The Future of Geothermal Energy
Structure and Outcome of the Analysis

Presentation at the
DOE Geothermal Program Workshop

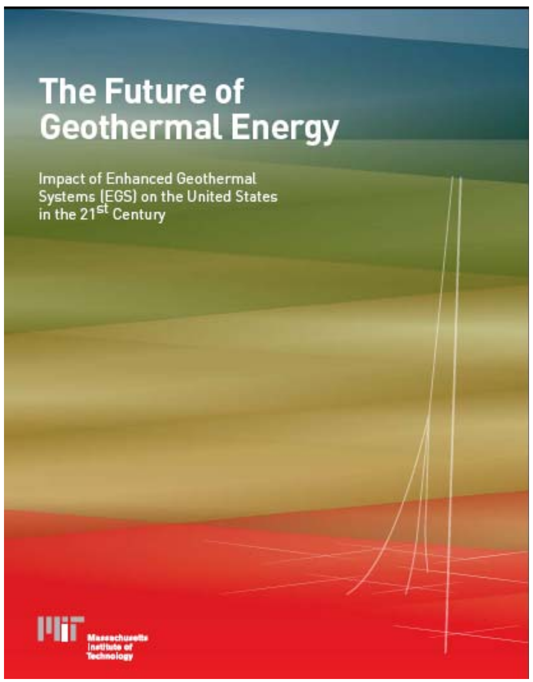
by Jeff Tester and Ron DiPippo
on behalf of the EGS assessment team

June 7 2007
Washington, DC

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



1. Project scope, objectives and approach, and findings and recommendations -- Jeff Tester
2. Resource base assessment -- David Blackwell
3. The recoverable resource -- Susan Petty
4. Lessons learned from field testing -- Susan Petty
5. Drilling technology and costs -- Bill Livesay
6. Surface plant options and costs – Ron DiPippo
7. Economic assessment -- Michal Moore

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 geotechnical 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

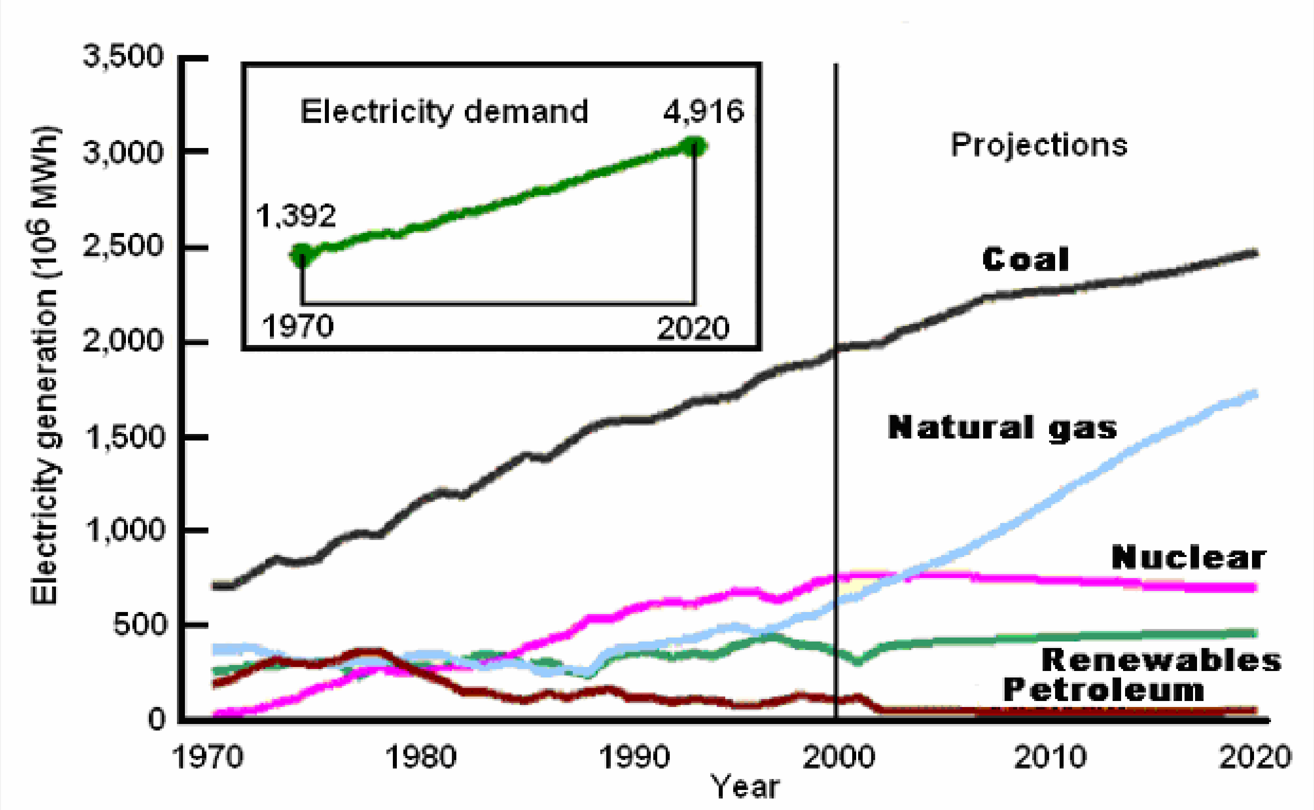
Associate Panel Members

- 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

A key motivation - US Electricity Supply for the long term



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

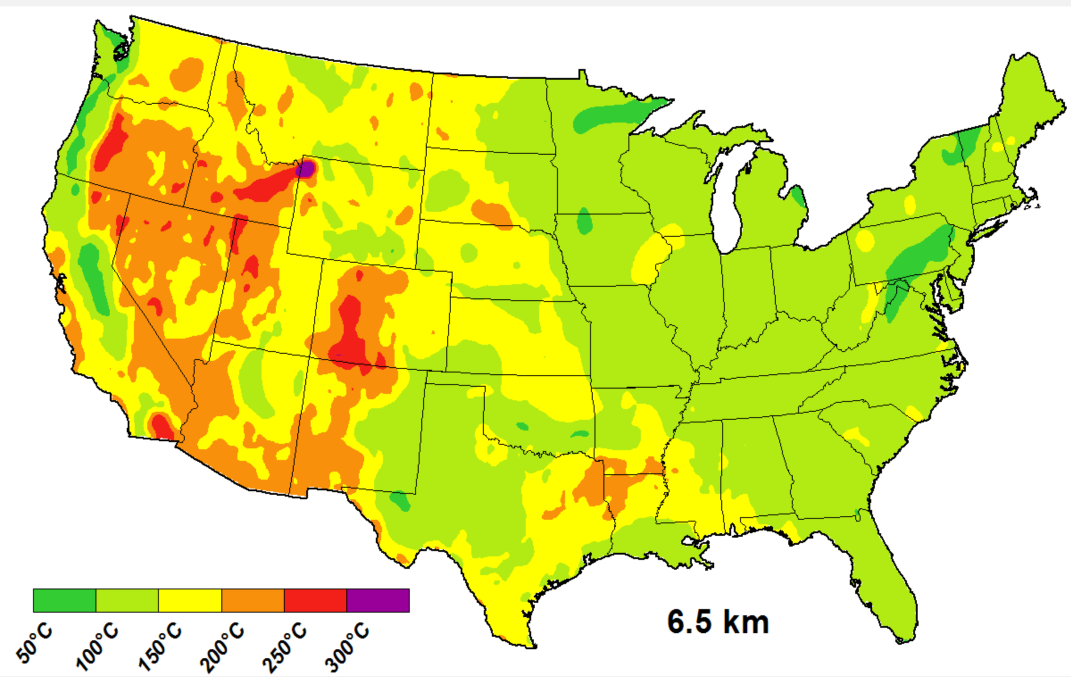
Current US generating capacity is now about 1,000,000 MWe or 1 TWe

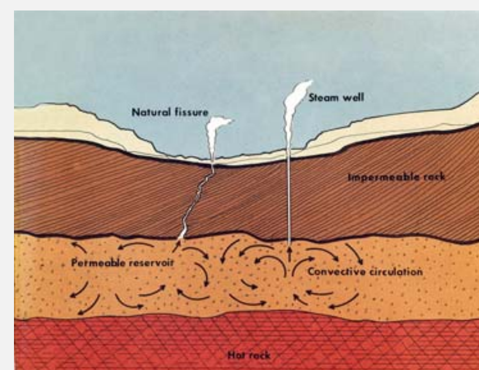
A key motivation - US Electricity Supply for the long term

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 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 changes** are needed for interruptible renewables including storage, inter-connections, and new T&D are large

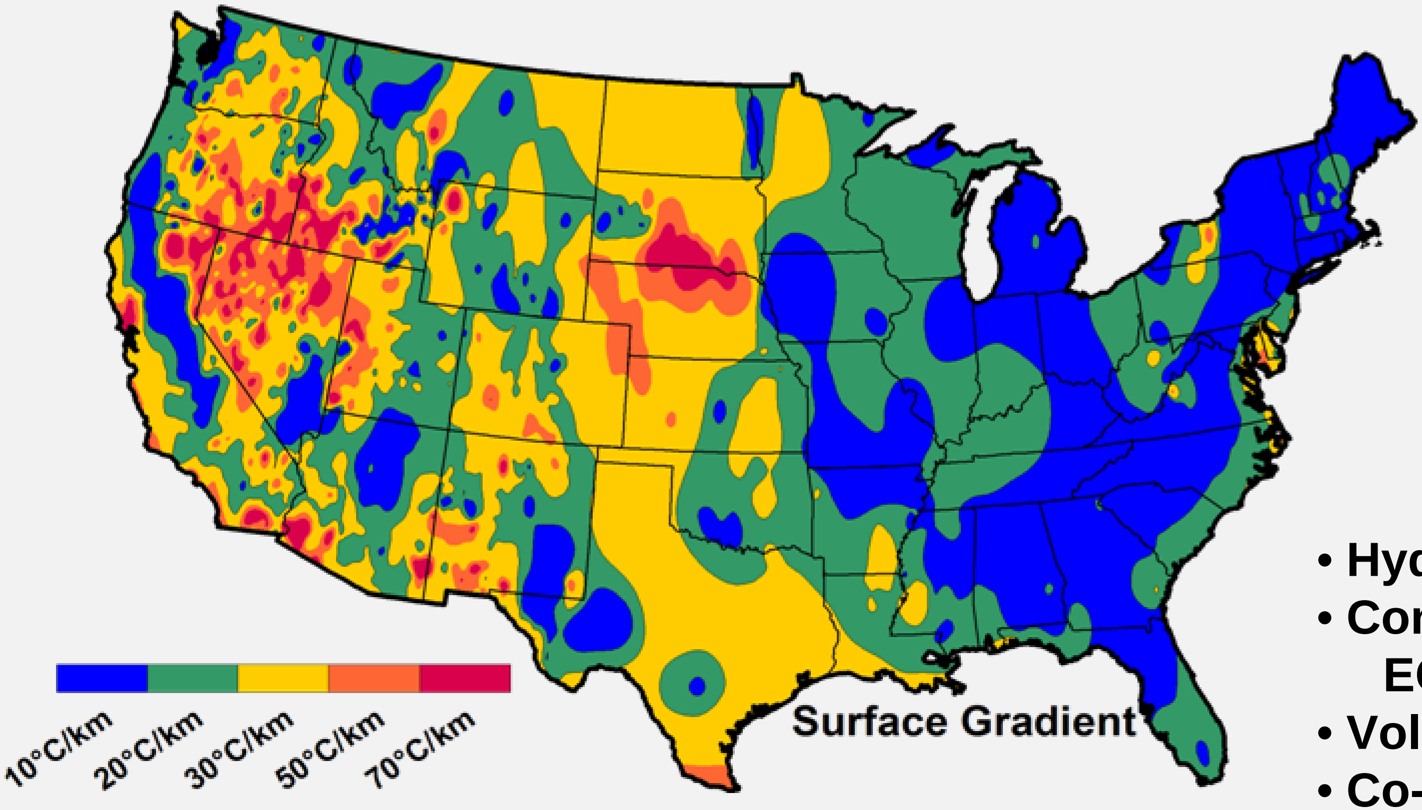
The Geothermal Option – "Back to the Future" -- a missed opportunity for the US ?

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 ?





A range of resource types and grades within the geothermal continuum

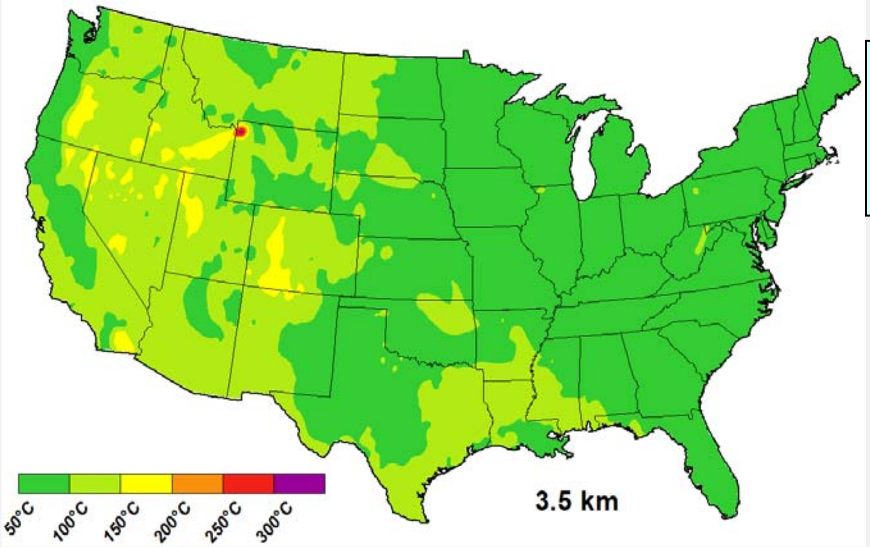


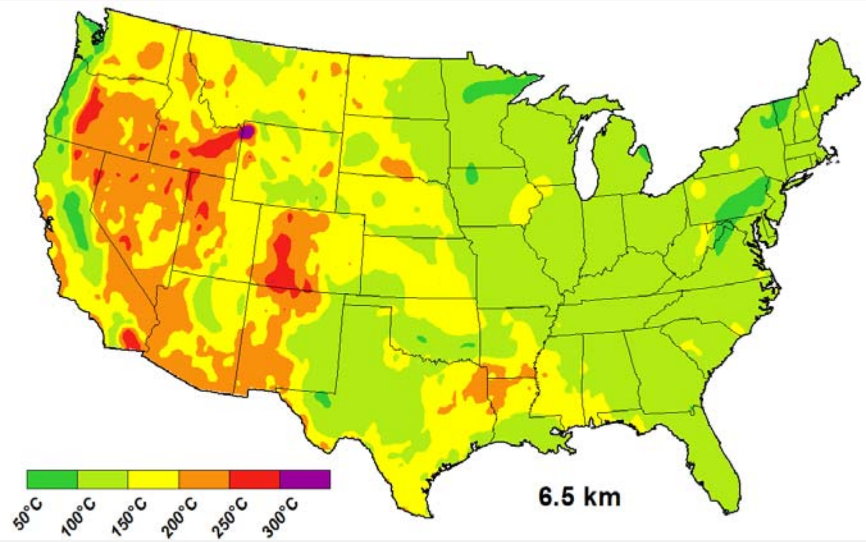
- **Hydrothermal**
- **Conduction-dominated EGS**
- **Volcanic EGS**
- **Co-produced fluids**
- **Geopressured**

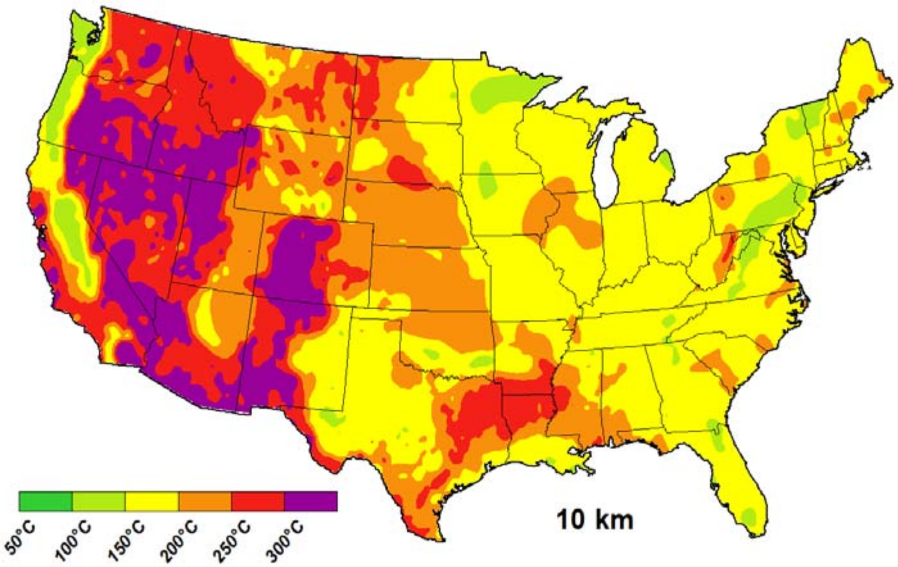
Average surface geothermal gradient

from Blackwell and Richards, SMU (2006)

Estimated Temperatures at Specific Depths







Why should the U.S. re- invest now in EGS ?

Because geothermal can provide a large amount of sustainable, indigenous, clean, base load and affordable energy for the nation

But, what are the technology requirements and what investments are needed to achieve this goal ?

Project Statement of Work

The MIT-led team will address several major questions affecting the future development of EGS:

1. **What are quality, grade and distribution of the EGS resource nationally?**
2. **What remains to be done technically to achieve complete EGS system feasibility?**
3. **What are the key technical and economic issues that must be resolved for EGS to have national impact in US energy supply by 2050?**

EGS Assessment Project Goals

Primary goal – to provide an in-depth 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

Major impact was defined as enabling 100,000 MWe of an economically viable EGS resource on line or as a true reserve by 2050

Approach – 4 key elements of the assessment

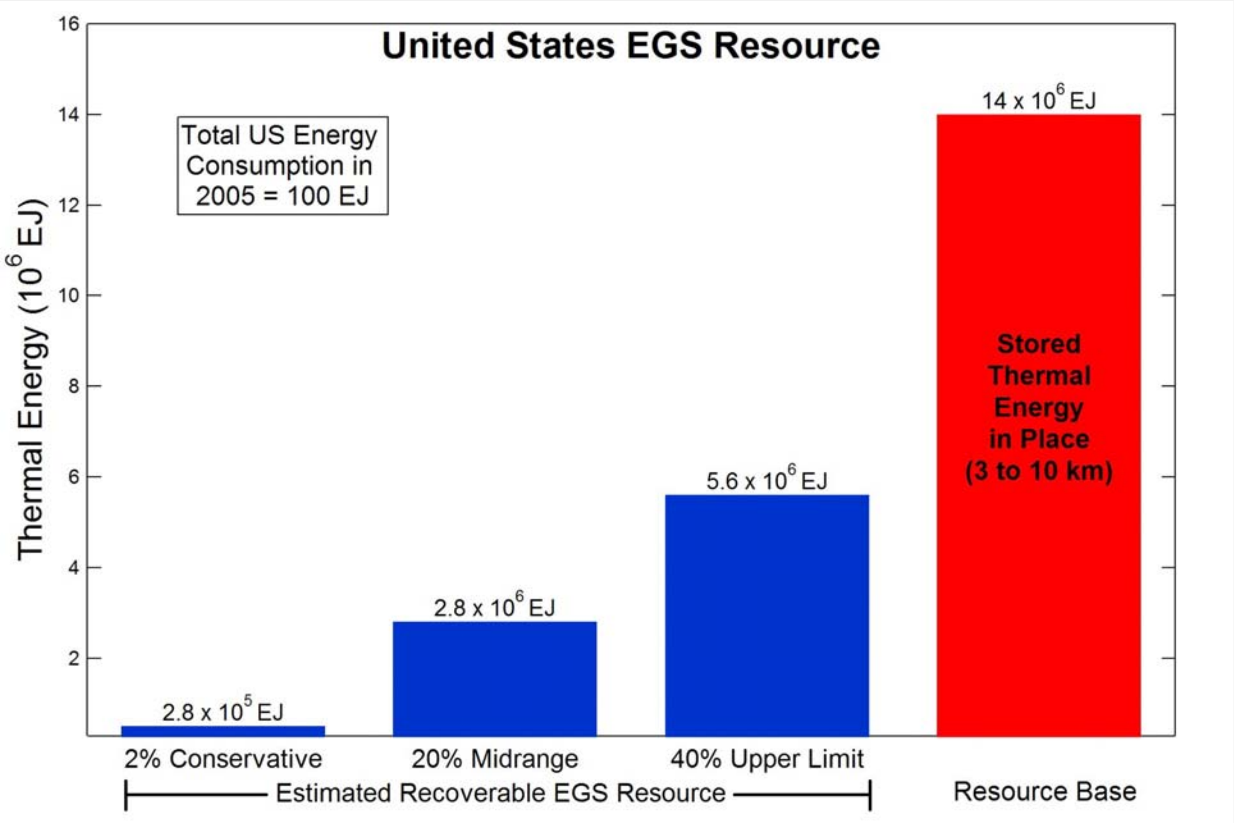
1. **Resource**
   - quantitative, national scale evaluation of current state of knowledge regarding geothermal resources
   - estimation of EGS Resource Base and recoverable resource
2. **Technology**
   - specification of requirements for **subsurface** and surface system components
   - retrospective review, analysis and lessons learned from 30+ years of field testing
3. **Environmental attributes and constraints**
4. **Economics**
   - evaluation and analysis of drilling and completion and energy conversion options and costs
   - economic modeling for prediction of costs using GETEM and MITEGS models
   - base case parameters and sensitivity to technology and financial parameter variations
   - learning curves, supply curves and R&D projections

Project timeline and documentation schedule

- Sept.1 2005 -- Project start – assembly of panel
- Sept. 2005 – Jan 2006 -- Series of meetings/workshops involving specific discussion topics and invited speakers
- Jan. 2006– Open meeting at the Stanford Reservoir Engineering Workshop
- April 2006 - First draft of report for internal review
- May 2006 - Second draft of report for external peer review
- May – June report under external peer review
- July -- Panel's response to peer review and revision of report
- July 15 2006 – submission of revised report for copy editing
- August 1 – Sept 8 2006 - final revision and production of the report
- Sept. 13 – GRC forum on EGS Assessment Panel findings and recommendations, distribute synopsis and executive summary
- Jan 2007- Release of complete final report (9 chapters, 350+ pages)
- Jan-June 2007 – Inform policy makers of results and recommendations

Summary of major findings

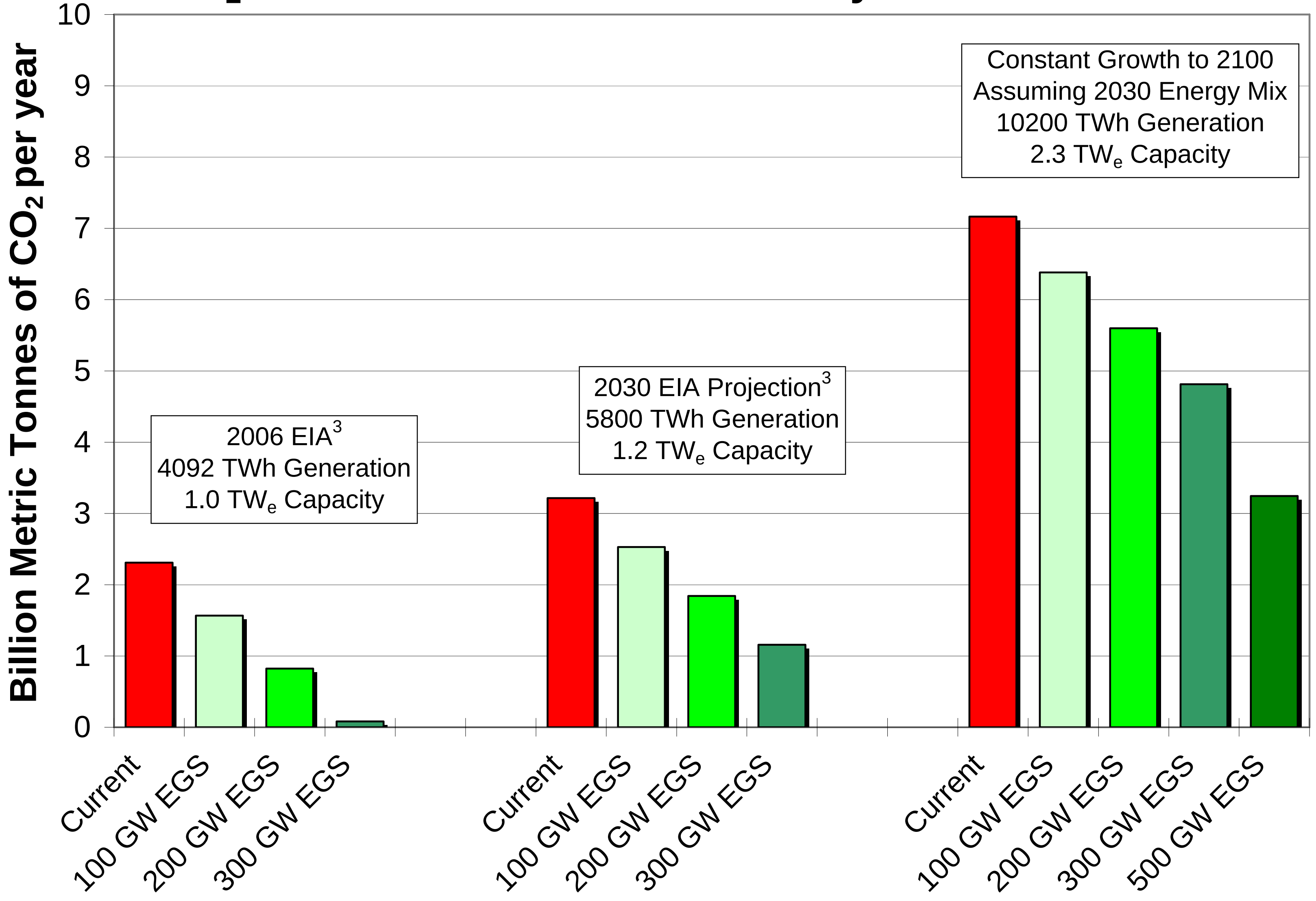
1. **Large, indigenous, accessible base load power resource** – extractable amount of energy that could be recovered is not limited by resource size. EGS can sustain production of ≥100,000 MWe of base load electric power



Summary of major findings

1. **Large, indigenous, accessible base load power resource** – extractable amount of energy that could be recovered is not limited by resource size. EGS can sustain production of ≥100,000 MWe of base load electric power
2. **Fits portfolio of sustainable RE options** - EGS complements the DOE"s RE portfolio and does not hamper the growth of solar, biomass, and wind in their most appropriate domains.

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

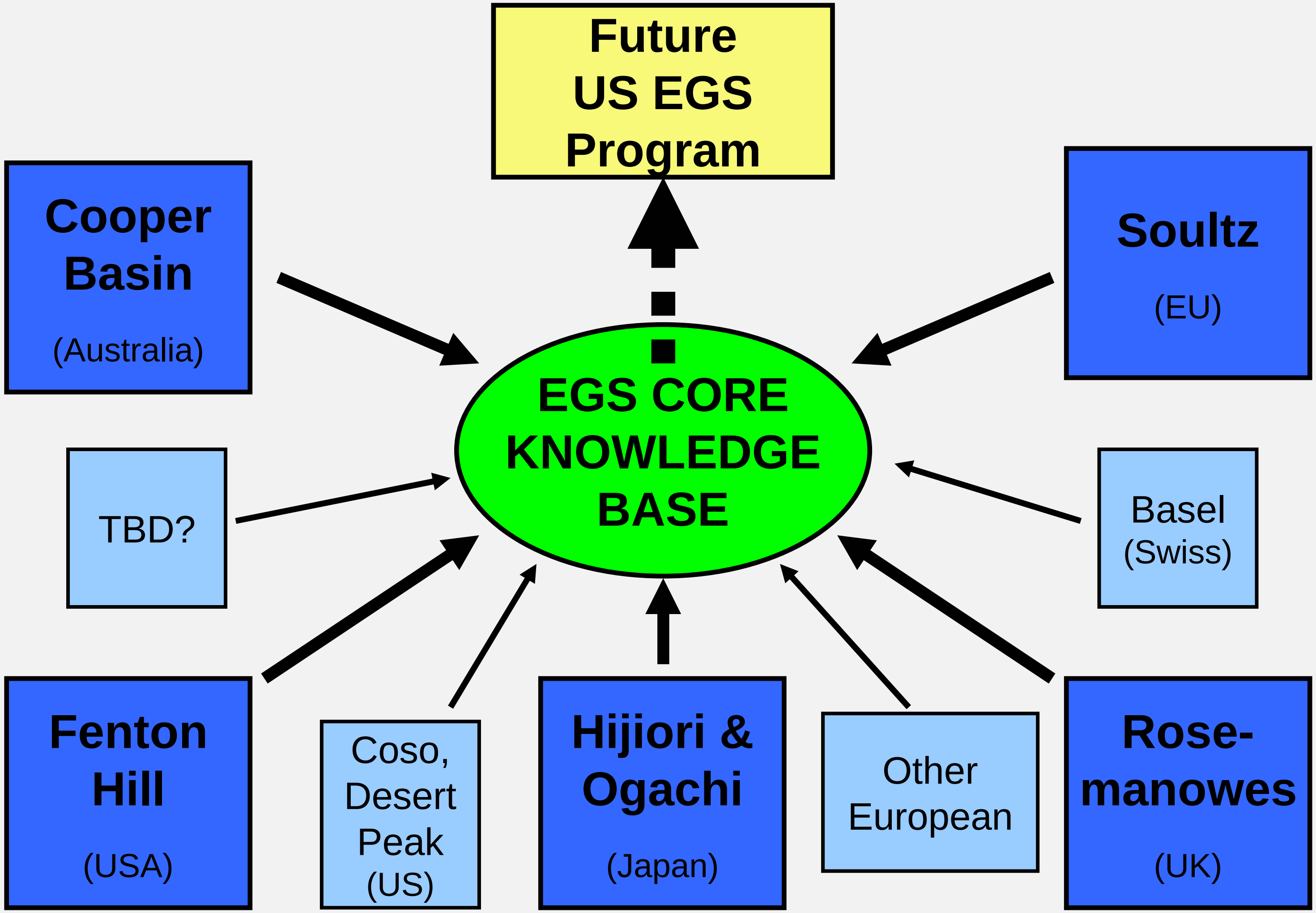


Notes: 1. 95% capacity factor assumed for EGS
2. Assumes EGS offsets CO2 emissions from Coal and Natural Gas plants only
3. EIA Annual Energy Outlook 2007

Summary of major findings

1. **Large, indigenous, accessible base load power resource** – extractable amount of energy that could be recovered is not limited by resource size. EGS can sustain production of ≥100,000 MWe of base load electric power
2. **Fits portfolio of sustainable RE options** - EGS complements the DOE"s RE 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 are inherent modular making them easily scalable from 1+ to 50+ MWe size individual plants – grouping to large base load facilitiies >1000MWe

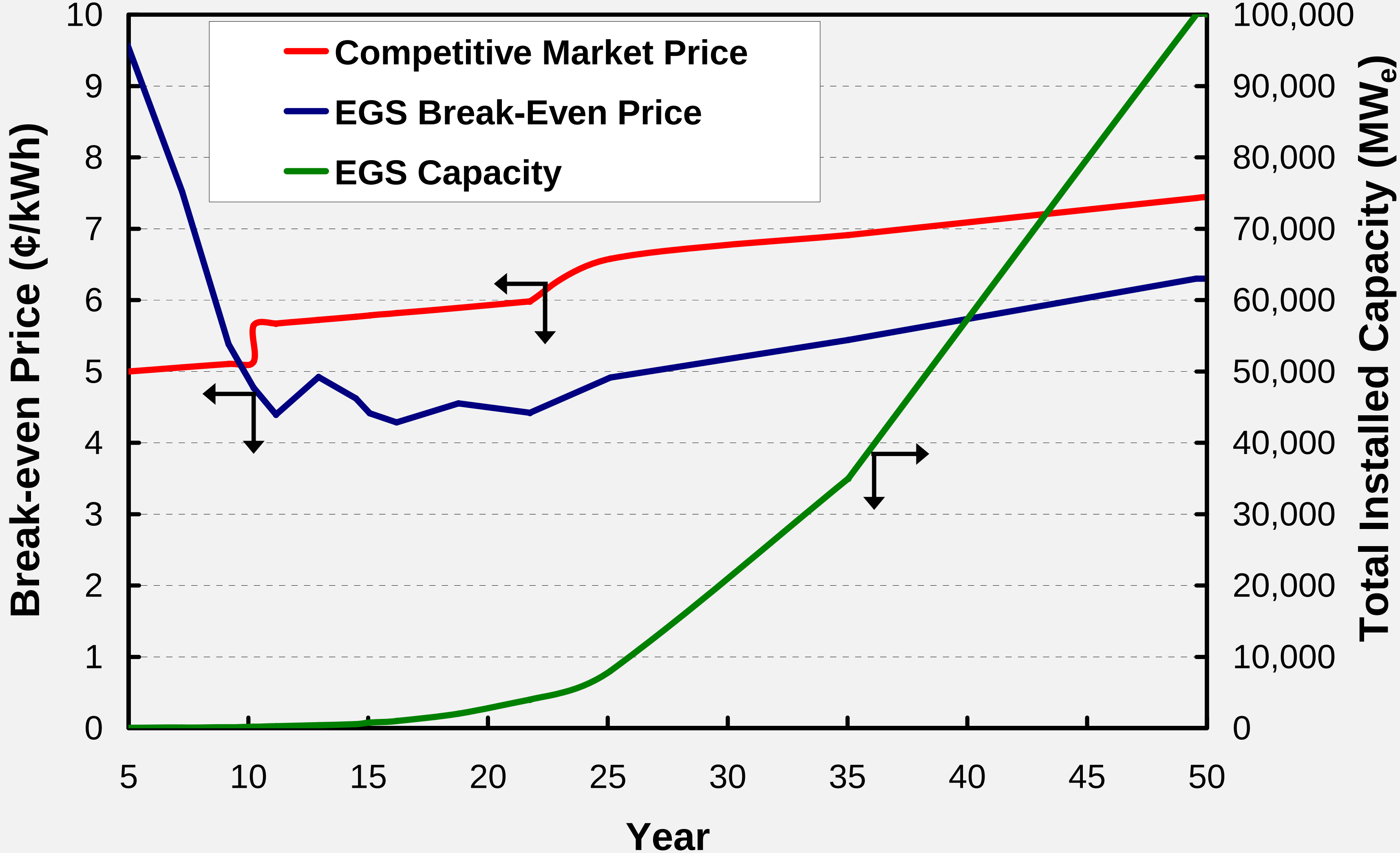
Much progress and many lessons learned in 30 years have clearly defined objectives going forward



Summary of major findings

1. **Large, indigenous, accessible base load power resource** – extractable amount of energy that could be recovered is not limited by resource size. EGS can sustain production of ≥100,000 MWe of base load electric power
2. **Fits portfolio of sustainable RE options** - EGS complements the DOE"s RE 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 are inherent modular making them easily scalable from 1+ to 50+ MWe size individual plants – grouping to large base load facilitiies >1000MWe
4. **Technically feasible** -- Much progress has been accomplished in 30+ years of testing worldwide – the major elements of the technology to capture and extract EGS are already 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.

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

Summary of major findings

1. **Large, indigenous, accessible base load power resource** – extractable amount of energy that could be recovered is not limited by resource size. EGS can sustain production of ≥100,000 MWe of base load electric power
2. **Fits portfolio of sustainable RE options** - EGS complements the DOE”s RE 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 are inherent modular making them easily scalable from 1+ to 50+ MWe size individual plants – grouping to large base load facilitiies >1000MWe
4. **Technically feasible** -- Much progress has been accomplished in 30+ years of testing worldwide – the major elements of the technology to capture and extract EGS are already 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 low** -- A modest investment of $300-400 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 are reasonable** – in comparison to other large impact alternative energy programs supported by the US govt.

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 $600 to 800 million for deployment assistance and research and development over 15 years -- $50 M/yr on average

Less than the price of **one clean coal plant**
Or the cost of developing **one new FDA approved drug!!**

Acknowledgements

Acknowledge Support for the Project provided by the Geothermal Division and its Laboratories

- ❑ **Idaho National Laboratory**
- ❑ **National Renewable Energy Laboratory**
- ❑ **Sandia National Laboratories**

We are especially grateful to the US DOE for its sponsorship and to many members of US and international geothermal community for their assistance, including Roy Mink, Allan Jelacic, Joel Renner,Jay Nathwani, Greg Mines, Gerry Nix, Martin Vorum, Chip Mansure, Steve Bauer, Doone Wyborn, Ann Robertson-Tait, Pete Rose, Colin Williams, and Valgudur Stefannson

Thank you