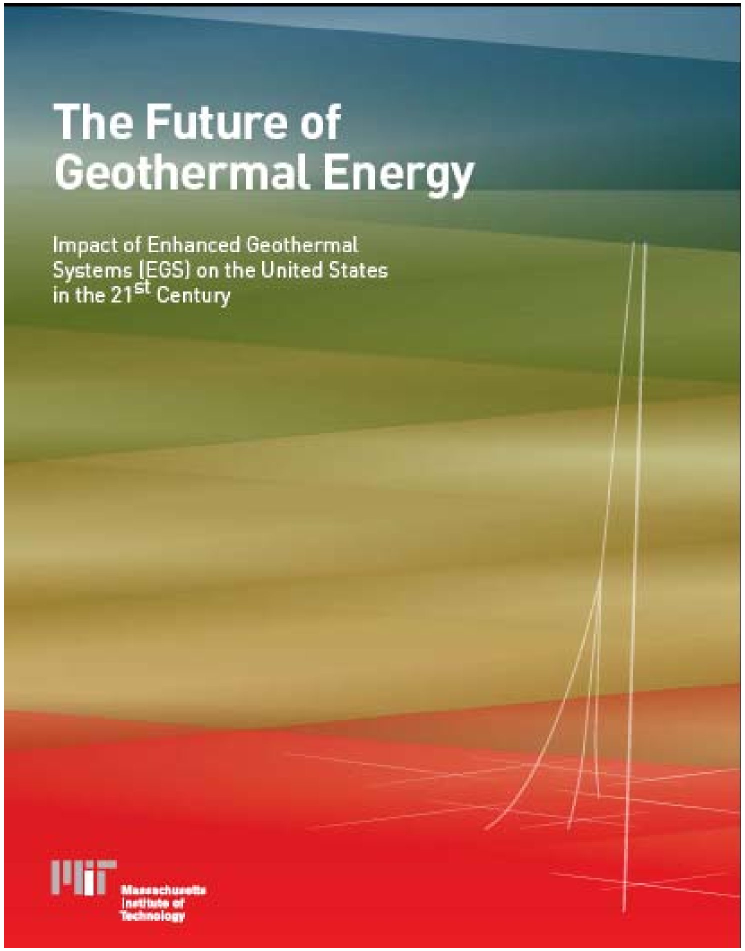
Recommended path for enabling 100,000 MWe from EGS by 2050

- **Support more detailed and site specific resource assessment**
- **Support 3-5 field demonstrations in the next 15 years to refine technologies for demonstrating commercial-scale EGS**
- **Develop shallow, high grade EGS sites at the margins of hydrothermal reservoirs along with co-produced hot water sites as short term options**
- **In the longer term, develop lower gradient EGS sites requiring deeper heat mining at depths >6 km**
- **Implement state and federal policies that incentivize EGS**
- **Maintain vigorous R&D effort on subsurface science, drilling, energy conversion, and systems analysis for EGS**

Invest a total of $300 to 400 million for deployment assistance and a comparable amount for research over 15 years

Less than the price of **one clean coal plant !**

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



Acknowledgements

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- Sandia National Laboratories

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