Status and Achievements in EGS Technology

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Status and Achievements in EGS Technology

- **Role on MIT panel**
- **Objectives**
- **Methodology**
- **Basis for analysis and assumptions**
- **Uncertainties**
- Affect of uncertainties on outcome
- Technology gaps and barriers
- Future work to overcome gaps and barriers

Role on MIT Panel

- Using data provided by Dave Blackwell and SMU group (Chapter 3):
  - Determine recoverable EGS resource
    - Conductive resource starting at 3 km
    - Convective resource above 3 km
- Review history of EGS technology development (Chapter 4) (Garnish, Batchelor, Baria, Tester)
  - Prepare database of EGS project data
  - Examine history of projects to determine lessons learned
- Evaluate current status of EGS technology (Chapter 5) (Baria, Garnish, Batchelor, Testor)
  - Determine current practice
  - Evaluate technology gaps
  - Recommend technology improvement areas

Objectives

- Make estimate of recoverable EGS resource in US
- Examine history of EGS development and lessons learned from past projects
- Determine current best practice for reservoir development
- Determine technical and economic feasibility of using EGS for power generation in US
- Recommend technology improvements to reduce cost and improve performance

Methodology for Study

- Recoverable resource
  - Use data from Blackwell/SMU on temperature at depth in 1 km slices
  - Review literature to determine standard practice for calculating recoverable heat
  - Review literature and work with power plant panel members to determine conversion efficiencies
  - Review available data on resource that should be excluded from development (Parks, wilderness recreation area)
  - Develop batch processing methods for determining project economics using DOE GETEM costing code
  - Develop database of site by site reserves estimates from existing data for identified EGS sites associated with hydrothermal sites from published sources

Energy from the Earth's Heat

- Conductive heat energy
  - Greater than 3 km
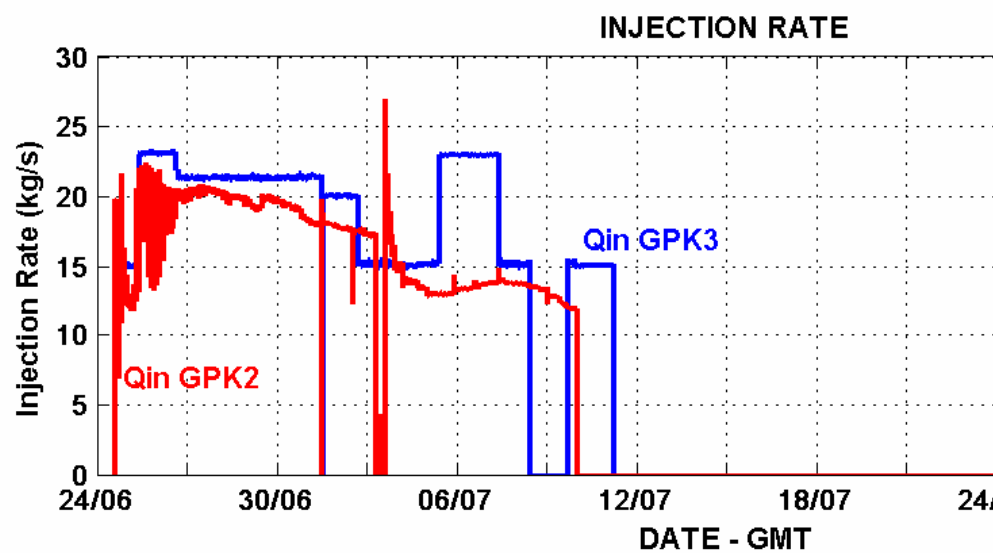 - Requires stimulation or other engineering to develop reservoir

- Convective heat energy
  - Hydrothermal systems
  - Impermeable or low permeability systems on the edges of hydrothermal systems
  - Fractured, but may require stimulation or engineering to develop

- Hot water co-produced with oil and gas

Methodology for Study

- History of EGS Technology Development
  - Review literature and data on past EGS projects
  - Meet with and discuss past projects with panel members and invited speakers
  - Prepare database of EGS projects including drilling data, well completion data, stimulation methods and test data
  - Evaluate data to determine lessons learned

Major EGS Projects Worldwide

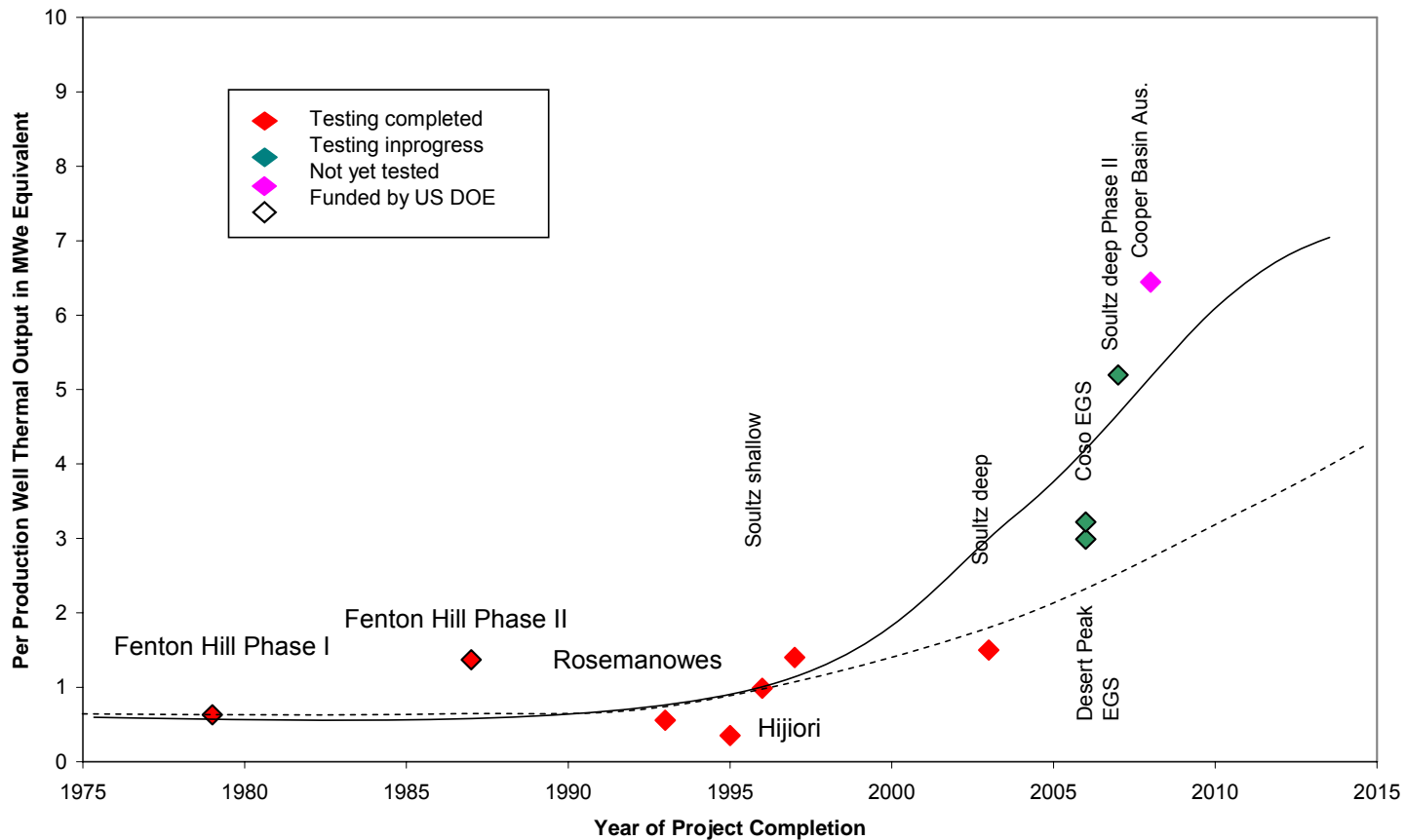| Year	France		Switzerland	Germany		UK	Sweden	USA		Australia		Japan	
1973													
1974								Fenton Hill Phase I 3000 m					
1975													
1976				Falken-berg 300 m		Rosema-nowes 300 m							
1977	La Mayet 300 m				Urach 3500 m								
1978													
1979													
1980													
1981													
1982						Rosema-nowes 2100 m						Ogachi Test Wells	
1983													
1984								Fenton Hill Phase II 4000-5000 m					
1985													
1986	La Mayet 800 m	Soultz 100 m				Rosema-nowes 2700 m							
1987													
1988													Hijiori 2000 m
1989													
1990		Soultz 3500 m			Urach Phase 2 4500 m						Ogachi OGC-1 & OGC-2 1000 m		
1991													
1992													Deepened to 2300 m
1993													
1994													
1995													
1996		Soultz Pilot Plant	Deep Heat Mining Basel Otterbach DHM-1 2200 m Geneva Planning				Fjallbacka						Hijiori Field Tests
1997													
1998												Ogachi OGC-3 1300 m	
1999													
2000													
2001		Soultz 5000m									Hunter Valley 3500 m		
2002									Desert Peak EGS	Cooper Basin 4300 m			Long-term Circ. Test
2003								Coso EGS					
2004													
2005													
2006													

Methodology for Study

- Subsurface system design current practice and issues
  - Review literature and data on current best practice for EGS stimulation
  - Meet with and discuss current technology with panel members and invited speakers
  - With panel members and outside experts determine issues and possible solutions for improving stimulation technology

Energy Output of Past and Current Projects

COMPARISON OF MAIN HDR RESERVOIRS IN THE WORLD

PROJECTS	PERIOD	MAX. ROCK TEMP. Deg C	RESERVOIR DEPTH meters	WELL SEPARATION meters	OUTLET FLOW l/s	WATER LOSSES %	IMPEDANCE MPa/l/s	THERMAL OUTPUT MWth	BREAKTHROUGH VOLUME Cubic meters
Los Alamos (USA)	1973-1979	232	3500	~ 150-300	~7	<10	2.5	~5	~ 80-100
Rosemanowes (UK)	1980-1993	80	2000	~ 180-270	~15	~25	0.4	~ 4	~ 200-300
Hijiori (Japan)	1985->	**270**	**2200**	~ 130	~12	~25	0.3	~7	~ 50-150
Soultz (France)	1989-1997	168	3500	**~ 450**	**~ 26**	**0**	**0.23**	**~ 11**	**~ 7000**
Anticipated 2000 +	1997->	202	5000	~ 600-700	~ 100	0	0.12	~ 50	~ 20,000
Actual in 2004	2004	202	5000	**~ 650 -730**	22 l/s	0	0.29 (2 wells)	~10	BTT 4.5 days

▮	**lower values = Advantageous; low running cost**
▮	**Higher value = Advantageous; bigger resource & longer life**
▮	**Lower value = Advantageous; lower capital investment.**
▮	**Best value achieved to date.**

RB/coparison1xls

Lessons Learned From Past Projects

- We can:
  - Drill deep, directional wells into hard, crystalline rock
  - 5000m for ~5 million EU ~$7.5 million (2003)
  - Reach targeted economic temperatures
  - Fracture large volumes – up to 2.5 km^2
  - Stimulate and improve permeability in pre-existing fractures
  - Map stimulated fractures using acoustic emissions
  - Drill into stimulated fractures
  - Make connection between wells at well separations that are suitable for long term heat mining
  - Complete more than one well in the same fractured volume
  - Circulate fluid between wells without high pressure drop
  - Circulate without high, or any, fluid losses
  - Circulate at moderate flow rates with potential for higher

Assumptions and Basis for Analysis

- Rejection temperature 10°C below mean temperature in 1 km slice
- Best case recoverability factor approaches 40%
  - 20% recovery likely
  - 2% conservative
- Energy conversion efficiencies based on resource temperature

Recoverable Heat
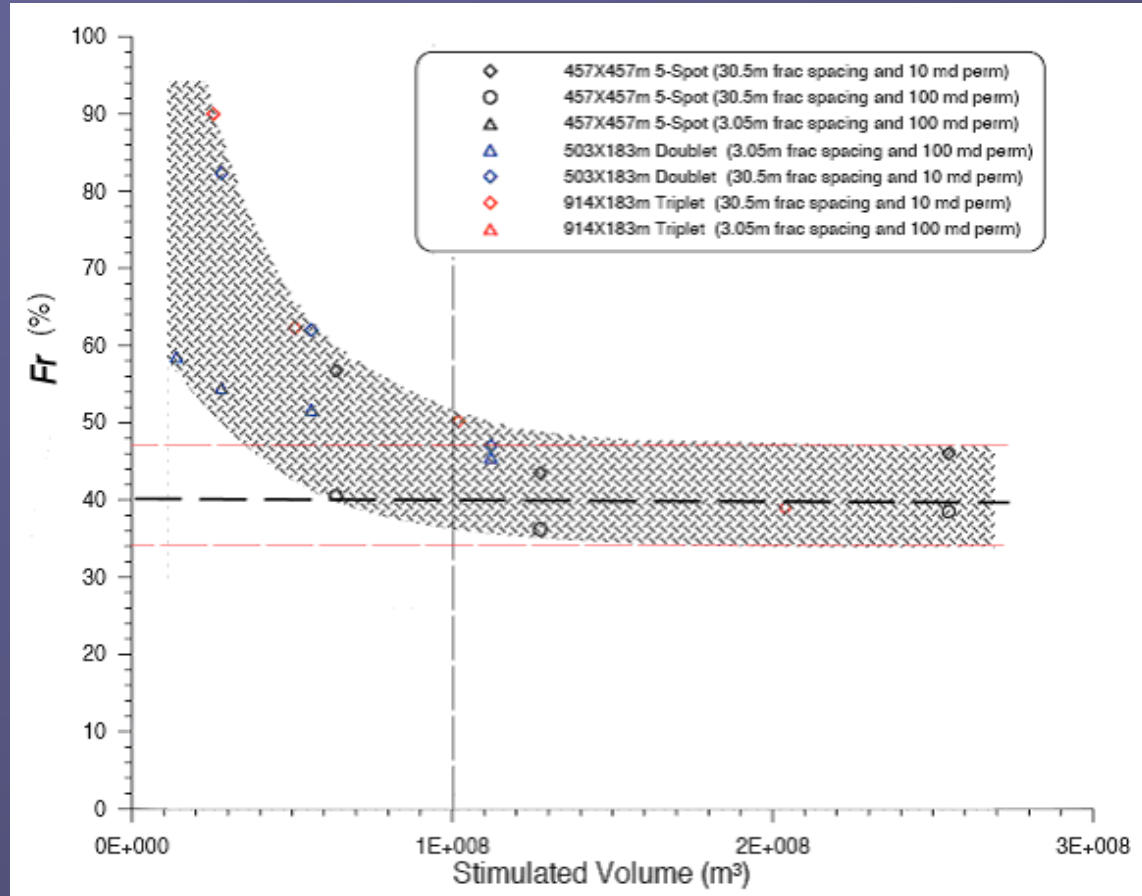
❑Sanyal and Butler, 2005.

Usable Energy – Converting Heat to Power

- Heat alone is beneficial.
- Conversion of heat to power better justifies well cost
- Heat in kilojoules = heat in kiloWatt-sec
- Convert heat to electric power
    - kW-sec/1000 kW/MW = MWt-sec
    - MWt-sec/(30 yrs in seconds)
    - Conversion efficiency MWt x ηth → MWe

Uncertainties

- Resource uncertainties
  - Temperature – range of temperatures in 1 km slices ±50°C
  - Areal extent of temperature at depth based on data density
  - Energy conversion efficiencies have large influence on calculated recoverable resource
- Uncertainties in history of technology development
  - Actual data availability limited.
  - Need to use mostly published data
  - Information filtered by author perception
- Uncertainties in assessment of current technology
  - Data on older projects hard to obtain
  - Current new projects in Europe and Australia
  - Data not always available.

Current Status of Technology

- How do we go about developing an EGS reservoir?
  - Install a microseismic monitoring system
  - Drill a well into high temperature rock >200°C
  - Evaluate the natural fracture system and stress state
  - Stimulate a large volume of rock by pumping cold water at just above the critical pressure for the local stress regime
  - Map the created fracture system using MEQ monitoring
  - Drill wells into created fractures
  - Re stimulate to improve connectivity
  - Circulate fluid by pumping production wells

Affect of Uncertainties on Outcome

- Range of values for recoverable resource
- Costs depend on temperature, depth and potential flow per production well.
  - Temperature variation linked to cost
  - Flow per well most important variable for cost but not related to recoverable resource
- Inaccessible areas with resource not directly removed- fraction that is inaccessible removed
- History of technology may be missing pieces deemed unimportant or detrimental to researchers efforts
- Status of technology constantly changing
- Technology for reservoir stimulation has very large impact on cost of power

Inaccessible Areas

- Some areas are inaccessible for development:
  - Parks – State and National
  - Recreation Areas
  - National Monuments
  - Wilderness

Subtract inaccessible fraction

Total Recoverable Power

| Total Recoverable Electric Power in Net MWe for 30 Years,						
20% Recoverable Fraction of Thermal Energy from the Reservoir						
Depth of Slice, km	Power available for slice, MWe	Amount at 150ºC, MWe	Amount at 200ºC, MWe	Amount at 250ºC, MWe	Amount at 300ºC, MWe	Amount at 350ºC, MWe
3 to 4	122,000	120,000	800	700	400	
4 to 5	719,000	678,000	39,000	900	1,200	
5 to 6	1,536,000	1,241,000	284,000	11,000	600	
6 to 7	2,340,000	1,391,000	832,000	114,000	2,800	
7 to 8	3,245,000	1,543,000	1,238,000	415,000	48,000	1,200
8 to 10	4,524,000	1,875,000	1,195,000	1,100,000	302,000	54,000
TOTAL	12,486,000					

Total Recoverable Power

Total Recoverable Energy in Net MWe for 30 Years						
2% Recoverable Fraction of Thermal Energy from the Reservoir						
Depth of Slice, km	Power available for slice, MWe	Amount at 150ºC, MWe	Amount at 200ºC, MWe	Amount at 250ºC, MWe	Amount at 300ºC, MWe	Amount at 350ºC, MWe
3 to 4	12,000	12,000	80	70	40	
4 to 5	72,000	68,000	4,000	90	120	
5 to 6	154,000	124,000	28,000	1,100	60	
6 to 7	234,000	139,000	83,000	11,000	300	
7 to 8	324,000	154,000	124,000	41,000	5,000	120
8 to 10	452,000	187,000	119,000	110,000	30,000	5,000
TOTAL	1,249,000					

Economic Modeling-GETEM

GETEM		BINARY SYSTEM INPUT SHEET		
Version:		GETEM-2005-A3 (dje-July-06-05)		
BINARY Case Name:		EGS-AC binary-200C-4km-2015-July 18 2005		
File Name:		GETEM-2005-EGS- 150C 2015-sp-1C-July 18 05		
		Baseline	**Change**	**Improved**
Case Date:	*1/8/2007*	**2005**		**2015**
Cost of Electricity, cent/kWh		**17.32**	**-63%**	**6.44**
Input		*Baseline*	*Change*	*Improved*
Global Economic Parameters				
Fixed.Charge.Rate	Ratio	**0.128**	**1.00**	0.128
Utiliz.Factor	Ratio	**0.95**	**1.00**	0.95
Contingency	%	**5%**	**1.00**	0.05
Input parameters				
Temperature of GT Fluid in Reservoir	Deg-C	**200**	**1.00**	200
Plant Size (Exclusive of Brine Pumping)	MW(e)	**500.0**	**1.00**	500.00
Number of independent power units		**10**	**0.50**	5.00
Brine Effectiveness (exclusive of brine pumping)	Calculate Y or N	**Y**		**Y**
If N (no), enter value in cell C19 and/or E19	W-h/lb	**8.00**	**1.00**	8.00
Calculated Brine Effectivenss	W-h/lb	10.86	**1.25**	13.57
Brine Effectiveness	W-h/lb	**10.86**		13.57
Apply improvement to reducing flow requirement or increasing power output	F - flow or power	P	**F**	
Plant Cost	Calculate Y or N	**Y**		**Y**
If N (no), enter value in cell C24 and/or E24	$/kW	$ **1,800**	**1.00**	$ 1,800
Calculated Plant Cost	$/kW	$ 1,551	**0.75**	$ 1,006
Plant Cost	$/kW	$ **1,551**		$ 1,006
Wells Cost Curve: 1=Low, 2=Med, 3=High		**4**	**1.00**	3
PRODUCTION WELL Depth	Feet	**13,123**	**1.00**	13,123
Estimated Cost, from SNL Curve	$K/well	*$6,955*	----	*$6,955*
User's Cost Curve Multiplier	ratio	**1.000**	TIO	1.000
Producer, Final Cost	$K/well	*$6,955*	**0.75**	$5,216
INJECTION WELL Depth	Feet	**13,123**	**1.00**	13,123
Estimated Cost, from SNL Curve	$K/well	*$6,955*	TIO	*$6,955*
Injector, Final Cost	$K/well	*$6,955*	**0.75**	*$5,216*

Supply Curve for U.S. Conductive EGS

Supply Curve for EGS Power in the United States

Supply Curve for EGS Power


Range of EGS Supply at Cost
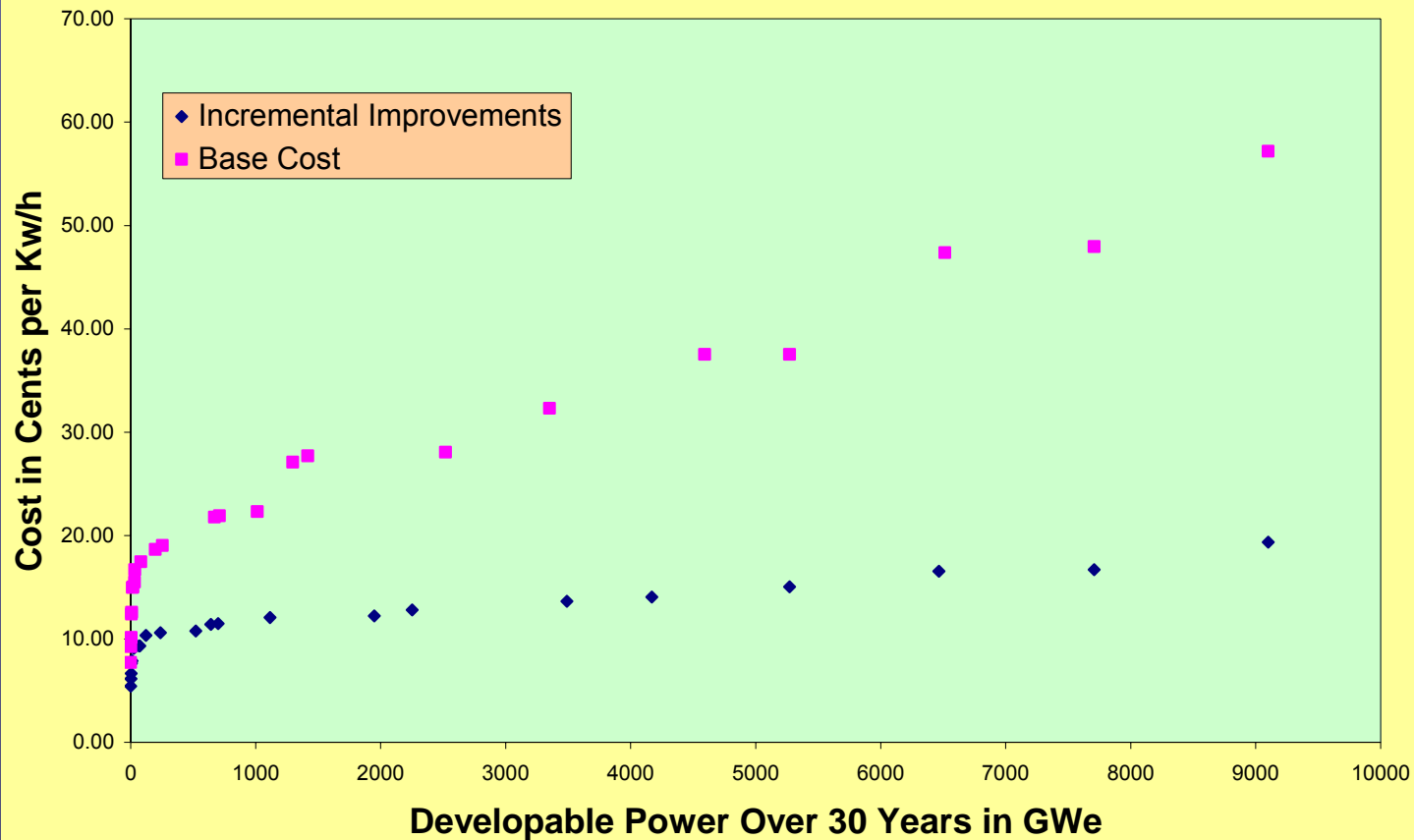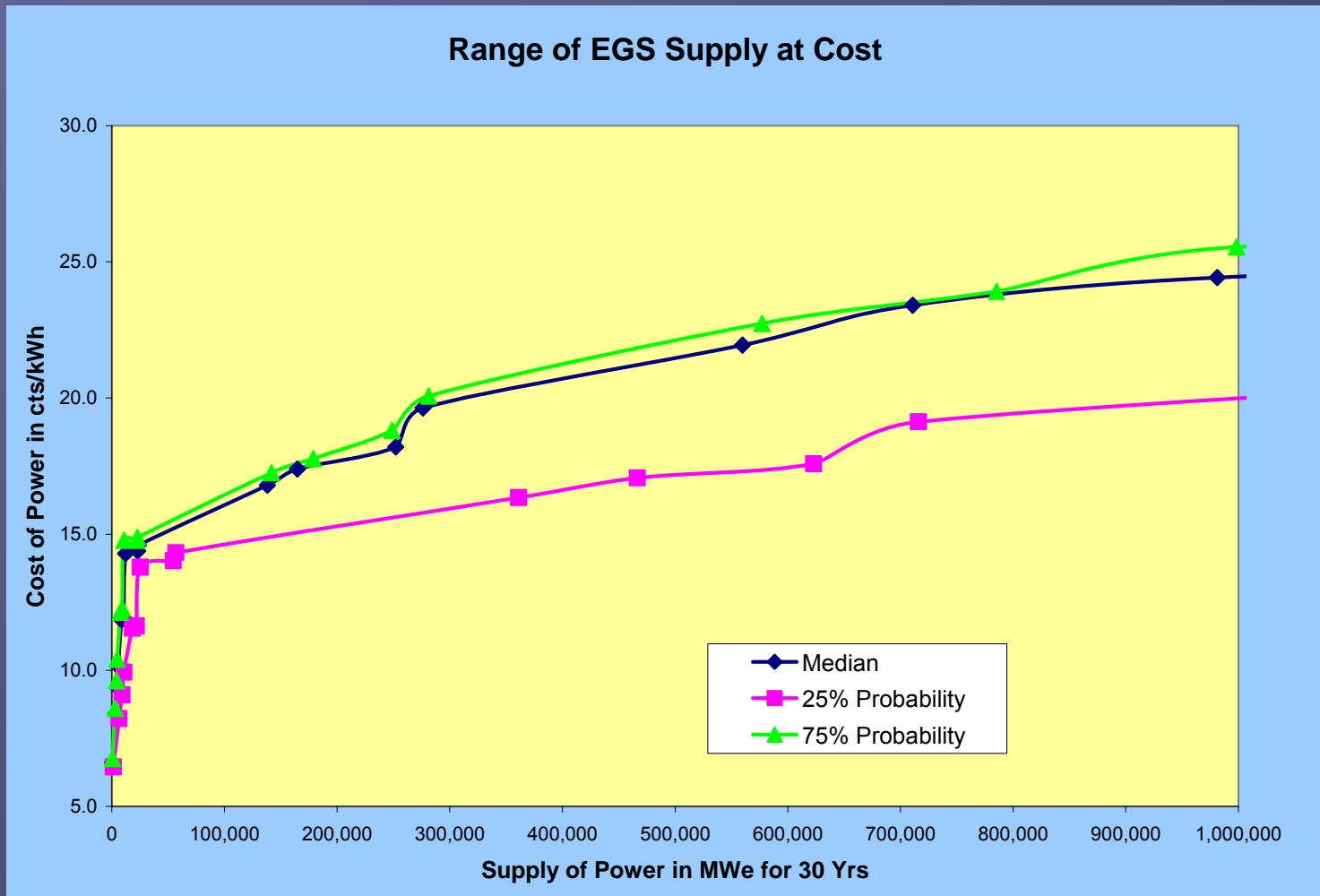
Reality Check EGS
What would need to happen to make EGS a reality?

- Reduce the cost of power through technology improvement and learning by doing
  - Increase flow rate per producer by improving stimulation methods
  - Reduce drilling cost by reducing number of casing intervals, improving rate of penetration and reducing risk
  - Improve conversion efficiency
- Demonstrate the technology at a number of sites with different geology
- Develop a large scale, ie >250 MW, commercial project with industry

Reaching the Goal

- To get 1000 MW of EGS power on line we need:
  - 1 well in 3 months, average 5 MW per well
  - 16 rigs drilling for three years
  - 4 sites with 250 MW potential
  - Test technology on edges of hydrothermal systems
  - Move to large areas of uniform hot rock at reasonable depth
 - Use hot oil/gas fields to get data and starting points for projects

50°C 100°C 150°C 200°C 250°C 300°C

5.5 km
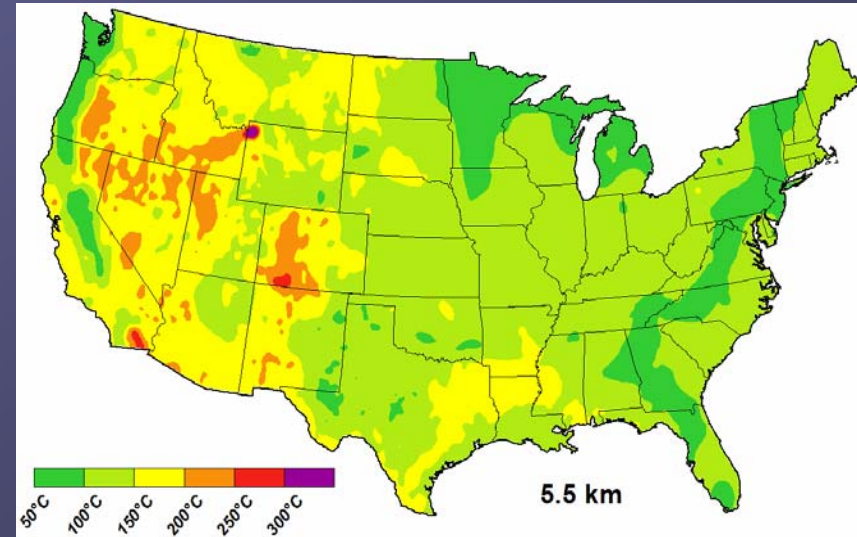
Technology gaps and barriers

- Need reliable methods to increase the fractured heat exchange area without inducing felt seismic events or making short circuits
- Need to divert stimulation to zones that have been less affected
- So far, can't reliably connect into an existing hydrothermal reservoir
- Short circuits may develop during treatment or during long term operation
- Injecting at high pressures to increase flow results in induced seismicity, reservoir growth and fluid loss
- Need to be able to pump production wells with electric submersible pumps at high temperatures to increase flow per well

Flow Profile & Significant Fracture Apertures
Openhole GPK-3 (4500 m - 5020 m)

CASING SHOE

~ 10% (5 l/s)

~ 70% (35 l/s)

~ 12% (6 l/s)

~ 8% (4 l/s)
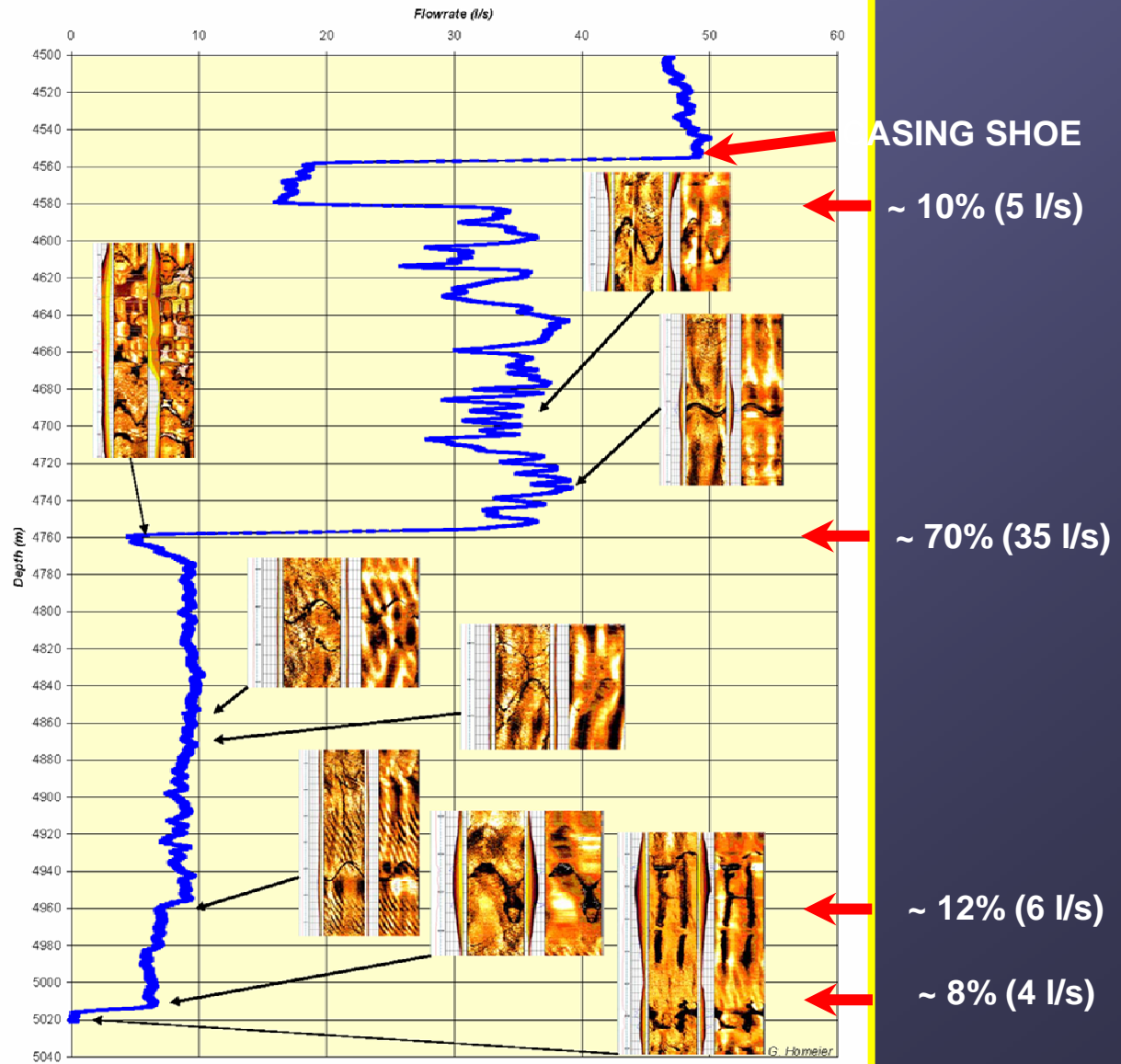
(G.HOMEIER, J.NICHOLLS)

Future Work to Overcome Gaps and Barriers

- Develop high temperature instrumentation to better evaluate fractures prior to stimulation (discriminate between open and sealed fractures)
- Develop methods to isolate zones for stimulation or divert treatment to unstimulated zones
- Develop methods for repairing short circuits
- Better understand link between stimulation, geology, tectonics and inducing felt earthquakes
- Develop high temperature electric submersible pumps