U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Geothermal Technologies Program Deep Dive

Technical Experts: **Arlene Anderson** (Planning & Analysis)
Jay Nathwani (System Demonstration)
Ray Fortuna (Component R&D)
Alison LaBonte (AAAS Fellow)
Tina Kaarsberg (Sr. Policy Analyst)

Program Manager: **Ed Wall**

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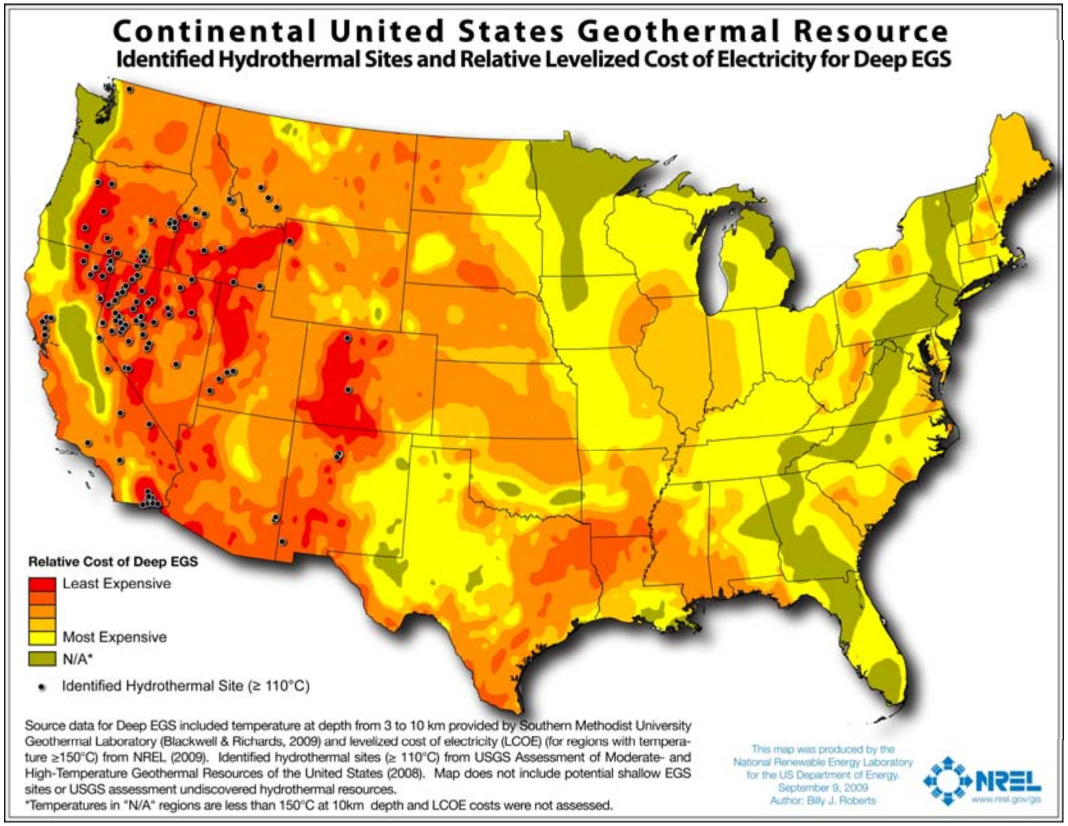
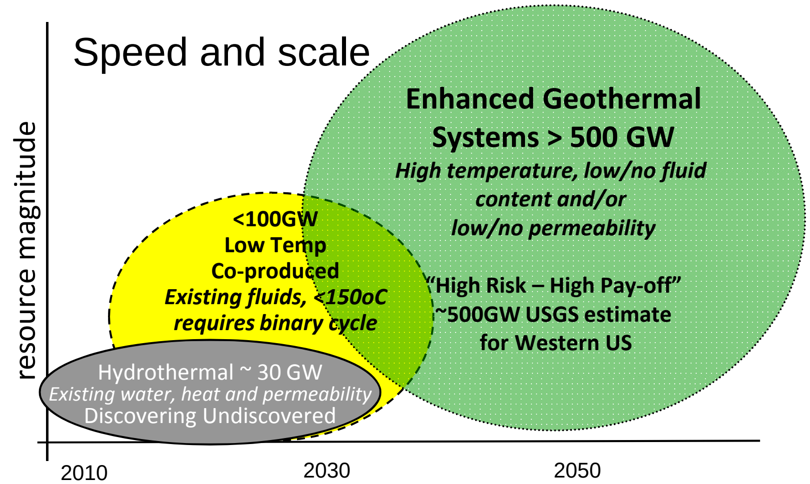
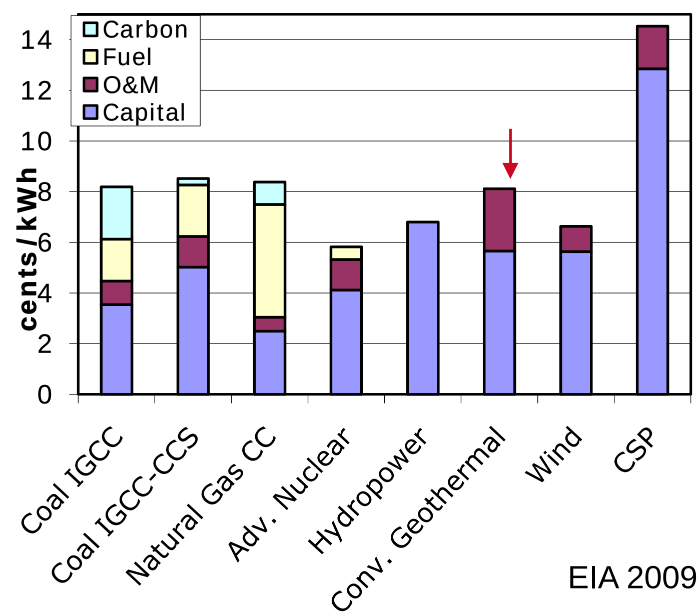
Geothermal Resource



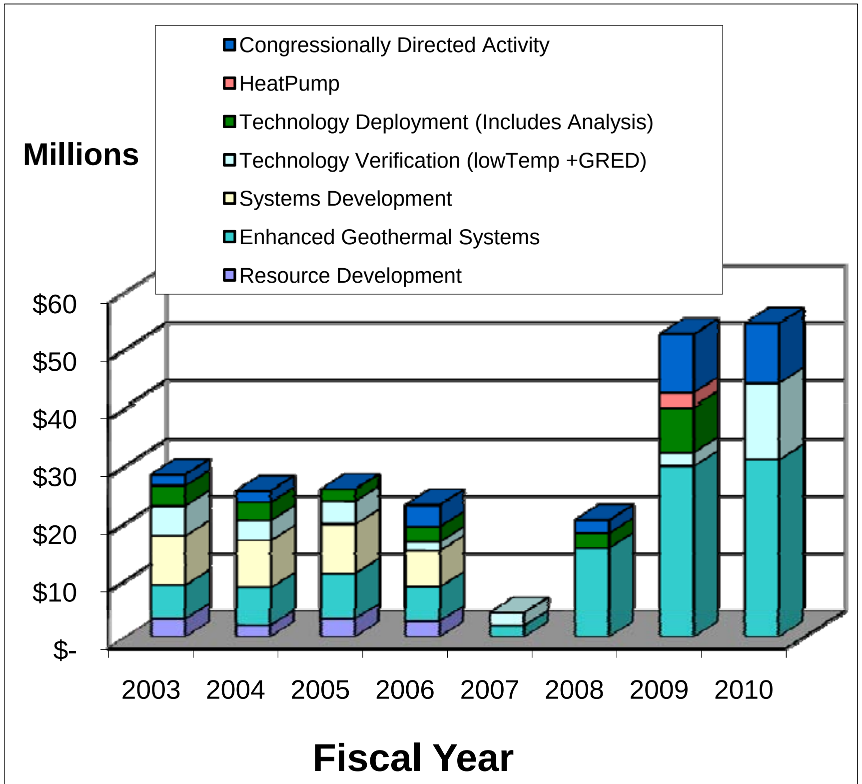


Benefit Description	Value of Benefit
Very Low to No Carbon Power	>7gmC/kwh vs. 270 for coal
Dispatchable (non-intermittent) Baseload renewable	>90% availability
Smallest surface footprint of any renewable	<2000 hectares per 100 MW

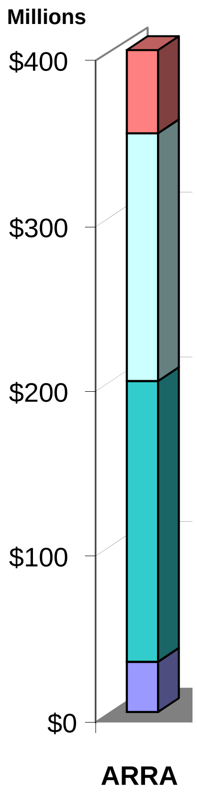


EIA 2009

DOE Geothermal Program Budget FY06-10



All actuals (<=2009) are after general reductions (SBIR, STTR, etc.)



GOALS

Complete resource assessment for hydrothermal, low-temp and EGS across the 50 states

Find 30GW of undiscovered hydrothermal using advanced remote sensing techniques

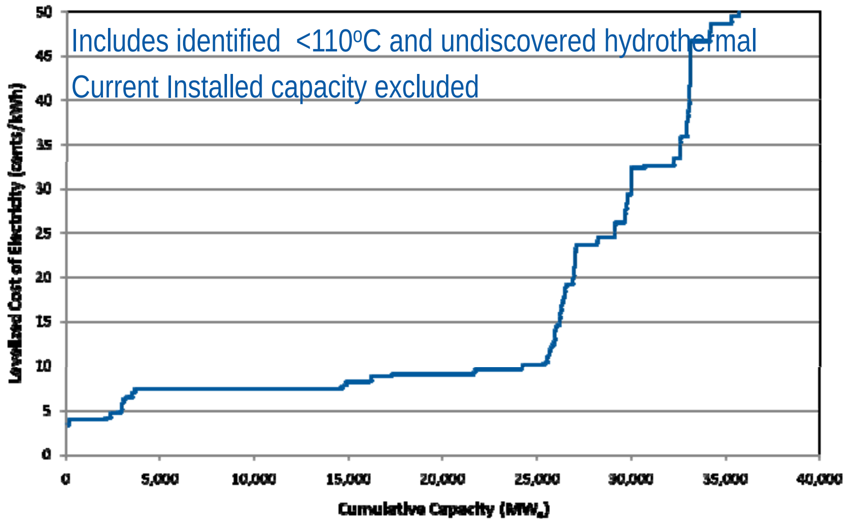
Validate that a 5-MW EGS is technically feasible by 2015 and sustainable to 2020

Geothermal Technologies Program - Methodology

PROBLEM	Explore	Develop	Compete	Select	Assess	OUTCOME
Need for focused RD&D base-line to optimize systems engineering	Technical goal setting through EERE-wide technology risk analysis. Expert opinions elicited to determine technology improvement ranges and develop supply curves for input to NEMS and MARKAL	Model expert inputs to assess improvement potentials of Program RD&D for: (1) EGS enabling technologies potential and (2) EGS cost improvement potential	Peer review conclusions and use as input to determining critical needs that can be funded through regular appropriations and where appropriate Recovery Act funding opportunity announcements	Select broad range of projects that target those areas that best enable EGS technical feasibility and lower costs.	Elicit expert opinion based on results of new technology and engage in next round of risk assessment to meet program technical goals and objectives	Enable EGS technical feasibility by 2015; identify additional areas of lower cost geothermal supply in or near existing hydrothermal and across the U.S
Well Field Construction	National Laboratory (Sandia) led an effort to explore EGS well field construction technologies	Domestic and international researchers identified critical technology barriers	Well-field development R&D topics were added to component R&D funding opportunity announcement	Component R&D awardees will be selected after conducting merit reviews	Component R&D awardees will be assessed through annual peer reviews and are subject to stage-gate reviews	R&D portfolio optimized to aim at largest challenges related to drilling and reservoir creation

Hydrothermal

Find 30GW of undiscovered hydrothermal and complete Resource Assessment



Status

- Largest producer in the world (3 GWe)
- Installed capacity projected to be doubled by 2013
- Installed capacity projected to be tripled by 2020
- Competitive to Coal and Gas
- Very little GHG emissions
- Funding:
  - 2009 - $0
  - ARRA - $100M will catalyze hydrothermal industry

Technical Barriers

- Tools and Signature Analysis to discover systems without surface expressions
- Need for Advanced Remote Sensing Tools
- Coupled Models (geochemical + geophysical + thermal + satellite)

Game Changing Breakthroughs

- Tools, Models or techniques that improves exploration success rate from 20% to 40% or more)

EGS R&D investment benefits hydrothermal
-> Hydrothermal exploration benefits EGS

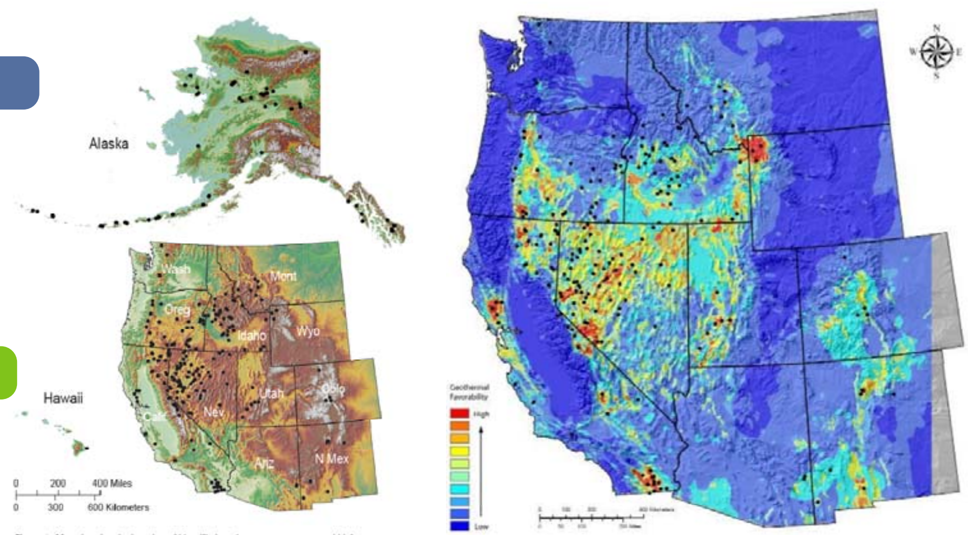


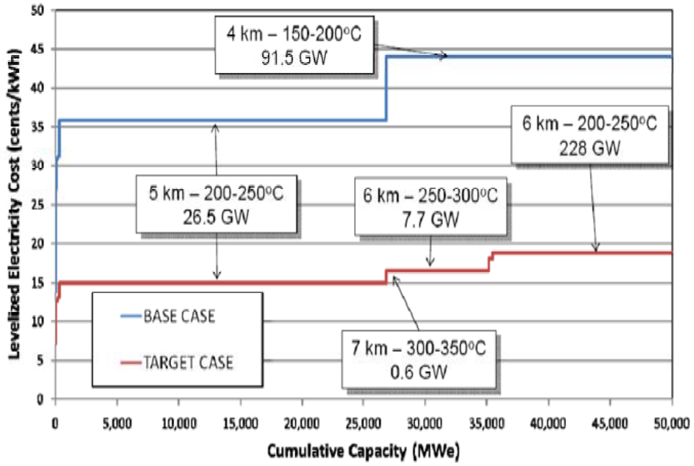
Figure 1. Map showing the location of identified moderate-temperature and high-temperature geothermal systems in the United States. Each system is represented by a black dot.

Gain insight by partnering with Energy and Service Companies

Enhanced Geothermal Systems

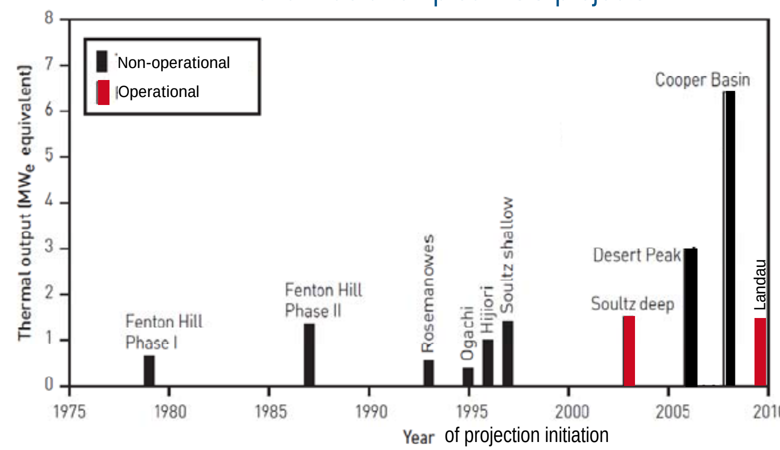
Deploy 100 GWe of EGS energy by 2050?

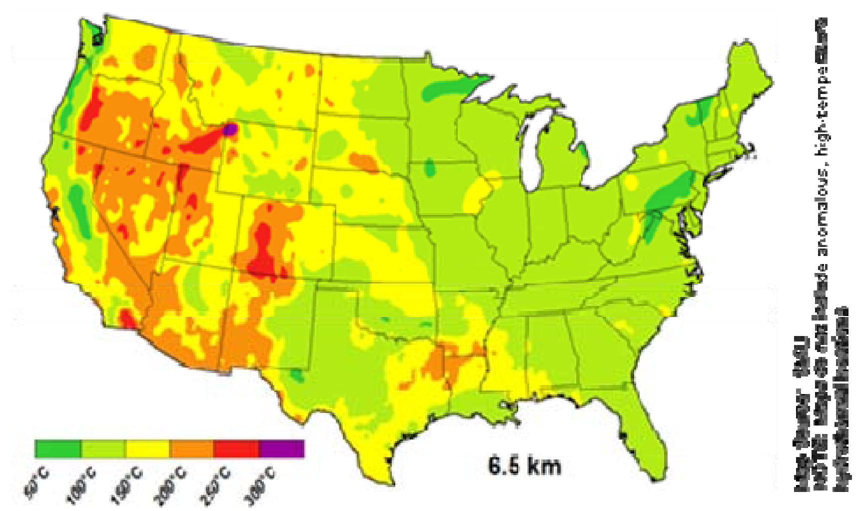
Base Case: 3%/year thermal drawdown rate, 30 kg/s producer well flow rate
Target Case: 0.3%/year thermal drawdown rate, 60 kg/s producer well flow rate
2:1 Production to Injector ratio



Status

World wide attempted EGS projects





Technical Barriers and Needs

- excessive well construction time (e.g. drilling and casing) & material cost (trouble costs high @ 4X hydrothermal)
- proving overall system (well, reservoir, plant) is scalable and replicable
- fracture stimulation modeling
- reservoir creation – fracturing
- sustain reservoir flow rate
- defined and controlled reservoir boundary

Game Changing Breakthroughs

- simultaneous drilling and casing; advanced drilling techniques (e.g. spallation) to reach 3 to 5x current speed through hard geothermal rock
- intelligent nanotracers and/or poro-chemo-thermo-elastic modeling for reservoir conditions, extent, permeability and pathway detection
- validation of C02 as a working fluid
- ability to model and control for induced seismicity
- heat mining techniques that don't require reservoir fracturing

EGS barriers common across sectors

EGS Supply Curve - LCOE

Levelized Cost of Electricity (LCOE) - cents/kWh						
BASE CASE (3%/yr & 30 kg/s)		Resource Temperature (°C)				
		150	*200*	*250*	*300*	*350*
Depth (km)	*4*	44.0	21.6	23.3	17.1	
	5	59.6	35.9	31.1	22.2	17.0
	6	85.5	50.6	44.2	30.9	23.3
	7	128.3	74.7	65.3	45.1	33.4
	8	198.3	114.0	99.7	68.0	49.9
	9	313.5	177.6	155.8	105.7	77.0
	10	504.6	281.2	247.5	167.2	121.3

Base Case

- 3%/yr thermal drawdown rate
- 30 kg/s production well flow rate
- 2:1 Producer/Injector Ratio

DOE Target Case

- 0.3%/yr thermal drawdown rate
- 60 kg/s production well flow rate
- 2:1 Producer/Injector Ratio

Levelized Cost of Electricity (LCOE) - cents/kWh						
TARGET CASE (0.3%/yr & 60 kg/s)		Resource Temperature (°C)				
		150	*200*	*250*	*300*	*350*
Depth (km)	*4*	20.3	12.6	10.9	8.6	
	5	24.7	15.0	13.1	10.1	8.2
	6	31.7	18.8	16.5	12.5	10.0
	7	43.1	25.1	22.4	16.5	13.0
	8	61.4	35.8	32.3	23.3	18.1
	9	92.4	53.3	48.3	34.5	26.4
	10	145.2	82.4	74.8	52.6	40.0

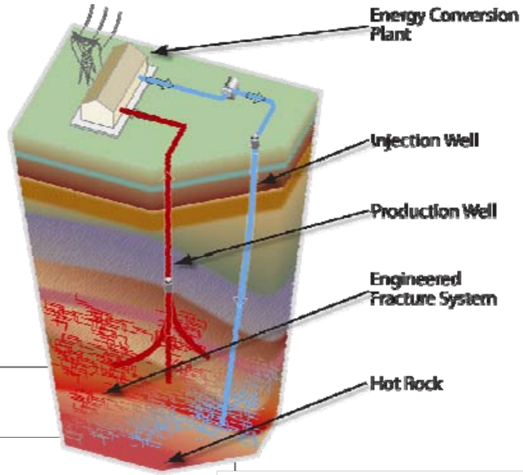
National Renewable Energy Lab, 2009 Geothermal Supply Curve

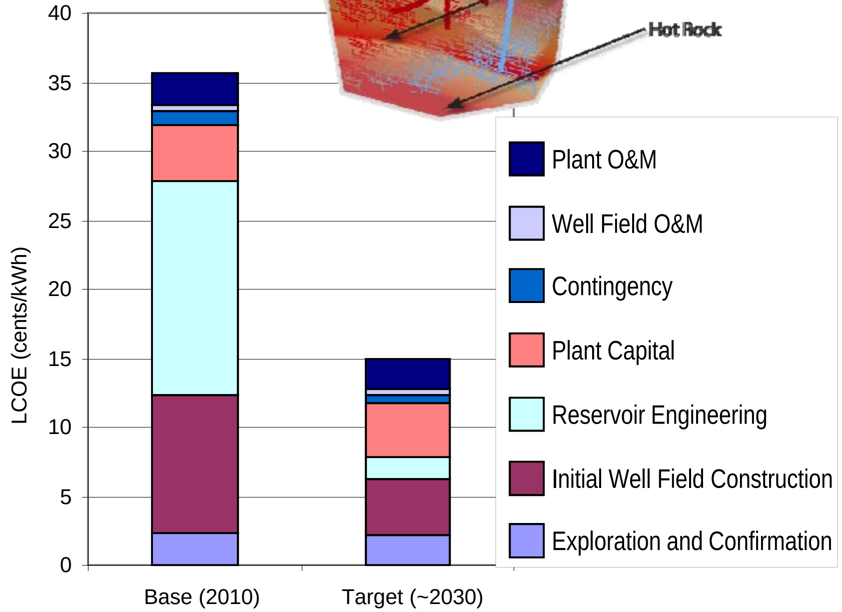
Cost analysis provides guidance for R&D efforts (EGS)

$20M in 2009 and 2010, $82M of ARRA to Enhanced Geothermal Systems R&D

Component	Base Case [1] (cents/kWh)	Barrier / Approach	Invested in R&D (2008)	ARRA R&D
Exploration	2.3	3D-Dimensional Resistivity Seismic Imaging	$0M	$1.5M
Initial Well Field Construction	9.9	Drilling Systems Downhole Tools Temporary Sealing of Fractures Downhole MWD Tools for Directional Drilling	$9M	$31M
Reservoir Engineering	15.5	HT HV lifting Zonal Isolation Image Fluid Flow Induced Seismicity Stimulation Prediction Models Tracers and interpretation Future characterization	$11M	$22M
Power Plant	4.1	Air Cooling Working Fluids for Binary Power Plants Supercritical C02 Recovery from Geothermal Fluids	$0M	$28M
Others	4.2	Not a focus	No funding	

[1] NREL Report on the US DOE Geothermal Technologies Program's Risk Assessment 2009





Base Case: 3%/year thermal drawdown rate, 30 kg/s producer well flow rate

Target Case: 0.3%/year thermal drawdown rate, 60 kg/s flow rate

Potential Showstoppers

- Seismicity concerns
- Availability of water resource

Low Temperature/Co-Produced/Geopressured

New resource assessment and cost data are needed to evaluate potential

Status

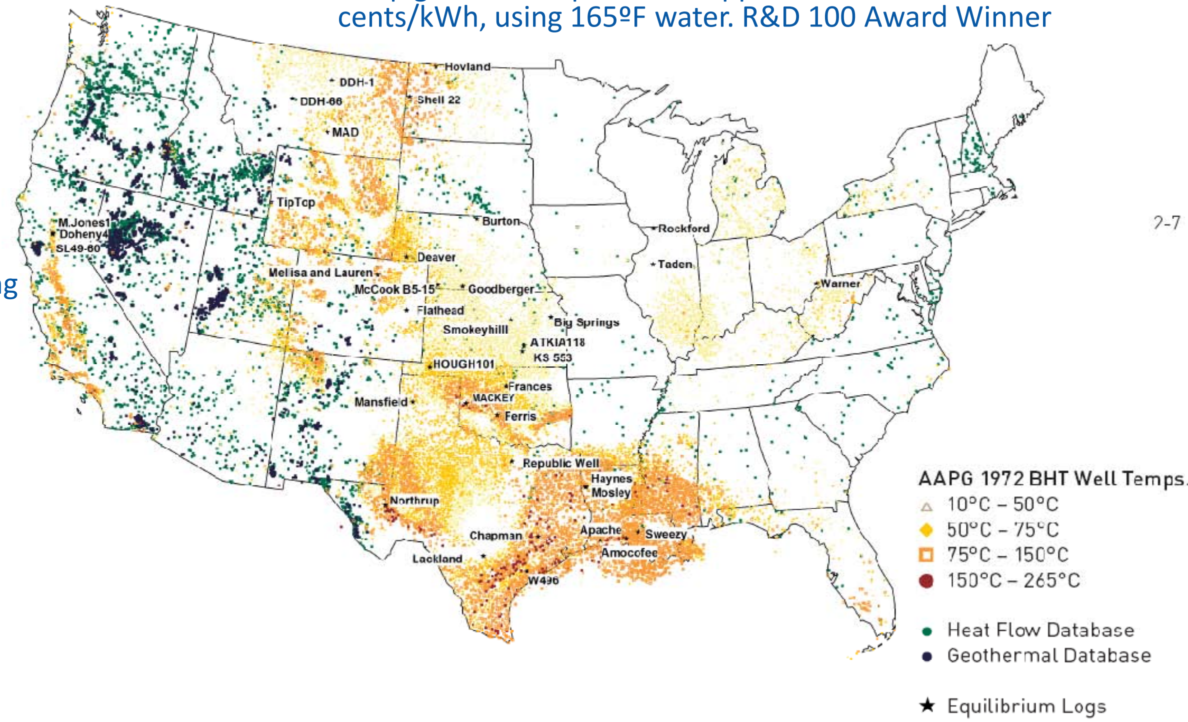
- 7.5 GW estimated potential from currently operating oilfields in 8 states
- Speedy modular plant construction has been demonstrated
- ARRA Funding (13 projects):
  - Low-Temp $12.5M
  - Geo Pressured $10M
  - Co-Produced $4.3M
- 2 GTP-funded projects currently operating in AK & WY
- **Collaboration with FE:** 1 Project operating at RMOTC. One 250-kW unit since 2008, another to be added. Objective is to gather data on reliability, capacity, climate variation, O&M needs, costs, etc.
- **Demonstration in AK:** Chena Hot Springs Resort uses 2 low temp geothermal plants to support all resort needs at 5 cents/kWh, using 165ºF water. R&D 100 Award Winner

Technical Barriers

- Long-term testing and reliability data needed
- Variable climate performance standards lacking
- Levelized Cost of Electricity (LCOE) data unknown
- High per-MW operation and maintenance costs

Game Changing Breakthroughs

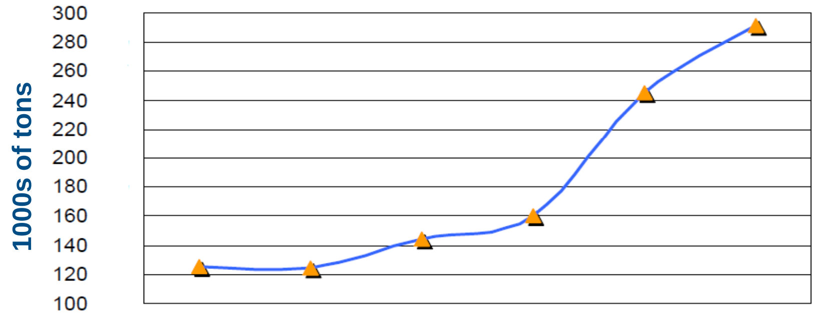
- Improved binary system working fluids
- Units adapted and optimized for this application
- New thermodynamic cycles for energy conversion (e.g. Hampson-Linde MEMs-Rankine)



These technologies have large near-to-mid term potential benefits

Increase Geothermal Heat Pump Deployment/Industry Scale – Address Market Barriers

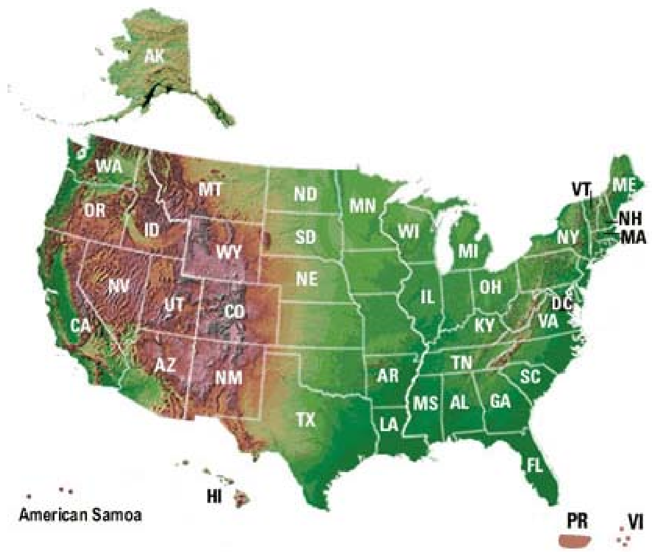
Rated capacity of annual shipments



Source: Energy Information Administration (EIA)
Form EIA-902, "Annual Geothermal Heat Pump Manufacturers Survey."

Status

- U.S. installed base ~ 1 million, <1% of all HVAC
- Double-digit annual growth for past 3-4 years
- Barriers – installation cost, limited installation infrastructure, lack of consumer awareness
- Minimal GHG emissions, highly efficient HVAC option for residential/commercial building applications
- Funding:
  - 2009 - $2
  - ARRA - $50M will increase deployment



GHPs – A 50 State HVAC Solution

Technical Limitations

- Validated hybrid system design & simulation tools
- Commercial-quality horizontal/lake/pond loop models and improved GHP design tools
- Detailed earth and well temperature data to facilitate installation of ground loop

Game Changing Breakthroughs

- Improved working fluids and loop designs obtained through new R&D activities that will reduce cost and improve performance
- Optimized drilling rigs and techniques that tangibly reduce cost and drilling time

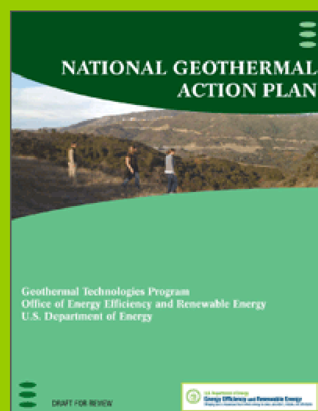
Need to develop new financial/delivery models to increase market adoption

Inter-Agency and Departmental Collaborators critical to achieving objectives

Interagency Geothermal Working Group

U.S. Department of Energy
- Office of Science
- Office of Fossil Energy
- Office of Electricity Delivery and Energy Reliability

- U.S. Naval Air Weapons Station Geothermal Program Office
- U.S. Department of Defense
- National Research Council Committee on Earth Resources
- U.S. Environmental Protection Agency
- National Science Foundation
- U.S. Department of Agriculture
  - U.S. Forest Service
- U.S. Department of Interior
  - U.S. Geological Survey
  - Bureau of Land Management



Outcomes:

National Resource Assessment and Classification, Inter-Agency Agreement (ARRA)

Streamline Geothermal Permitting

Leverage RD&D Funding

Coordinate ARRA Metrics

Address Environmental and Transmission Issues

Facilitate System Demonstrations

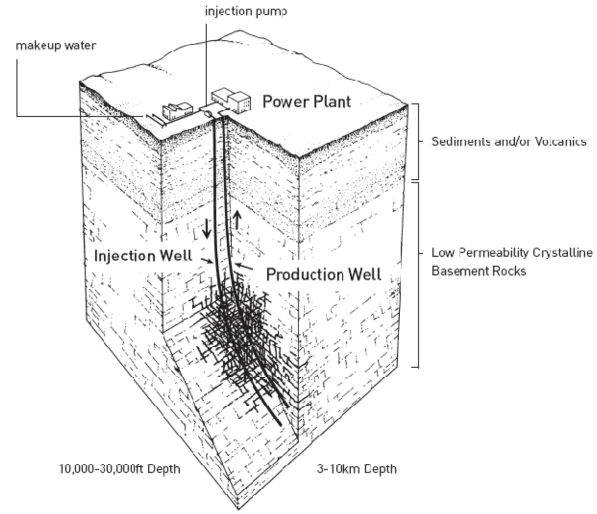
The Geothermal Technologies Program

BACKUP

Geothermal Illustrated Glossary

- ***Hydrothermal Resource:*** an underground reservoir of hot pressurized water in permeable rock that can be used to generate electricity with a ***steam turbine*** (for T>300F) or with a ***binary cycle*** (for T=150-300F).

- ***Enhanced Geothermal System*** *(EGS)* an underground area of hot rock that can engineered, by adding fluid and/or enhancing rock ***permeability*** to act like a ***hydrothermal resource***. See Figure right.



Schematic of a conceptual two-well EGS in hot rock in a low-permeability crystalline basement formation.

	Term/Definition
EGS	*Directional drilling* – The science of drilling nonvertical wells; it is sometimes known as slant, horizontal or deviated drilling. *Heat Mining:* A process that includes the use of at least one injection well and at least one production well to extract heat from the Earth. Water is pumped down to and circulates through the fractured reservoir; the natural heat exchanger delivers hot, pressurized water to the production well(s). The thermal energy is converted into electric power by means of a turbine-generator unit; *Makeup water:* in EGS context, water added to provide geothermal fluid as part of engineering a reservoir. *Permeability:* The capacity for upflow through tectonically active continental crust, resulting in a pathway for geothermal fluids.
Cross-cutting	*Conventional Hydrothermal:* Oldest type of geopower made from a hydrothermal resource at T>300F with a ***steam turbine*** . Mature Technology *Binary cycle* – An energy-conversion system that uses a closed Rankine cycle having an organic working fluid that receives heat from a hot geofluid and rejects waste heat to the surroundings while generating electrical power. Commercial, but not fully mature technology. *Identified Resource:* when referring to geothermal resource, denotes hydrothermal resource with a surface expression. *Potential Resource:* USGS term to denote the fraction of a resource that is recoverable *Reservoir:* In the geothermal context, refers to an area of underground rock pore spaces holding geothermal fluid. *Steam Turbine:* Rankine cycle prime movers used with hydrothermal resources include flash steam turbines, and dry or hot water steam turbines. *Unidentified Resource*: when referring to geothermal resource, denotes hydrothermal resource without a surface expression.

Hydrothermal Resource *(Potential)* in the Western US

Identified Resources
- Mean = 9,057 MWe
- F95 = 3,675 MWe
- F5 = 16,457 MWe

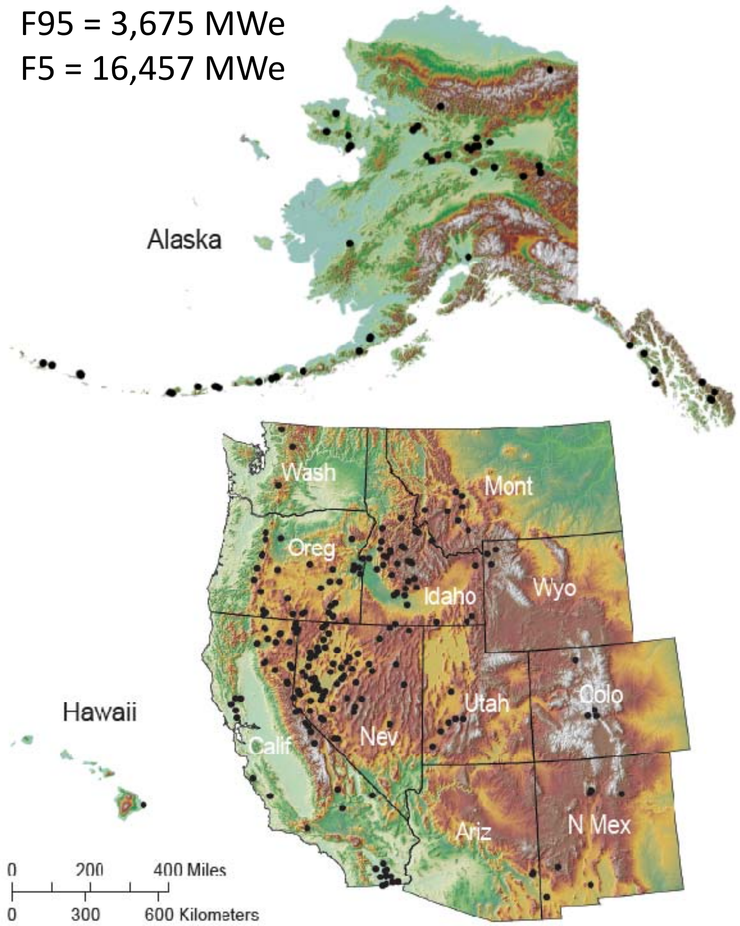
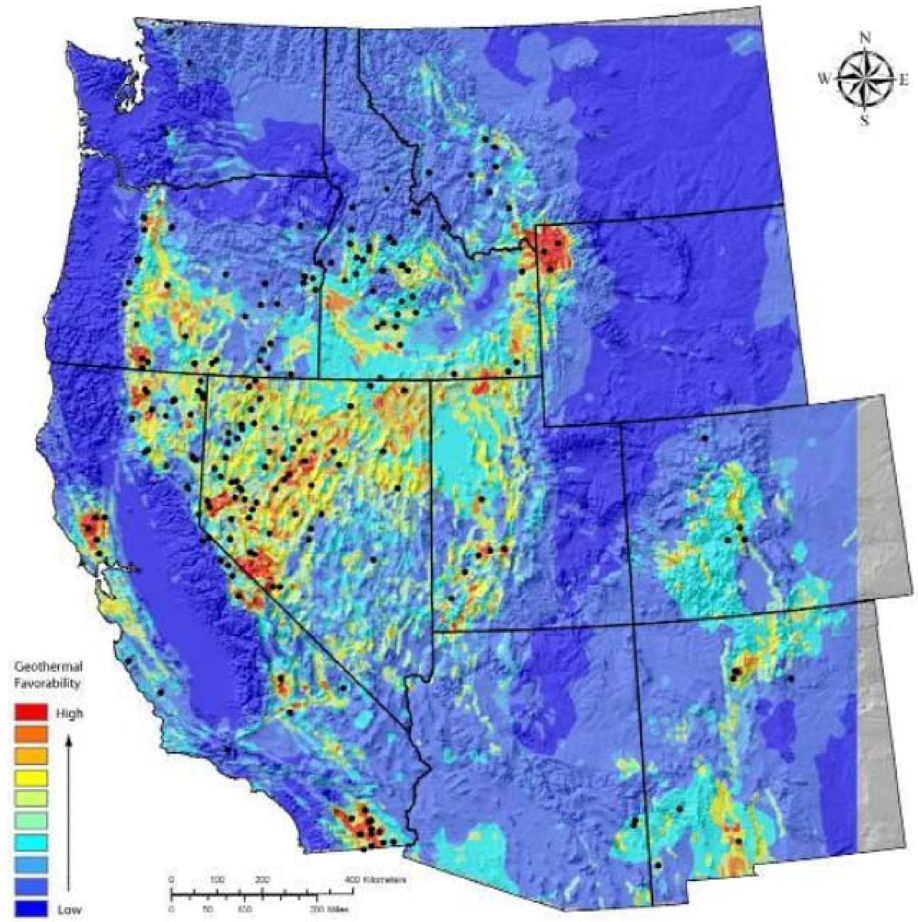


Figure 1. *Map showing the location of identified moderate-temperature and high-temperature geothermal systems in the United States. Each system is represented by a black dot.*

Undiscovered Resources
- Mean = 30,033 MWe
- F95 = 7,917 Mwe
- F5 = 73,286 MWe



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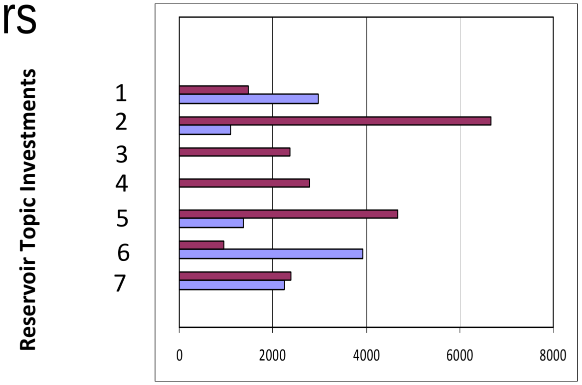
Using Funding to Overcome Major Barriers

High Cost of Reservoir Creation ($31 M)

1) Fracture Characterization
2) Tracers & Tracer interpretation
3) Stimulation Prediction Models
4) Induced Seismicity
5) Image Fluid Flow
6) Zonal Isolation
7) HT HV lifting

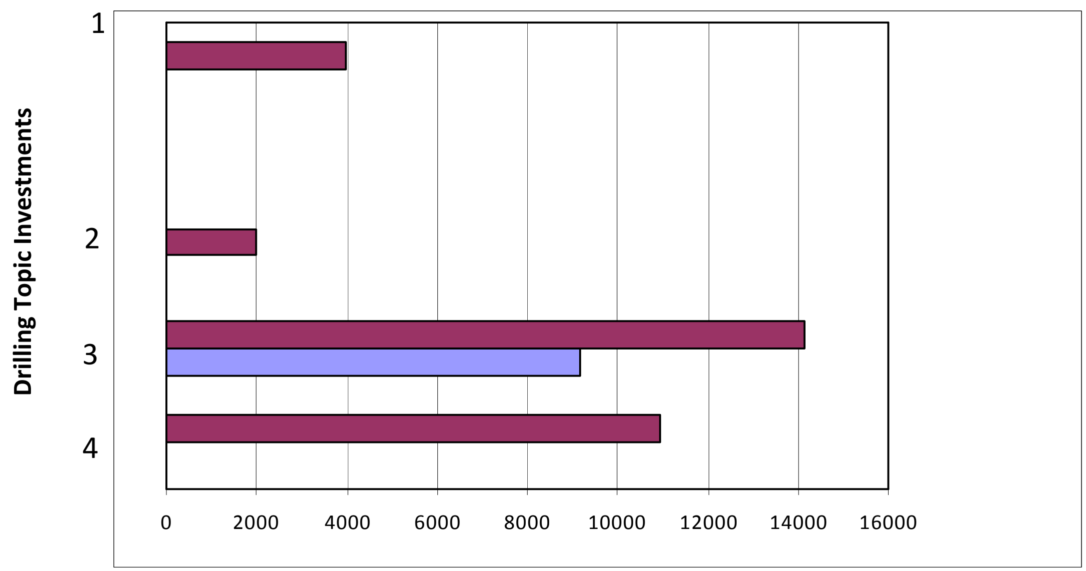


FY 2008

FY 2009, incl. ARRA

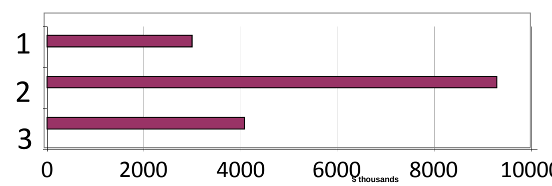
High Cost of Drilling ($ 40 M)

1) Downhole MWD Tools for Directional Drilling
2) Temporary Sealing of Fractures
3) Downhole Tools
4) Drilling Systems



High Plant Cost ($16 M)

1) Recovery from Geothermal Fluids
2) Working Fluids for Binary Power Plants
3) Air Cooling



All Funding $ thousands