Transitioning Coal To Geothermal

Baseload Renewable Power with No CO2

The Energy Under Our Feet

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Replace Coal With Geothermal

- 50,000 MW of aging coal fired generation needs to be repowered or shut down because it can't meet current emissions standards
- *Repowering with natural gas doesn't solve the problem of greenhouse gas emissions and many of these plants need expensive gas pipelines to provide enough supply to repower with gas*
- *Repowering with EGS takes advantage of existing infrastructure, means zero emissions with very low cost to operate and keeps jobs.*

This takes radical rethinking.

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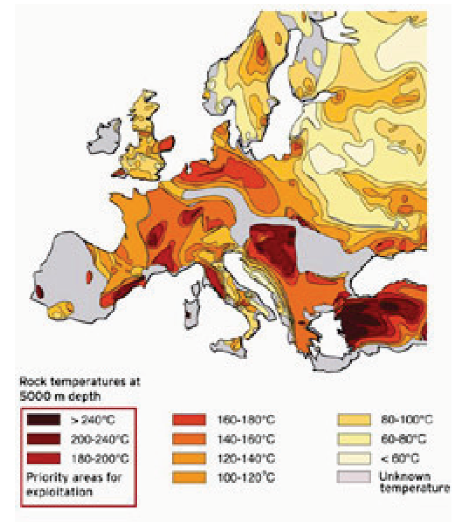
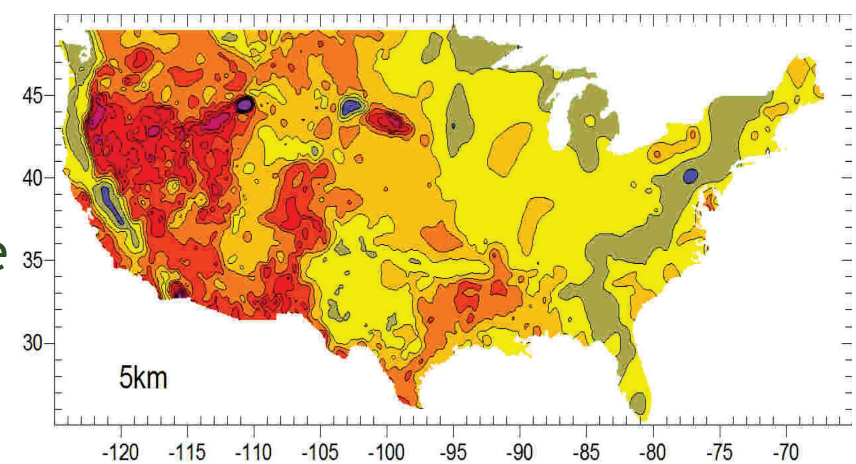
The Resource is Enormous

- Enormous resource stored as heat in rock
- Natural heat flow recharges stored heat
- Areas with high heat flow
  - Across the US
  - Around the world
- We can generate power and use the heat with today's technology
- We can make it cheaper with tomorrow's
- USGS: 500,000 MW of recoverable heat resource in the Western US



Rock temperatures at 5 km depth



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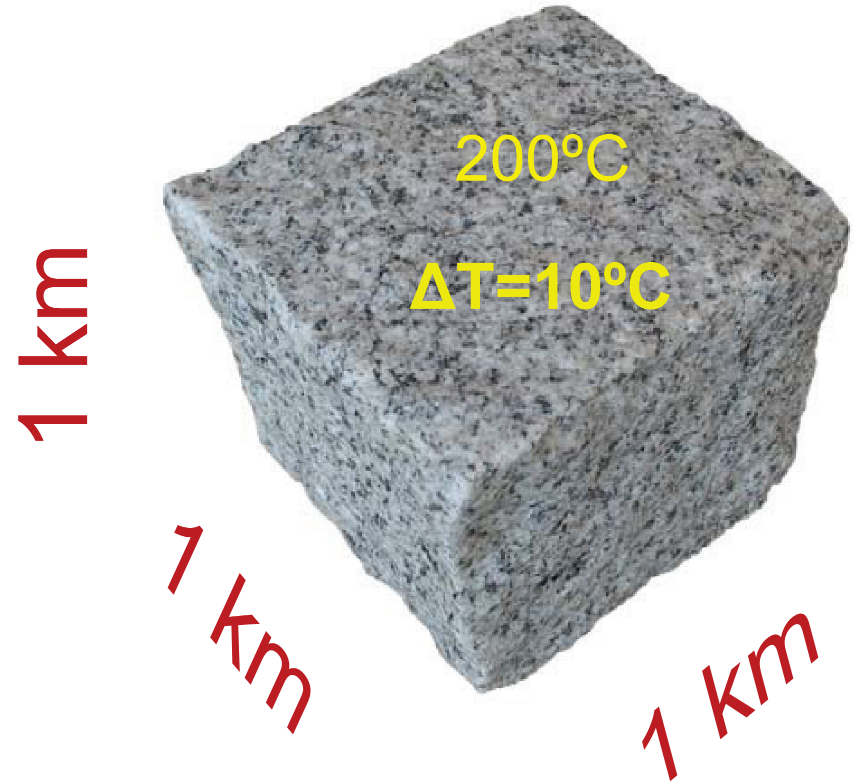
Heat Stored in Rock



1 km^3 Granite

3,490,000 BBL of Oil
Equivalent
or
1,360,000 MWh
as electricity
(155 MWe)

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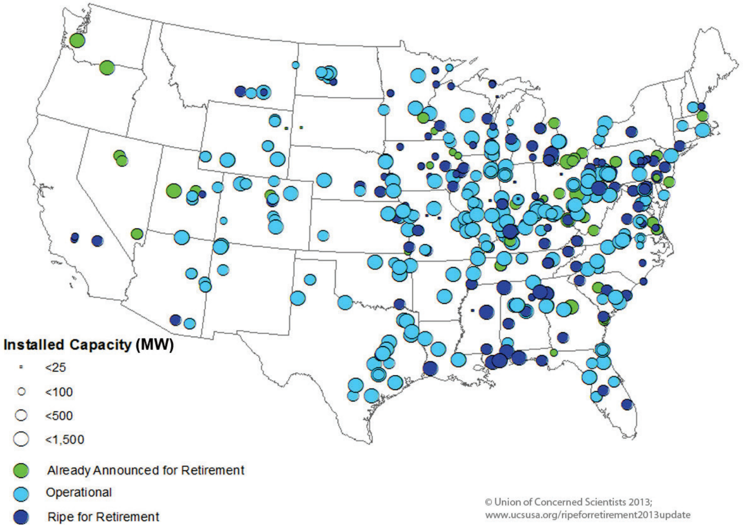
50,000 MW Aging Coal Fired Power Plants

- Plants more than 50 years old
- Currently can't be relicensed because they don't meet emissions standards for mercury, CO2, NOX, SOX, particulates.
- Can't be repowered for coal to meet standards: Too expensive
- Repowering with natural gas
  - Still doesn't solve the greenhouse gas problem
  - Subject to gas pricing volatility long term
  - Many of these plants need an expensive gas pipelines to convert to gas
  - The public and environmental groups push back



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Coal Plants Ready for Retirement

- Clean power plan has accelerated the timing for coal retirement in the U.S.
- COP21 commitments will extend this worldwide
- Air quality issues are impacting coal plant new development even in China.
- Replacement with EGS allows transition gradually over time for power generation, workforce and takes advantage of infrastructure

Years Built	# of Units	Total Capacity (MW)
2005-2009	21	6,785
2000-2004	13	1,382
1995-1999	24	4,372
1990-1994	67	8,638
1985-1989	102	23,734
1980-1984	117	56,105
1975-1979	125	55,879
1970-1974	137	66,466
1965-1969	158	41,656
1960-1964	157	25,310
1955-1959	209	28,883
1950-1954	213	17,518
1940-1949	93	2,583
1930-1939	20	132
1920-1929	10	69

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The Solution: Advanced EGS Geothermal Technology

- Need to drill ~10,000 deep geothermal wells to supply 50,000 MW of power with geothermal
- In order to do this over the entire US we need advanced EGS technology
- Phased development while coal plant runs can maintain revenues/jobs
  - Workforce development to transition coal plant workers to geothermal
  - Reduced generation from coal plant as geothermal generation increases reduces emissions
  - Learning by doing and technology improvement will reduce costs as we build
- Binary closed loop zero emission power generation technology
- Can use waste water from coal plant holding ponds to fill EGS reservoir
- EPRI Feasibility Study completed showing technical feasibility and economics

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Old Coal Plants: Waste Water

- Waste coal, liquid coal waste, coal ash and scrubber sludge can't be discharged without treatment
- Holding untreated wastewater in ponds at plants
  - Overflow to rivers and lakes in Maryland, West Virginia, Alabama
  - Groundwater contamination in North Carolina, Maryland, Tennessee
- Disposal to treatment plants not set up to handle these contaminants
- Fines for disposal into inland waters
- Public concern over environmental risk

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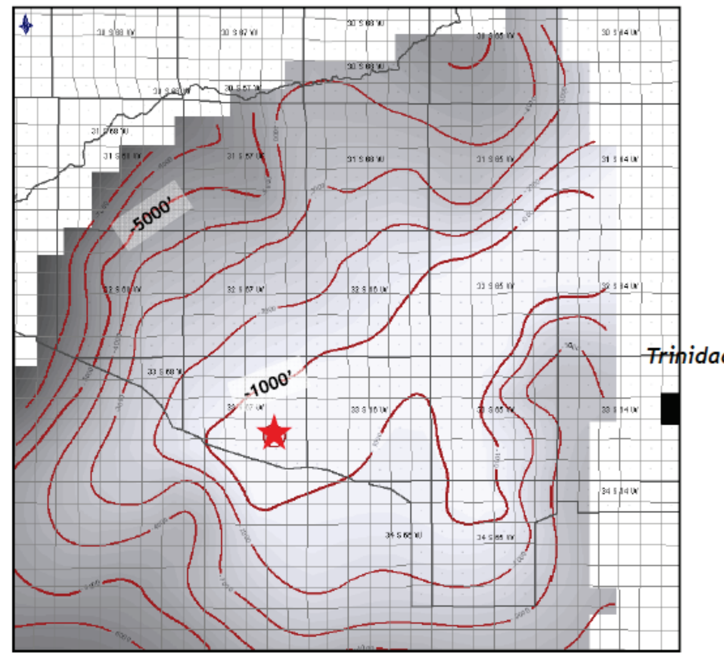
Combining Waste Water Injection and EGS Power Generation

- Phased development of geothermal resource uses up waste water while coal plant continues to operate
- Put surplus water to work generating electric power
  - Use water to develop EGS reservoir
  - Lose water to the reservoir during power project operation
  - Lose water to evaporation for wet cooling
- Reduce cost of managing waste water
- Use generated power to gradually replace coal fired generation
- Take advantage of higher than normal temperature gradients
  - Option 1: Drill into sedimentary basin to develop EGS reservoir in basal sandstone
  - Option 2: Drill deeper to get higher temperatures in crystalline basement



Surface of T=300°F
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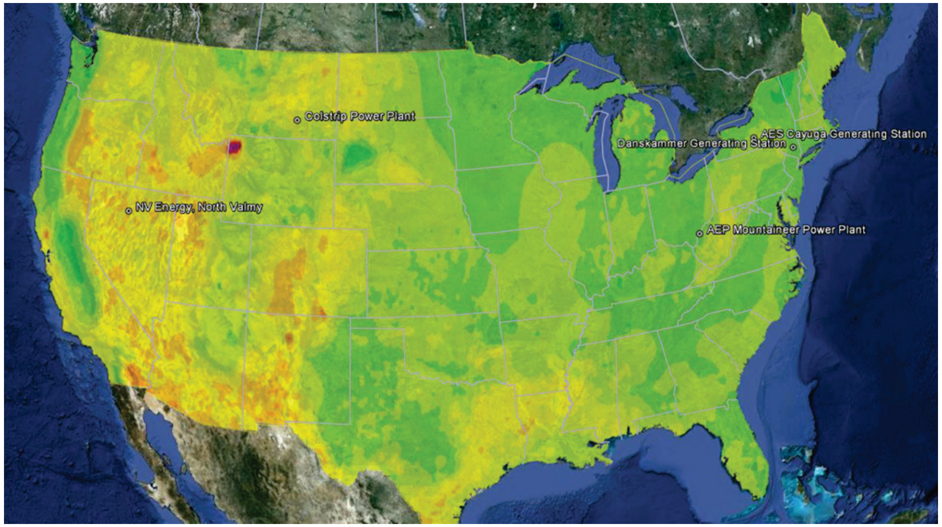
Case Studies



Plant Name	Location	Operator	Gross Rating (MW)	Disposal Rate (MLD)	Waste Treatment
Mountaineer Power Plant	New Haven, WV	AEP	1300	19	Surface Discharge
North Valmy Generating Station	Valmy, NV	NV Energy	522	2.2	Ponds
Colstrip PPL	Colstrip, MT	Colstrip PPL	2094	1.1	Ponds
Cayuga Generating Station	Lansing, NY	AES	323	26	Surface Discharge
Danskammer Generating Station	Newburgh, NY	Dynegy	537	34	Surface Discharge

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EGS Resource Potential at Selected Coal Plant Sites

Site	Coal Plant Capacity (MW)	Available Land Area (Acres)	Net Reservoir Thermal Potential (MW)	Recoverable Heat (MW)	Electricity Potential (MW)
Colstrip Power Plant	2094	56,000	2.69E+11	207,088	41,418
AEP Mountaineer Power Plant	1480	1700	1.02E+10	7,861	1,572
AES Cayuga Generating Station	306	1100	6.60E+09	5,086	1,017
Danskammer Point, Newburgh, NY	Converted to Natural Gas 2014	550	3.30E+09	2,543	509
NV Energy North Valmy Generating Station	522	10000	4.80E+10	36,980	7,396

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Western States Coal Plants

Example: NV Energy North Valmy Generating station.

- Valmy plant slated to close between 2019-2025
- High geothermal gradient with ample data.
- Potential for conventional geothermal project as first phase
- Holding residual waste water in holding/evaporation ponds.

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Eastern States Coal Plants

Example: Cayuga Power Plant near Lansing, New York.

- Plant is located in one of the best areas for geothermal energy in the east.
- Slated to close in Feb., 2015 but governor stopped closure to preserve jobs/property taxes
- Gas repower would need expensive pipeline the public doesn't want
- Utility wants to build new T-line, shut down the plant and buy power from the market
- Looking for a solution that makes sense.

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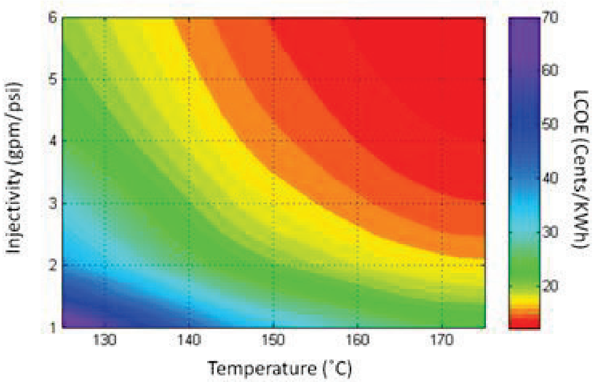
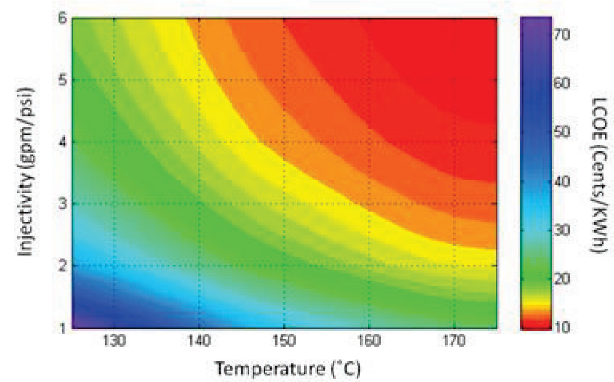
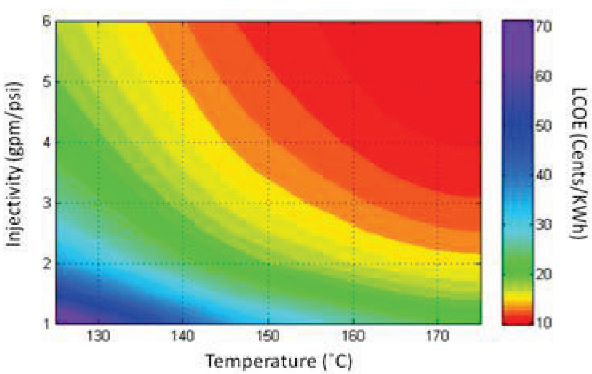
Modeled LCOE Results: 2103 EPRI Study



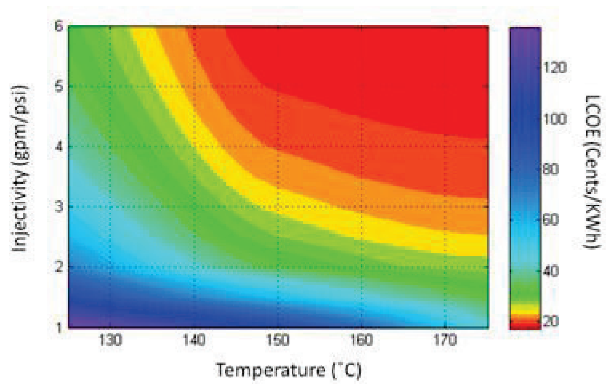
Colstrip Power Plant



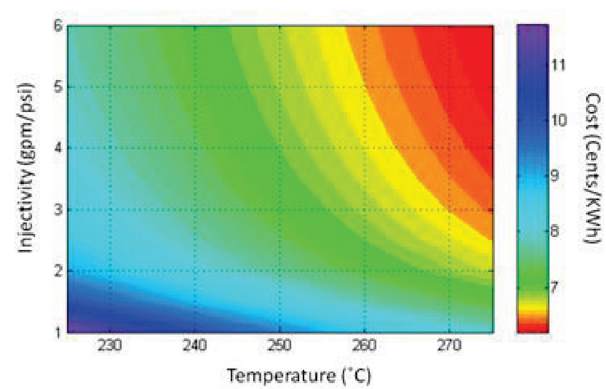
AEP Mountaineer
Power Plant



AES Cayuga

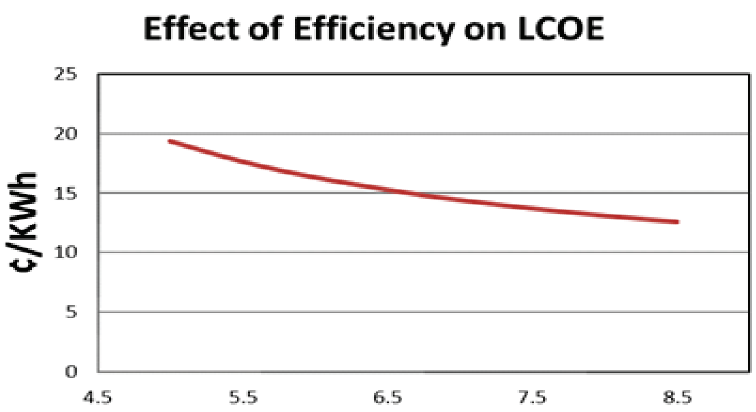


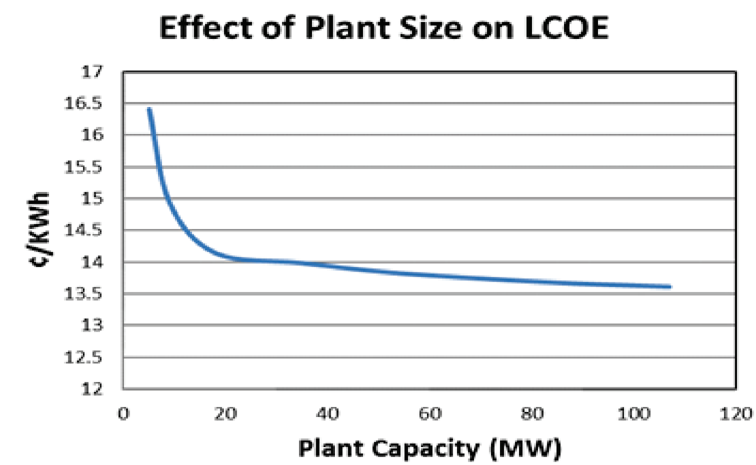
Danskammer Station

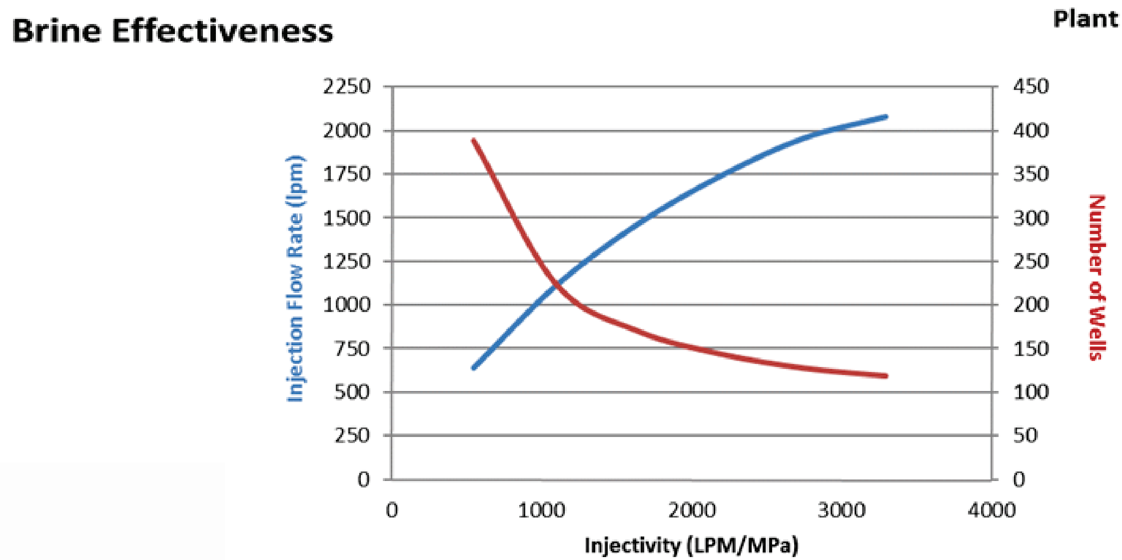


NV Energy North Valmy

Sensitivity of LCOE to Cost Factors: 2013 EPRI Study







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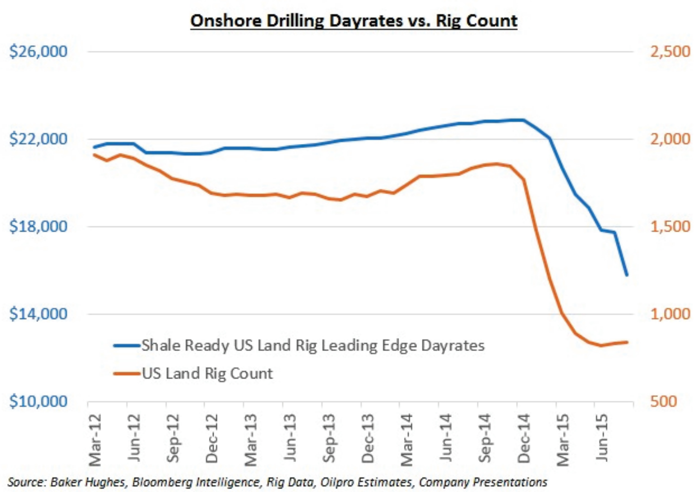
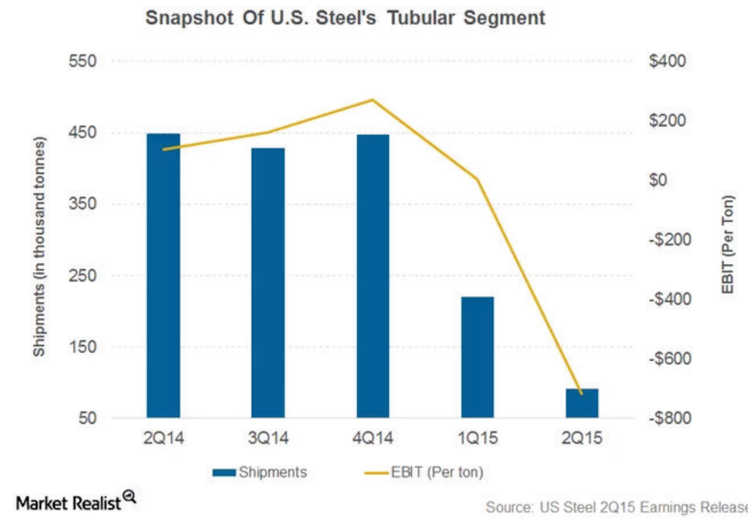
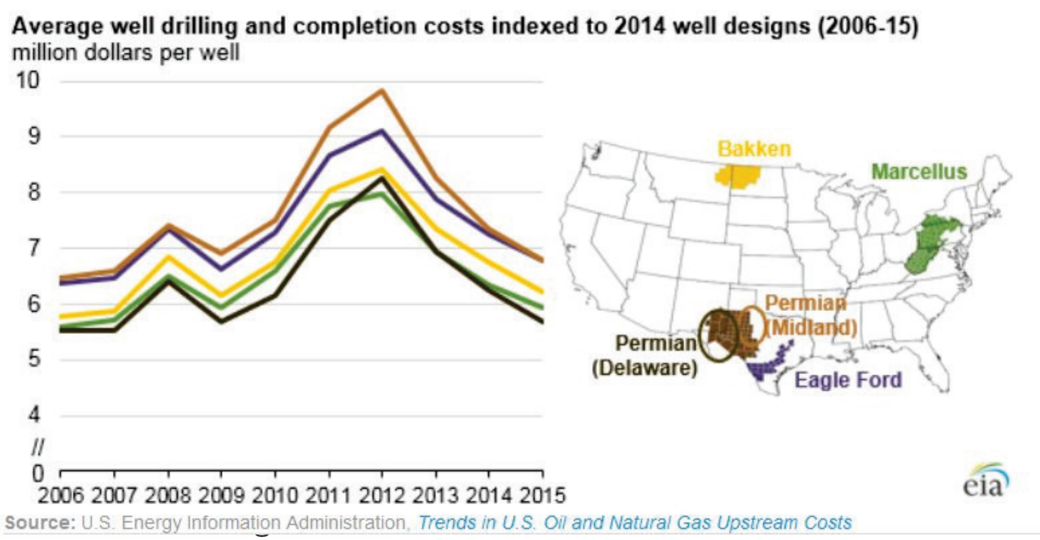
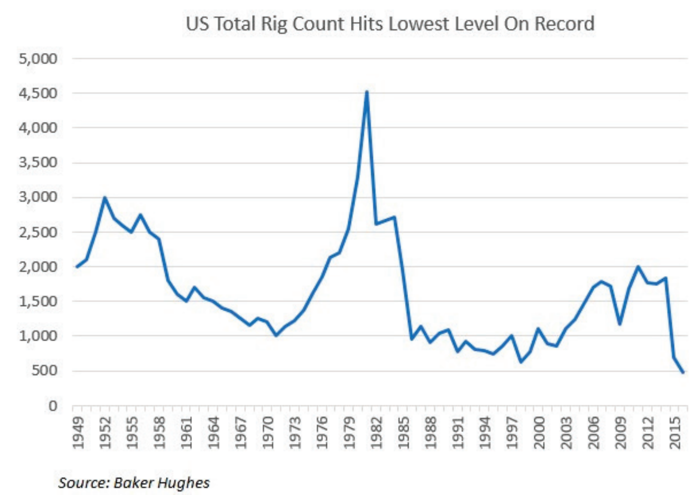
Why Do An Update?

- Drilling costs are at an all time low



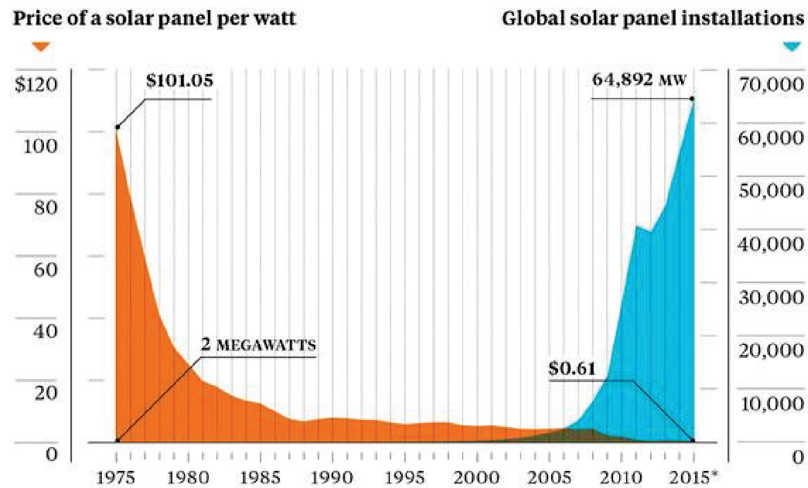


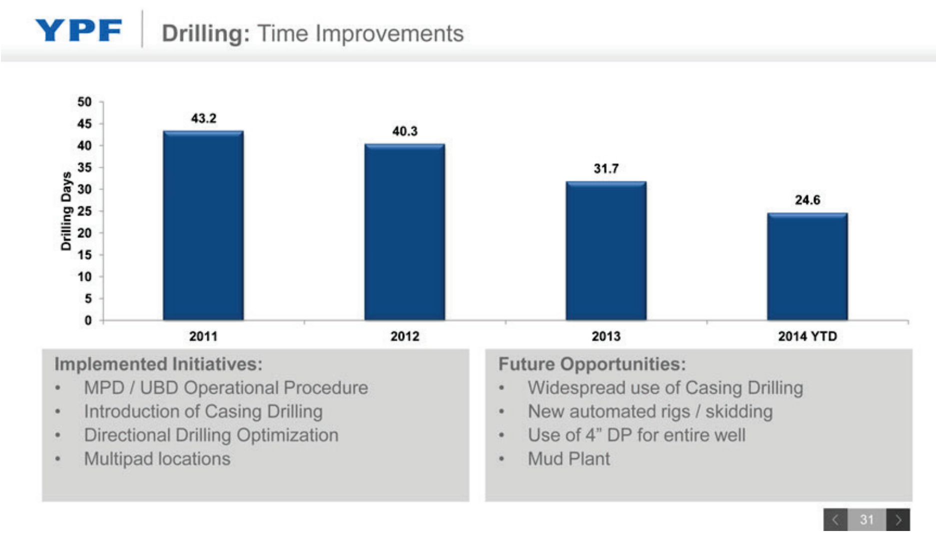




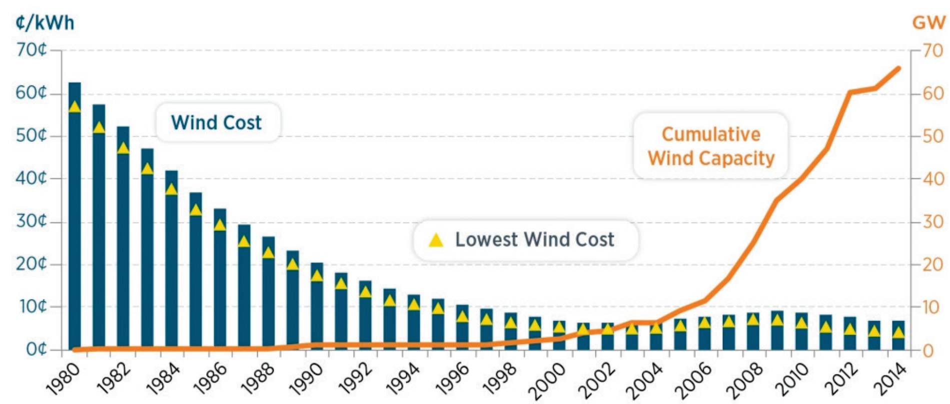
Learning By Doing Reduces Costs

- Dramatic drop in solar costs with number of installations





- Drilling time improvements in oil and gas with number of wells



- Wind energy costs drop as installations increase

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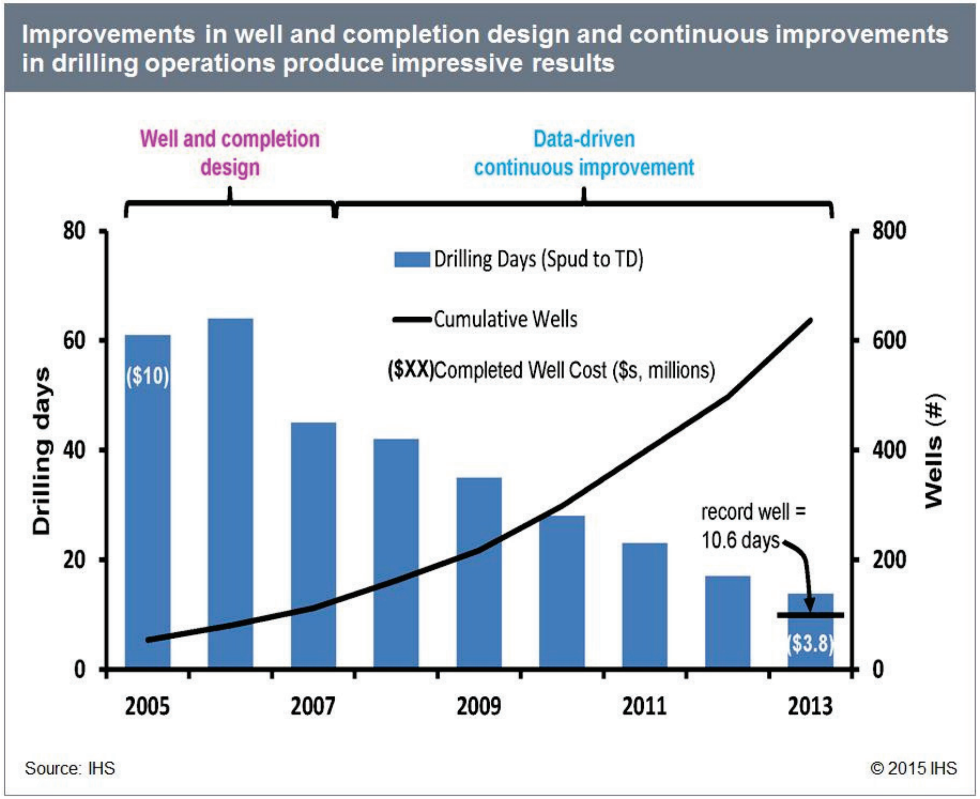
Learning By Doing Reduces Costs For Oil And Gas Drilling: *Can Geothermal Drilling Costs Do The Same?*

- Oil and gas drilling costs drop as large numbers of wells are installed in the same geologic setting
- Decrease in drilling time for geothermal wells at Awibengkok from 55 days to 20 days 2006-2008 93 new wells



Utility scale EGS requires 100s of wells drilled and stimulated in the same geology: Costs will come down!!

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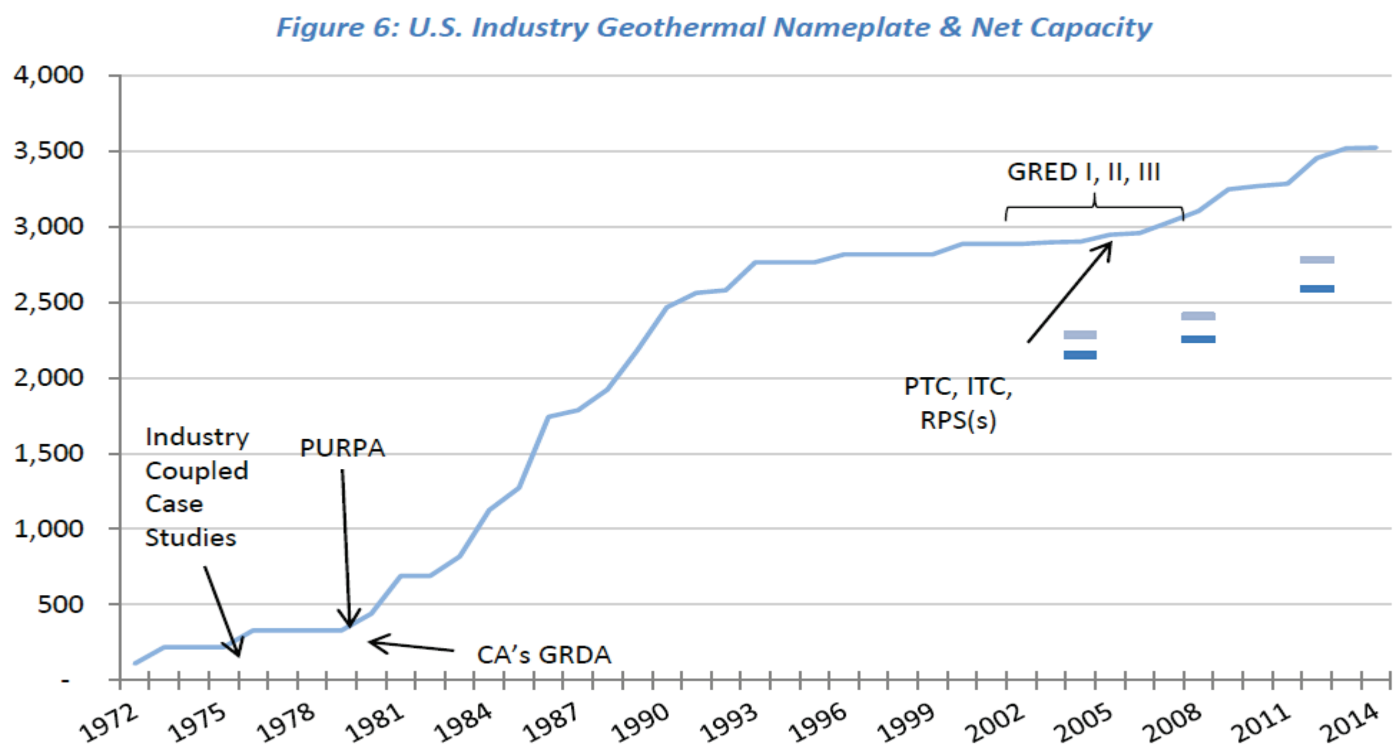
Geothermal Capacity Growth In the US

- Large fields discovered early
- Number of new wells currently low
- Tax incentives intermittent



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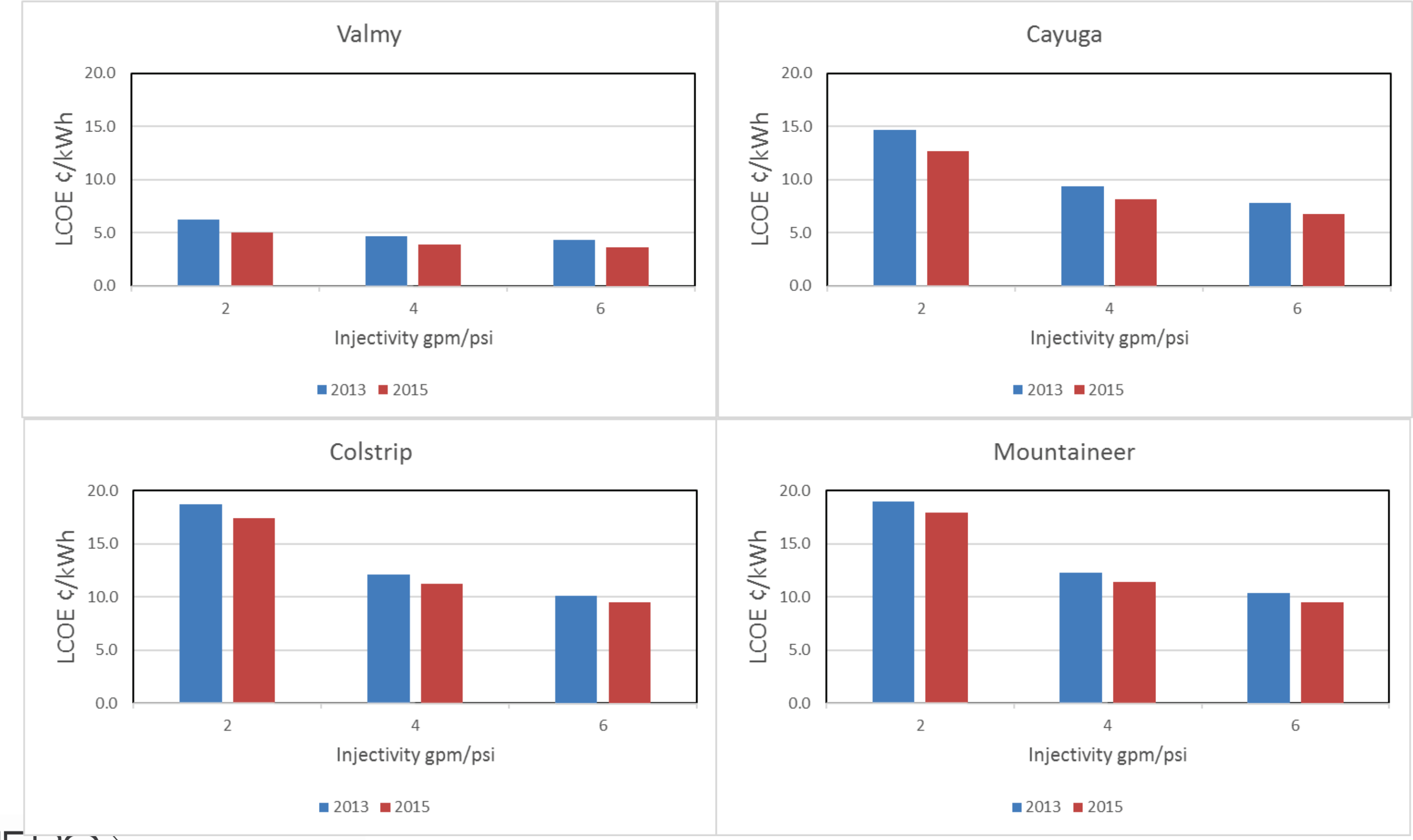
Updated LCOE with Current Drilling Costs



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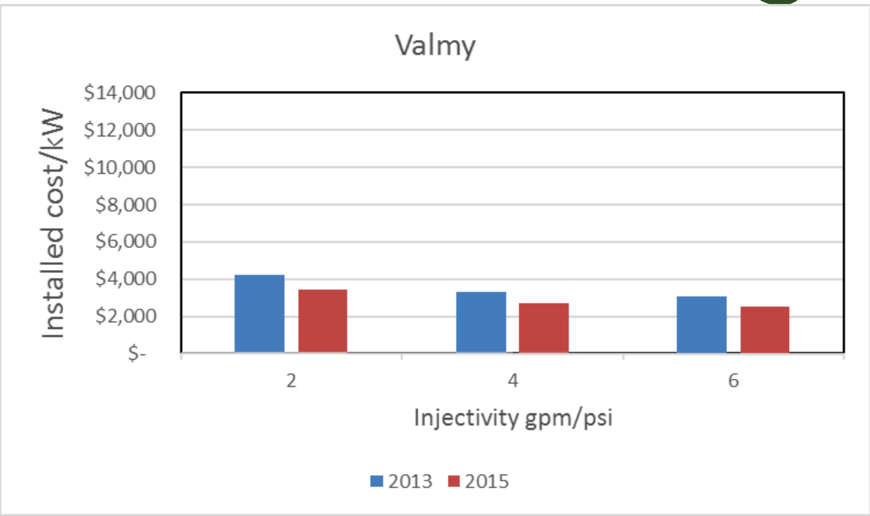
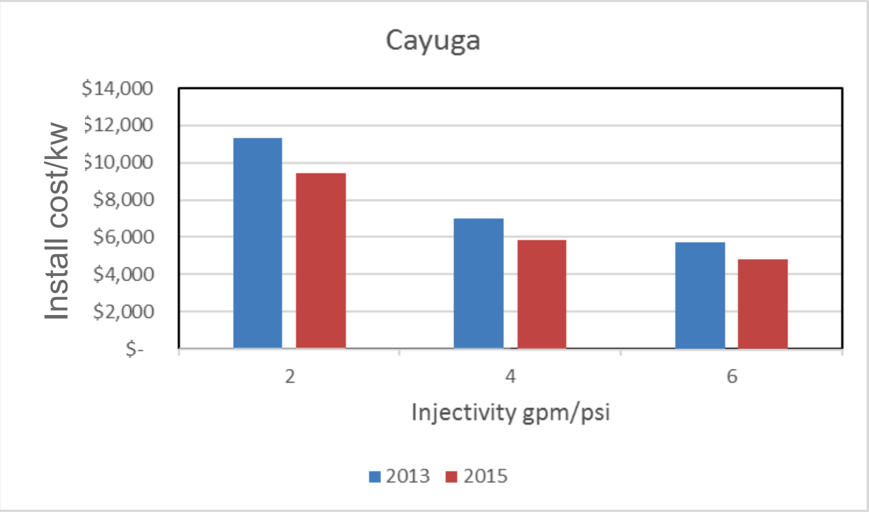
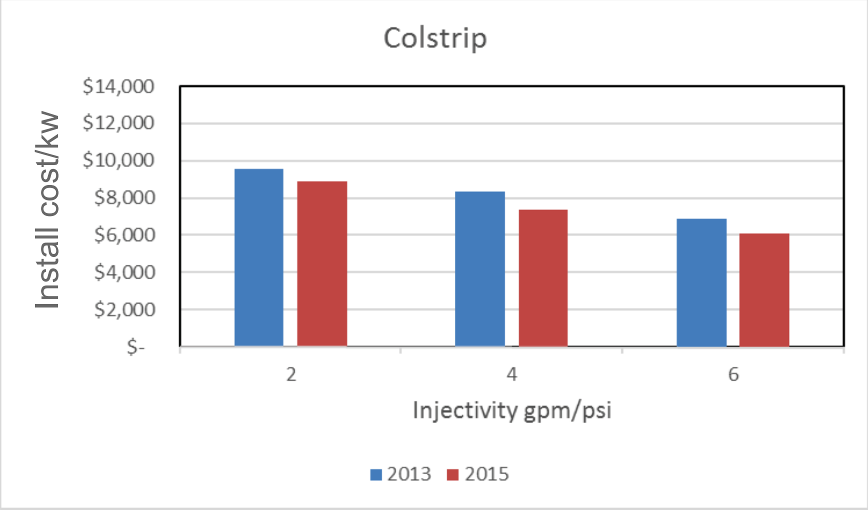
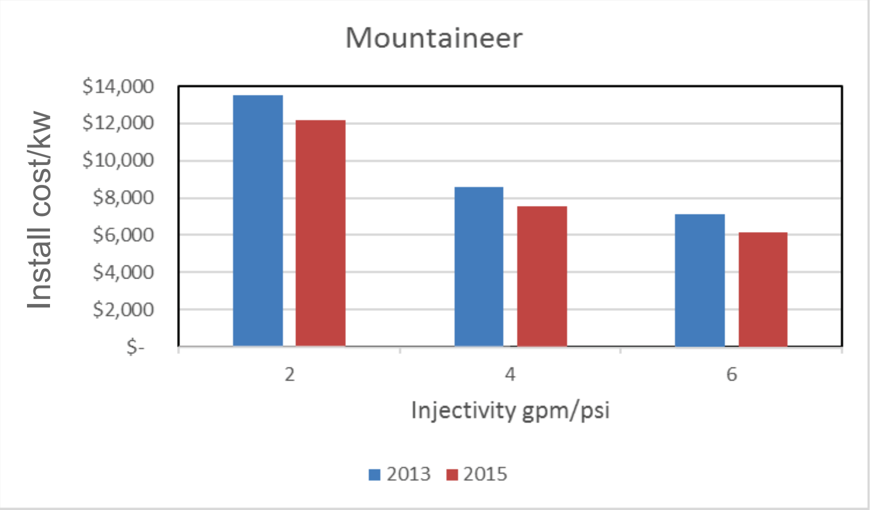
Updated Capital Cost with Current Drilling Costs









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Estimated Project Water Use

Reservoir stimulation/make-up water

- Water use is one of the most important environmental issues for EGS
- Need about 215-370 acre-feet (70-120 million gallons) of water for initial hydroshearing stimulation per 5-18 MW
- Lose 1-10% of water to rock during operation of field. Pressure controls magnitude of losses
- Can be managed to lose more or less water with production and injection pressures.
- Water can be minimally treated to remove particulates, but dissolved solids are not usually an issue.
- Closed loop operation prevents escape of contaminants into environment

Cooling water make-up

- Need ~400 gpm circulating water per MW
- Lose ~10% to evaporation in evaporative cooling tower
- Binary plants can use dry cooling, but efficiency is reduced
- Overall conversion efficiency has impact on EGS costs
- Hybrid systems possible
- Innovative cooling systems under development
- Water quality for cooling needs is higher than for circulating in the EGS reservoir

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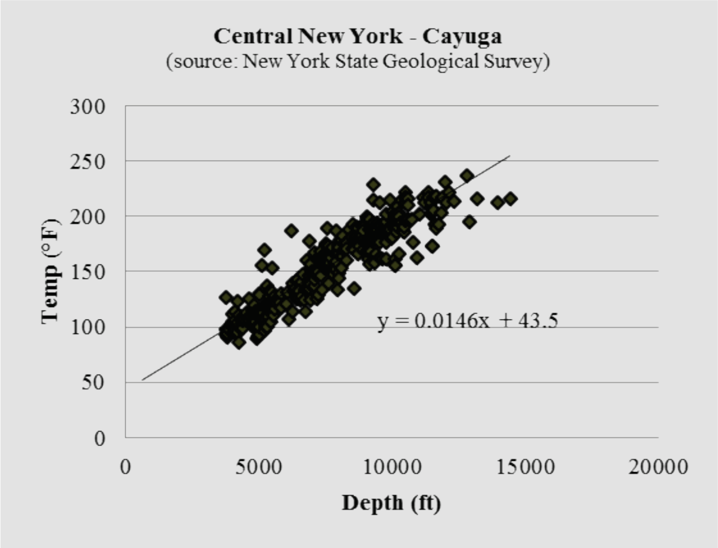
Example 1:

Central New York

- Wells drilled for oil and gas exploration in the Finger Lakes region of New York show an elevated temperature gradient of 32-38°C/km.
- Areas with high heat flow observed.
- Ample well data available with depth ranging from 1,125 m to 4400 m. Temperature data correlated
- Abundant structure and stress data for stimulation modeling
- Coal fired power plants offer opportunity for grid interconnect, waste water streams for reservoir fill-up and shared cooling cycle



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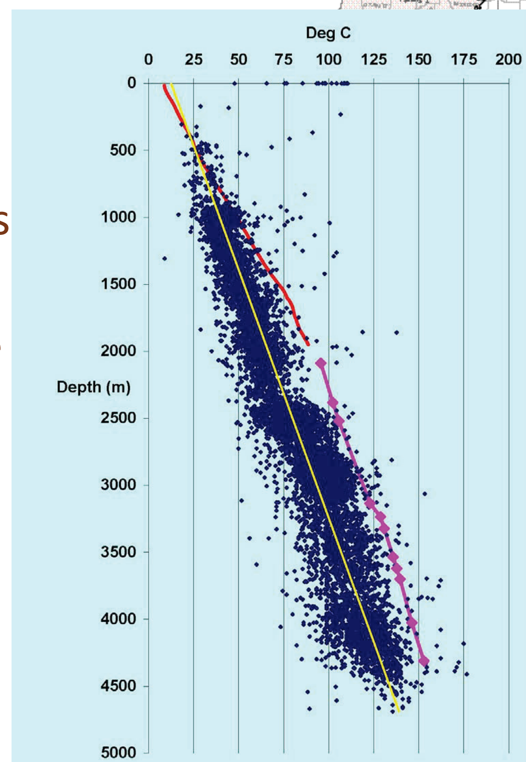
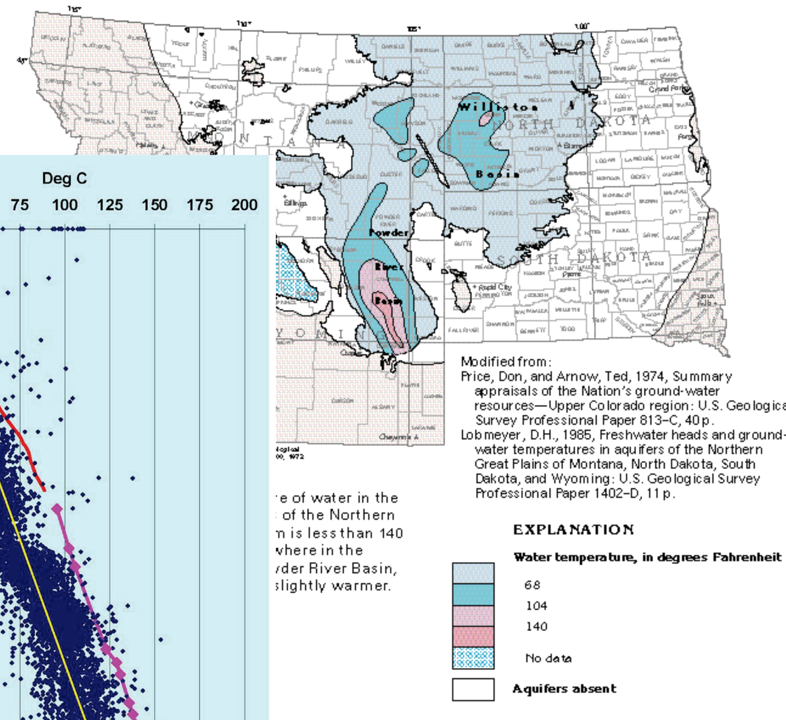
Example 2:

Central Montana: High Temperature Gradients

- Deep sedimentary basins with ample data from oil wells
- Williston Basin oil wells have demonstrated elevated temperatures with depth
- Best sites for deep hot water
- Coal fired power plants across the area
- Temperature gradients above 45ºC/km
- Deep disposal well drilled for Colstrip plant found good temperatures for EGS geothermal





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How Would EGS Work at a Typical Site?

- Create EGS reservoirs with cool waste water using multizone stimulation to fill reservoir with stored waste water
- Once EGS reservoir is operating, water loss to rock managed to dispose of all waste water from coal plant
- Reduce coal fired generation as geothermal project expands
- Two options:
  - 2-5 km (8000-16,000 ft) deep wells in Sedimentary Basin
    - Temperature known – 302ºF (150ºC)
    - Binary power plant with wet cooling
    - Water losses to rock higher due to natural permeability in sediments
    - 3-5 MW per well so for 1000 MW plant 200-300 wells
  - 3-7.5 km (10,000-25,000 ft) deep wells in crystalline basement rocks
    - Temperature (>225ºC, 440ºF) projected from shallower wells
    - Better conversion efficiency means more power per well even with lower flow rates
    - Flash plant with evaporative cooling or hybrid flash/binary plant with air cooling
    - Water losses: evaporation in cooling tower and loss to reservoir rock
    - 5-9 MW per well for 1000 MW plant

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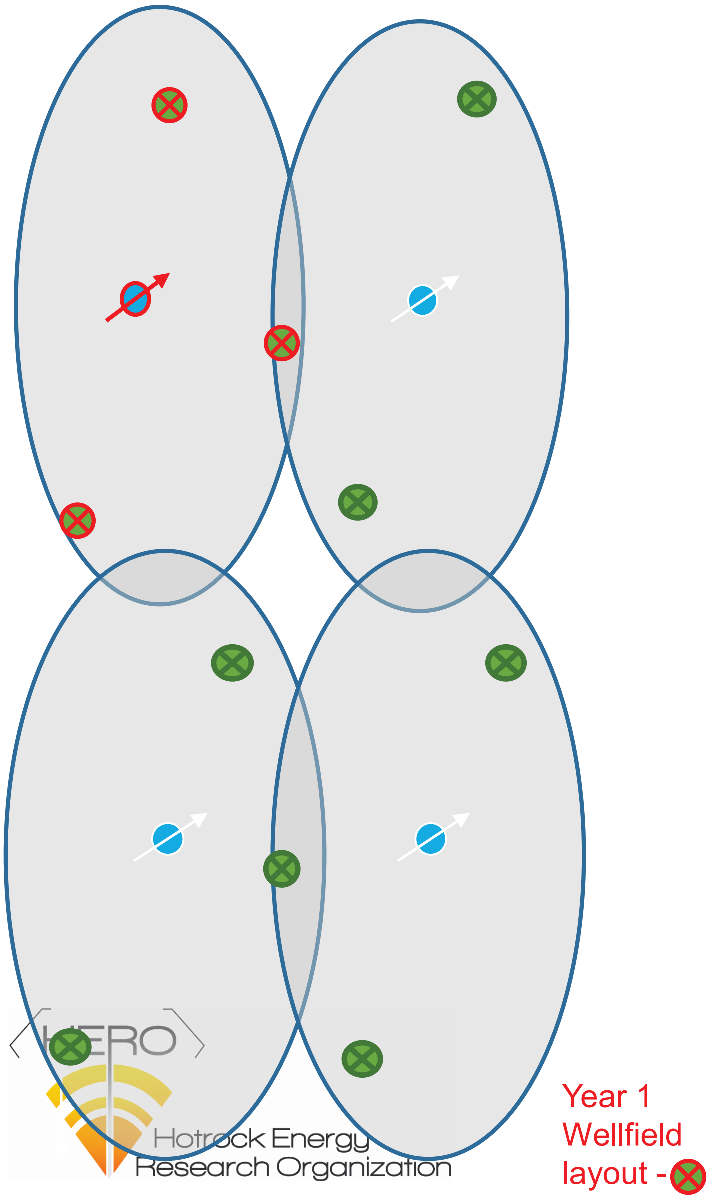
EGS Project: Moderate Temperature

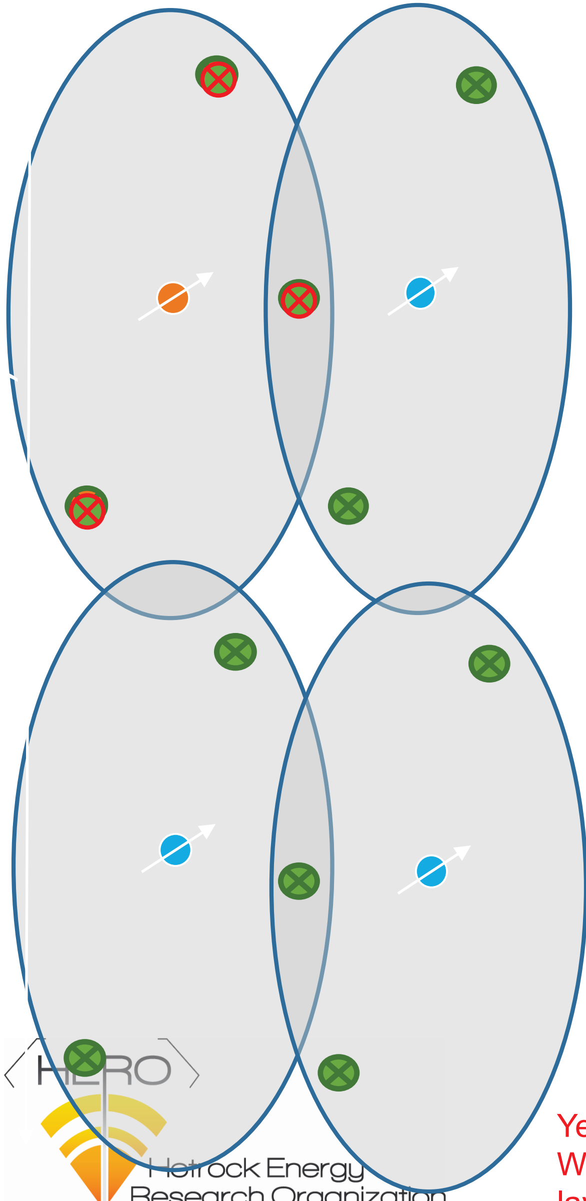


Water use during EGS Reservoir Creation

Year	New Wells	Annual Water Loss from Operations (Mgal)	Annual Water Loss from Stimulation (Mgal)
1	13	344	518
2	12	661	478
3	10	926	398
4	8	1,138	319
5	8	1,349	319
6	6	1,508	239
7	6	1,667	239

- 15,000 ft wells
- 320ºF resource temperature
- Average 3.5-5 MW per producer using TZIM stimulation
- 740 acres can yield 50 MW with little surface disturbance

EGS project – High Temperature



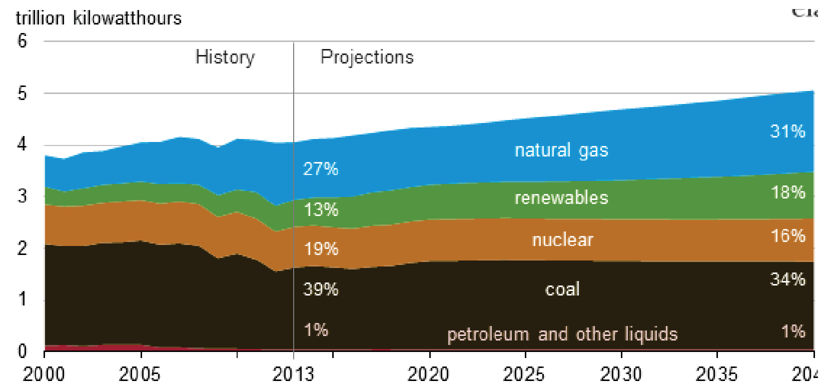
Year 1 Wellfield layout

Water use during EGS Reservoir Creation

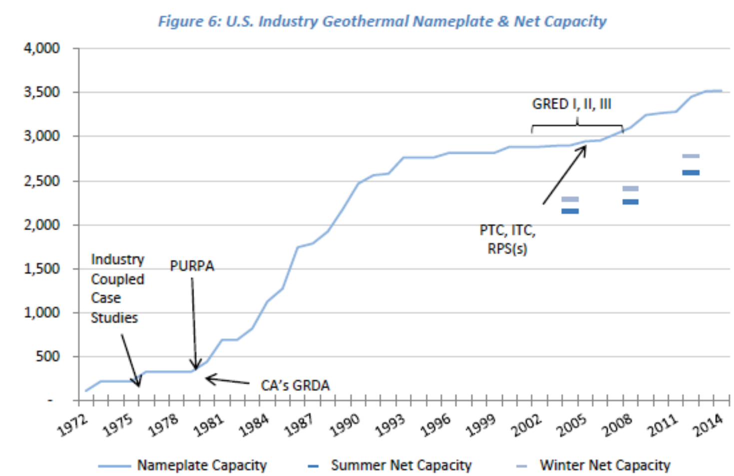
Year	New Wells	Annual Water Loss from Operations (Mgal)	Annual Water Loss from Stimulation (Mgal)
1	12	741	418
2	8	1235	279
3	8	1728	279
4	6	2099	209
5	4	2346	139
6	4	2592	139
7	0	2592	

- 11,150-16,000 ft wells in basement
- 480ºF resource temperature
- Average 6-8 MW per producer using TZIM stimulation
- 740 acres can yield 80 MW

Development Potential for Geothermal



- Geothermal now makes up a small fraction of total energy consumption
- Opening up the EGS resource to development can move geothermal from small to large scale



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What Research is Needed to Move the Technology Forward

- Better stimulation methods to increase ouput of each well
- Improved understanding of resource characteristics
- Improved drilling technology to reduce drilling costs
- Better reservoir management for long term use

AltaRock has proven stimulation technology for multizone stimulation in high temperature wells

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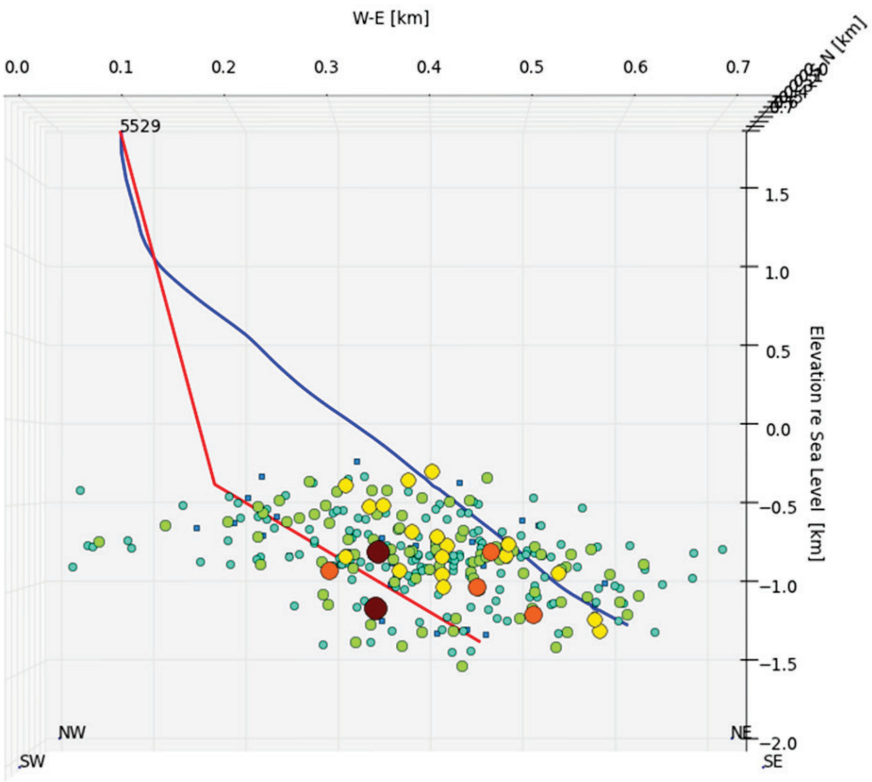
How Will We DO It?

- Feasibility studies
- Pilot projects at coal plants
  - Variety of geologic settings
  - Different geothermal gradients
  - Different water management needs
- Scale to reduce cost/risk
- Now is the time to start:
  - Drilling is on sale
  - 30% or more reduction in drilling costs



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