PS Building a Geothermal Future on a Sedimentary Foundation*

John Holbrook[1]

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[1] Texas Christian University, Fort Worth, Texas (john.holbrook@tcu.edu)

Abstract

Geothermal energy from sedimentary basins has emerging possibilities that speak to both a new future for sedimentary sciences and a new and important role for sediments in the emerging market for renewable energy. These opportunities, however, are not necessarily linked or limited to conventional views of geothermal energy extraction. This is the primary finding of the SedHeat initiative. The SedHeat initiative is a Research Coordination Network funded by the National Science Foundation to explore the potential for sustainable geothermal energy from sedimentary basins. The network includes over 300 members from academia and industry dedicated to identifying and overcoming the challenges for economic extraction of geothermal energy from sedimentary basins. The group spans the fields of geology, engineering, economics, social sciences, and education.

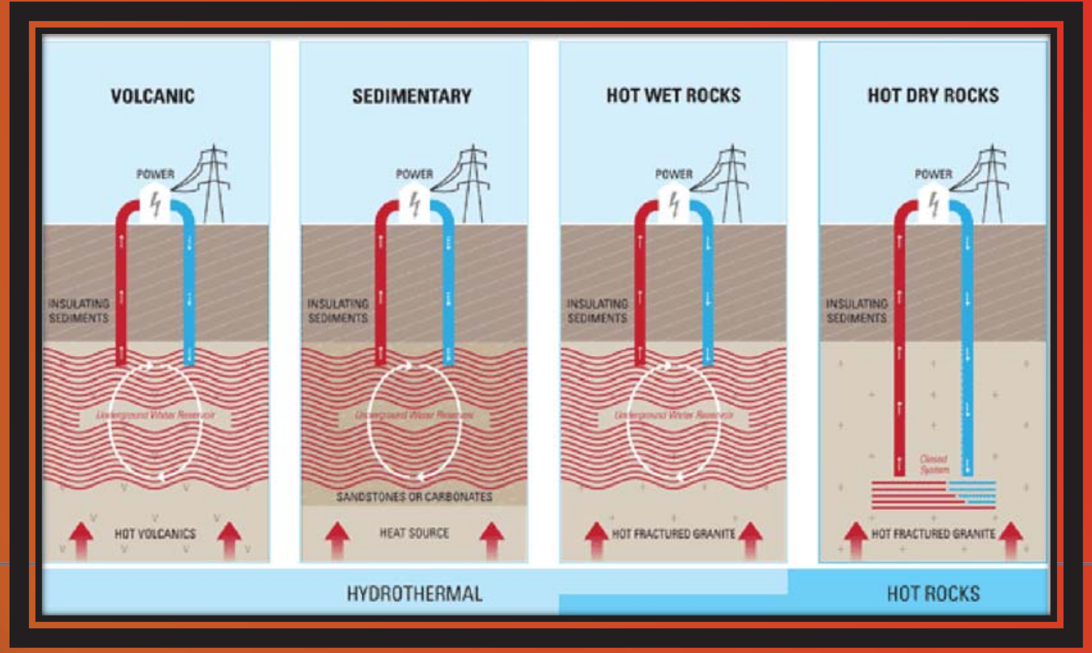
The group has come to some conclusions over the span of its current six years. First, conventional geothermal power extraction is now possible from sedimentary basins because of new technologies in heat-to-electric conversion. Most conventional geothermal energy depends on flash steam power, which depends on very high heat levels that are rare in sedimentary basins. The newer Rankin-cycle generators are able to run fluids with temperatures below 200 degrees Celsius, temperatures more common in sedimentary basins. They can do so at the current margins of economic viability, and are becoming increasingly competitive. Second, much of the domestic and commercial energy consumed is used to heat spaces and fluids. Upscaling of direct heating systems to manage large infrastructure from large-flow and deep-basin wells is already initiating and has promise for future expansion. Third, the Earth is a good battery. Growth of renewables like solar and wind energy are severely hampered by their intermittent nature. Their future use depends on megawatt-scale energy storage systems that thus far have not emerged. Coupling of geothermal and solar systems is an encouraging solution. Solar energy is stored in deep sedimentary basins through injection of water superheated by thermal solar systems. The heat is later retrieved as stored base-load geothermal energy. The marginal lower heat of most sedimentary-basin geothermal systems is spiked for maximum output. The solar lost to non-demand periods is smoothed into peak demand times. Two problems with two renewables are solved by linking them together. Each of these options can be applied by expanding existing technologies. Each addresses the push for carbon-neutral energy and gives sedimentary science a large space to occupy in the emerging global renewables market. These speaks to a deep relevance of sedimentary basins and sedimentary science in a currently emerging future.

Building a Geothermal Future on a Sedimentary Foundation

John Holbrook, Texas Christian University, Dept. of Geological Sciences and Energy Institute

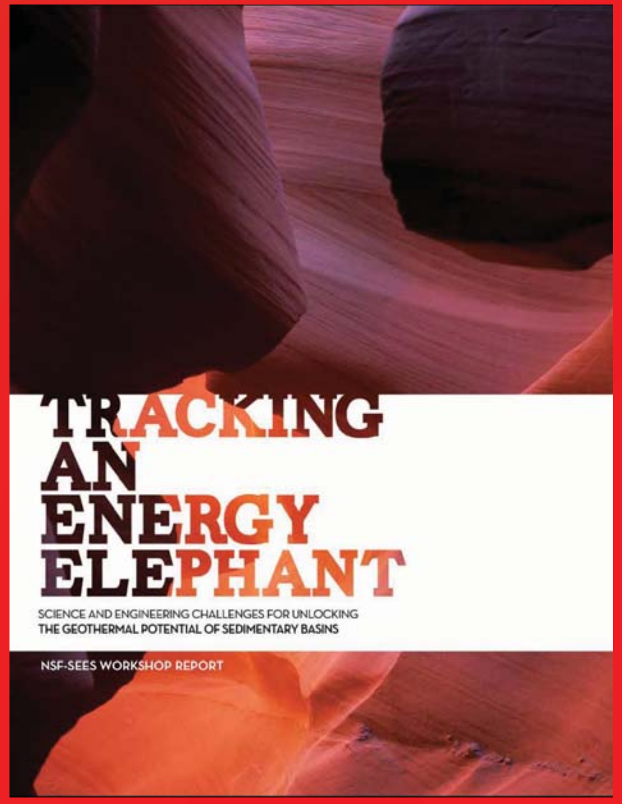
Abstract:

Geothermal energy from sedimentary basins has emerging possibilities that speak to both a new future for sedimentary sciences and a new and important role for sediments in the emerging market for renewable energy. These opportunities however are not necessarily linked or limited to conventional views of geothermal energy extraction. This is the primary finding of the SedHeat initiative. The SedHeat initiative is a Research Coordination Network funded by the National Science Foundation to explore the potential for sustainable geothermal energy from sedimentary basins. The network includes over 300 members from academia and industry dedicated to identifying and overcoming the challenges for economic extraction of geothermal energy from sedimentary basins. The group spans the fields of geology, engineering, economics, social sciences, and education. The group has come to some conclusions over the span of its current six years. First, conventional geothermal power extraction is now possible from sedimentary basins because of new technologies in heat-to-electric conversion. Most conventional geothermal energy depends on flash steam power, which depends on very high heat levels that are rare in sedimentary basins. The newer Rankin-cycle generators are able to run fluids with temperatures below 200 degrees Celsius, temperatures more common in sedimentary basins. They can do so at the current margins of economic viability, and are becoming increasingly competitive. Second, much of the domestic and commercial energy consumed is used to heat spaces and fluids. Upscaling of direct heating systems to manage large infrastructure from large-flow and deep-basin wells is already initiating and has promise for future expansion. Third, the Earth is a good battery. Growth of renewables like solar and wind energy are severely hampered by their intermittent nature. Their future use depends on megawatt-scale energy storage systems that thusfar have not emerged. Coupling of geothermal and solar systems is an encouraging solution. Solar energy is stored in deep sedimentary basins through injection of water superheated by thermal solar systems. The heat is later retrieved as stored base-load geothermal energy. The marginal lower heat of most sedimentary-basin geothermal systems is spiked for maximum output. The solar lost to non-demand periods is smoothed into peak demand times. Two problems with two renewables are solved by linking them together. Each of these options can be applied by expanding existing technologies. Each addresses the push for carbon-neutral energy and gives sedimentary science a large space to occupy in the emerging global renewables market. These speaks to a deep relevance of sedimentary basins and sedimentary science in a currently emerging future.



The Types of Geothermal Production

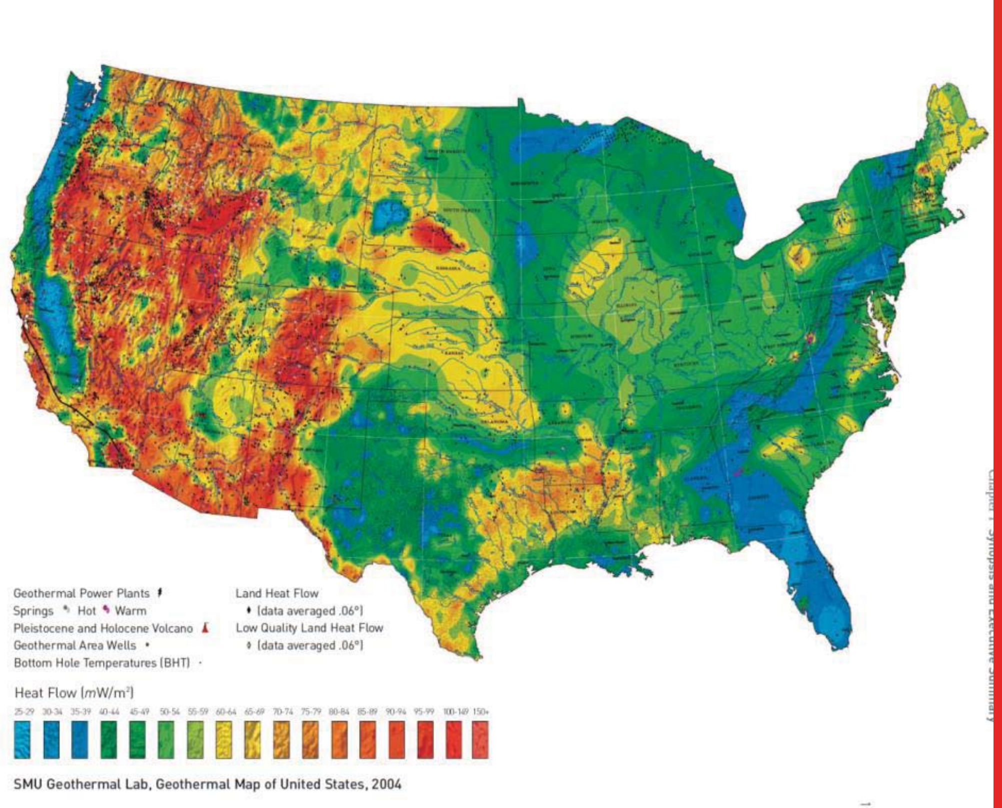
Take a Flyer!
Read more about the Challenge


TRACKING AN ENERGY ELEPHANT

SCIENCE AND ENGINEERING CHALLENGES FOR UNLOCKING THE GEOTHERMAL POTENTIAL OF SEDIMENTARY BASINS

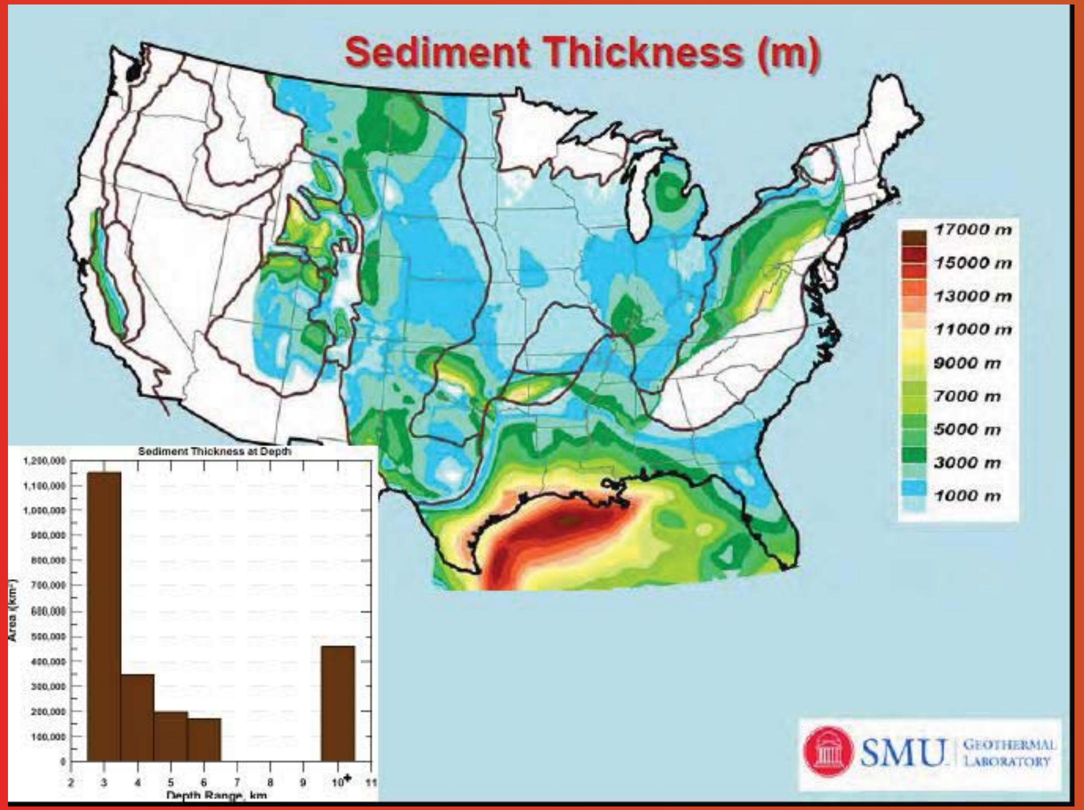
NSF-SEES WORKSHOP REPORT

The Resource
How Much Heat is there?



SMU Geothermal Lab, Geothermal Map of United States, 2004

The Resource
How Much Power is there in SEDHEAT?



1000 years of heat in sedimentary basins

Category of Resource	Thermal Energy, in Exajoules (1EJ = 10^{18}J)	Reference
Conduction-dominated EGS		
Sedimentary rock formations	100,000	MIT, 2006
Crystalline basement rock formations	13,300,000	MIT, 2006
Supercritical Volcanic Systems	74100 excludes Yellowstone NP, Hawaii	USGS Circular 790
Hydrothermal	2,400 – 9,600	USGS Circular 726 and 790
Coproduced (oil field) fluids	0,0944 – 0,4510	McKenna, et al. (2005)
Geopressured systems	71,000 – 170,000 (includes methane)	USGS Circular 726 and 790

US Power useage is ~100 EJ/~100 quad BTU

The Future
Geothermal as Power Storage?

Spike It

Typical Injection well at about 100C

1. Disposal well 2. Enhanced oil recovery 3. Production well 4. Injected brine 5. Injected fluid 6. Oil

Earth Battery

Economic Sedheat

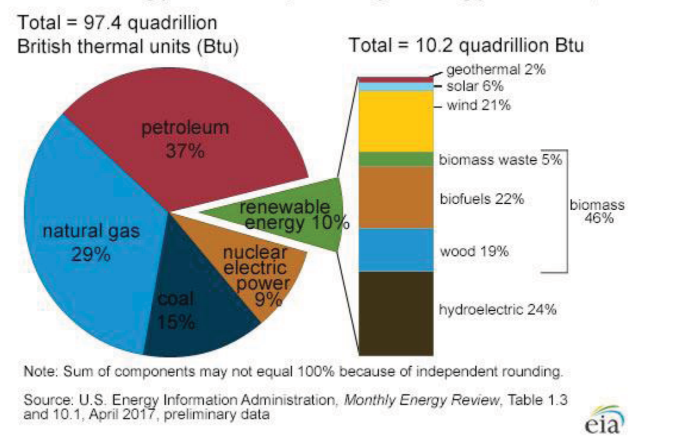
0.5 barrels/sec at 150C

(80 l/sec at 150C for 5MWe; MIT Panel, 2005)

Power From the Battery

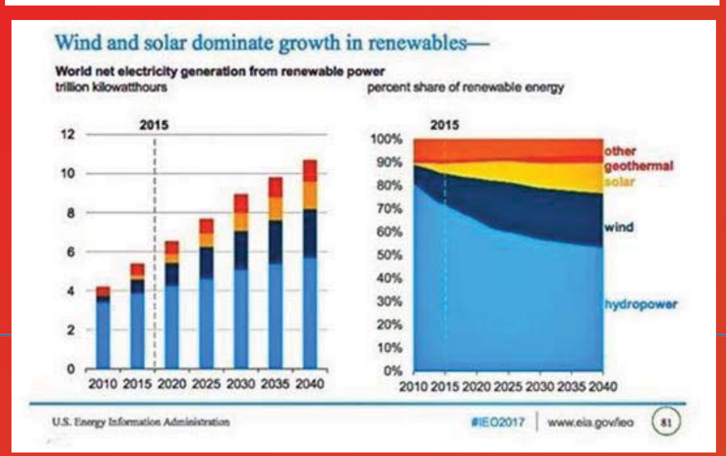
Solar Base Load!!

The Need
How Much Power do we use?


U.S. energy consumption by energy source, 2016

Note: Sum of components may not equal 100% because of independent rounding.

Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2017, preliminary data


Wind and solar dominate growth in renewables—

Learn More

Slide 2

-The SEDHEAT Challenges

Slide 3

-How Much Power Do We Use?

Slide 4 & 5 Profit from Wastewater

- Co-Producing From Your Well?

-Geothermal as Power Storage

and the Way Forward

C.O. Joe Moore

Building a Geothermal Future on a Sedimentary Foundation

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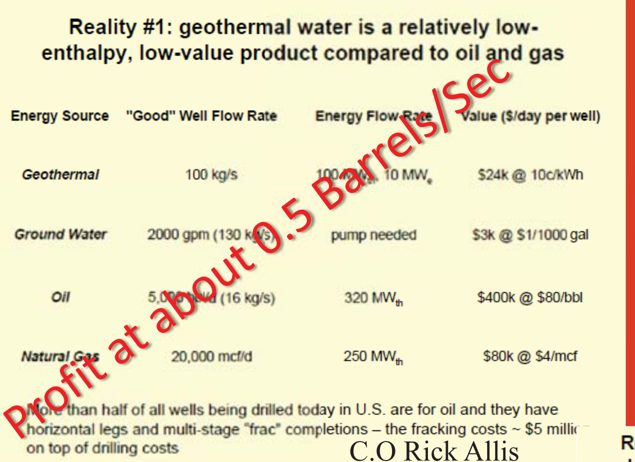
The SEDHEAT Challenges

The Cost Challenge

Costs vs return means wells must rarely miss and pay of over long periods



Reality #1: geothermal water is a relatively low-enthalpy, low-value product compared to oil and gas

Energy Source	"Good" Well Flow Rate	Energy Flow Rate	Value ($/day per well)
Geothermal	100 kg/s	100 MW$_{th}$, 10 MW$_e$	$24k @ 10c/kWh
Ground Water	2000 gpm (130 kg/s)	pump needed	$3k @ $1/1000 gal
Oil	5,000 bbl/d (16 kg/s)	320 MW$_{th}$	$400k @ $80/bbl
Natural Gas	20,000 mcf/d	250 MW$_{th}$	$80k @ $4/mcf

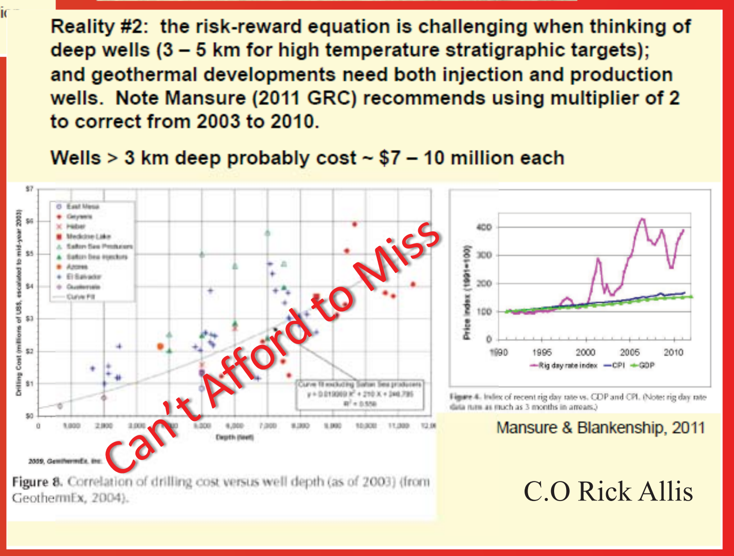
More than half of all wells being drilled today in U.S. are for oil and they have horizontal legs and multi-stage "frac" completions – the fracking costs ~ $5 millio on top of drilling costs

Profit at about 0.5 Barrels/Sec

C.O Rick Allis

Challenges!

Hurdles!



Reality #2: the risk-reward equation is challenging when thinking of deep wells (3 – 5 km for high temperature stratigraphic targets); and geothermal developments need both injection and production wells. Note Mansure (2011 GRC) recommends using multiplier of 2 to correct from 2003 to 2010.

Wells > 3 km deep probably cost ~ $7 – 10 million each

Figure 8. Correlation of drilling cost versus well depth (as of 2003) (from GeothermEx, 2004).

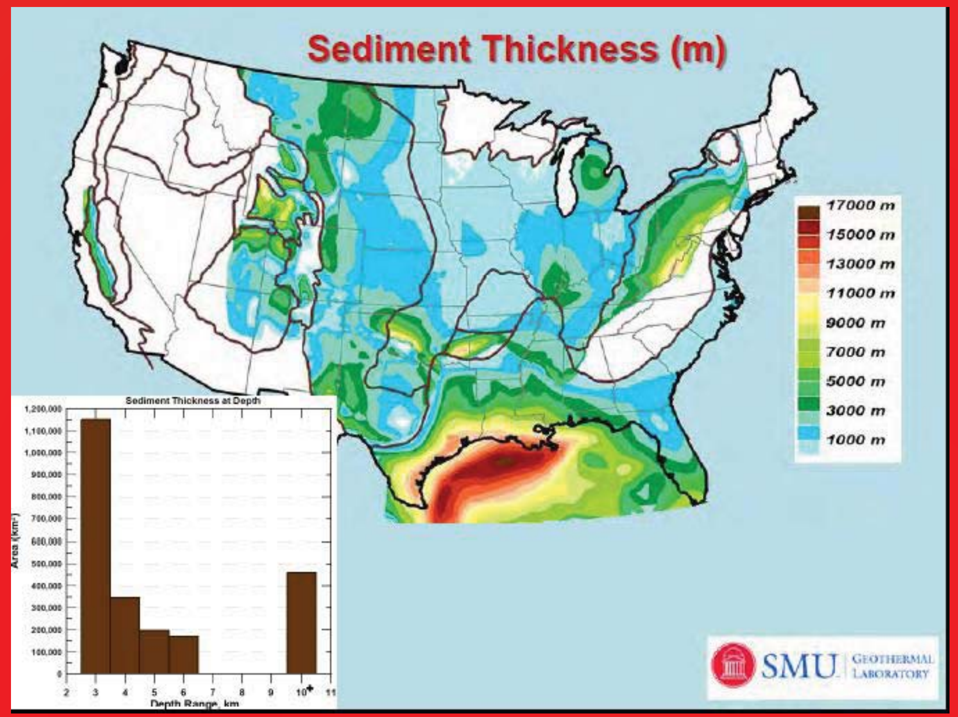
Figure 4. Index of recent rig day rate vs. GDP and CPI. (Note: rig day rate data runs as much as 3 months in arrears.)

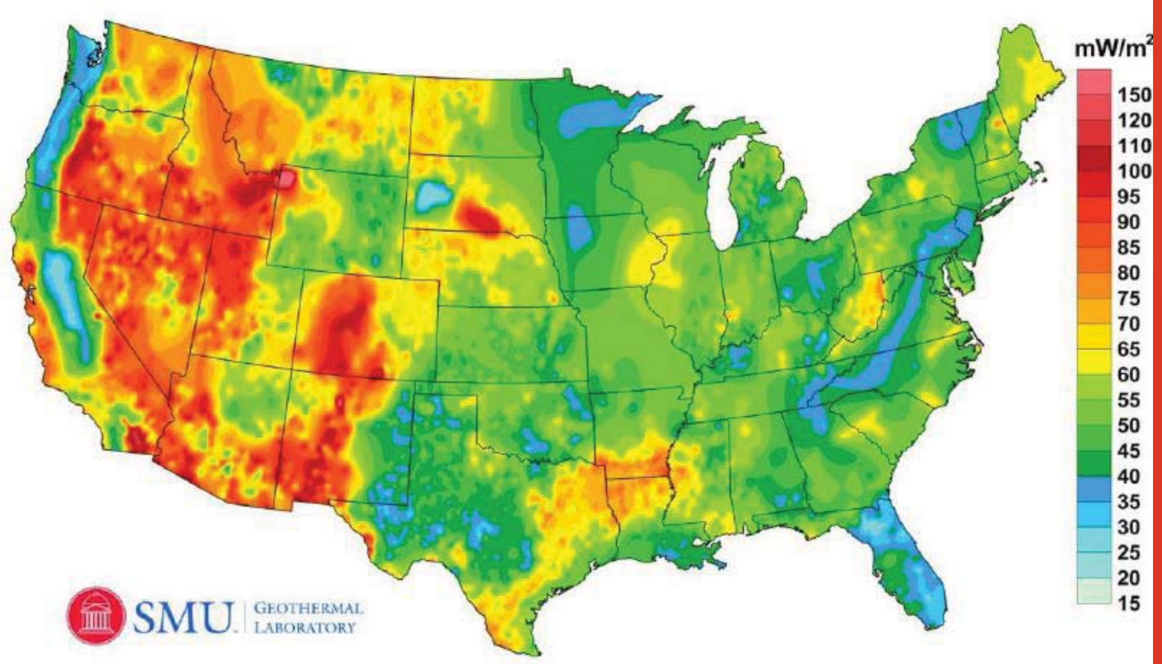
Mansure & Blankenship, 2011

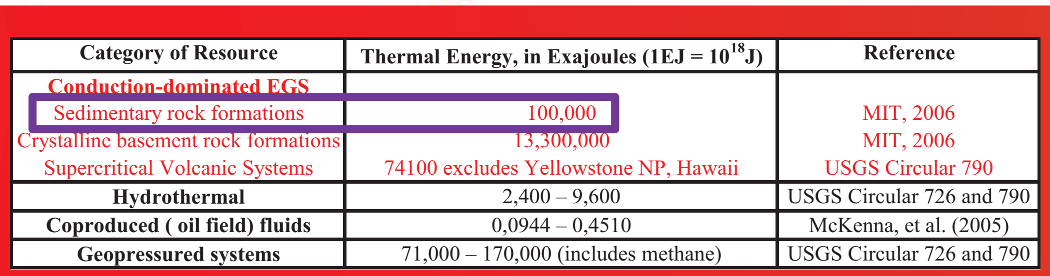
C.O Rick Allis

The Resource Challenge

There is enough heat but it is a little low for production in most places. About 100-150 C is optimal for traditional geothermal but well temps at high porosity are usually about 80-100C.







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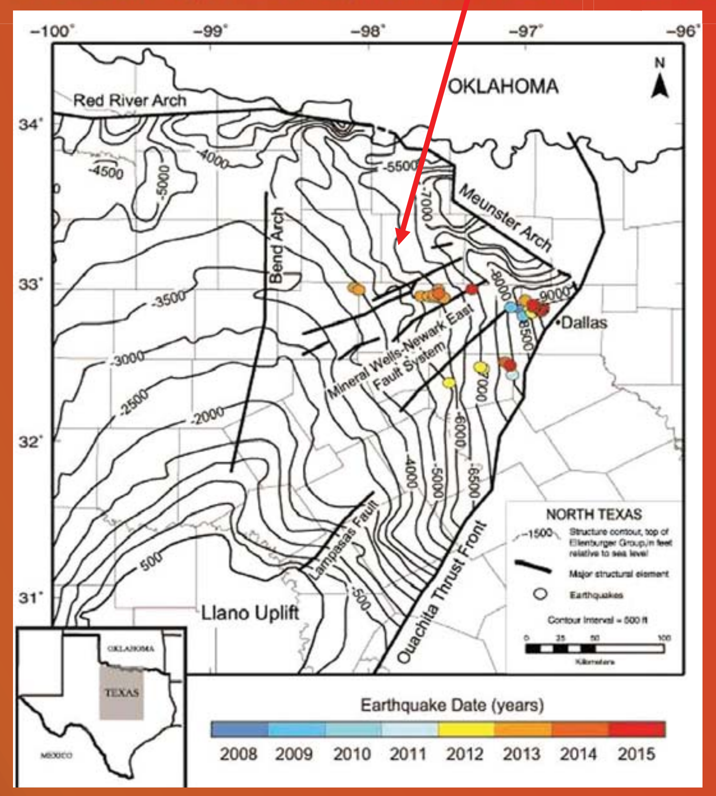
Got Alotta Sedimentary Basins

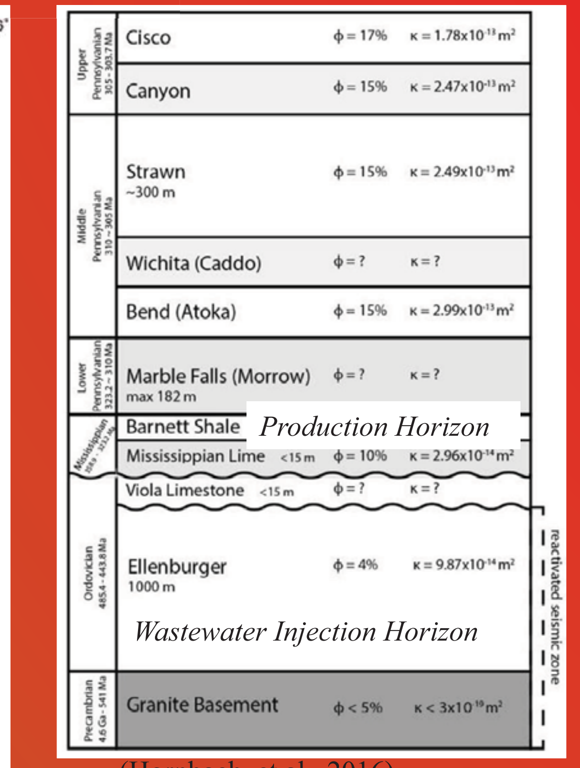
The Water Challenge

We commonly inject and often extract the needed flow rates of ~0.5 barrels per second already

Wise County, The Birthplace of the Shale-Gas Revolution!

Ft Worth Basin - A Production and Injection Experiment





Age	Formation	Porosity	Permeability
Upper Pennsylvanian 305 - 303.7 Ma	Cisco	$\phi = 17\%$	$\kappa = 1.78\times10^{-13}$ m^2
	Canyon	$\phi = 15\%$	$\kappa = 2.47\times10^{-13}$ m^2
Middle Pennsylvanian 310 ~ 305 Ma	Strawn ~300 m	$\phi = 15\%$	$\kappa = 2.49\times10^{-13}$ m^2
	Wichita (Caddo)	$\phi = ?$	$\kappa = ?$
	Bend (Atoka)	$\phi = 15\%$	$\kappa = 2.99\times10^{-13}$ m^2
Lower Pennsylvanian 323.2 ~ 310 Ma	Marble Falls (Morrow) max 182 m	$\phi = ?$	$\kappa = ?$
Mississippian	Barnett Shale		
	Mississippian Lime <15 m	$\phi = 10\%$	$\kappa = 2.96\times10^{-14}$ m^2
Ordovician 485.4 - 443.8 Ma	Viola Limestone <15 m	$\phi = ?$	$\kappa = ?$
	Ellenburger 1000 m	$\phi = 4\%$	$\kappa = 9.87\times10^{-14}$ m^2
Precambrian 4.6 Ga - 541 Ma	Granite Basement	$\phi < 5\%$	$\kappa < 3\times10^{-19}$ m^2

Production Horizon

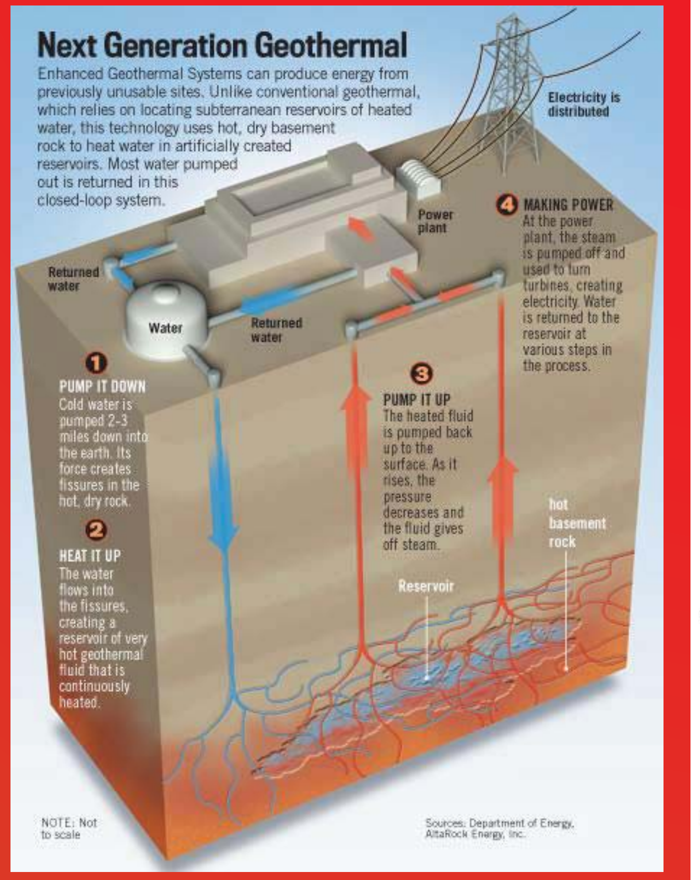
Wastewater Injection Horizon

reactivated seismic zone

(Hornbach, et al., 2016)

The Seismic Hazard Challenge

The Geothermal Difference? Extraction During Injection



Next Generation Geothermal

Enhanced Geothermal Systems can produce energy from previously unusable sites. Unlike conventional geothermal, which relies on locating subterranean reservoirs of heated water, this technology uses hot, dry basement rock to heat water in artificially created reservoirs. Most water pumped out is returned in this closed-loop system.

① PUMP IT DOWN Cold water is pumped 2-3 miles down into the earth. Its force creates fissures in the hot, dry rock.

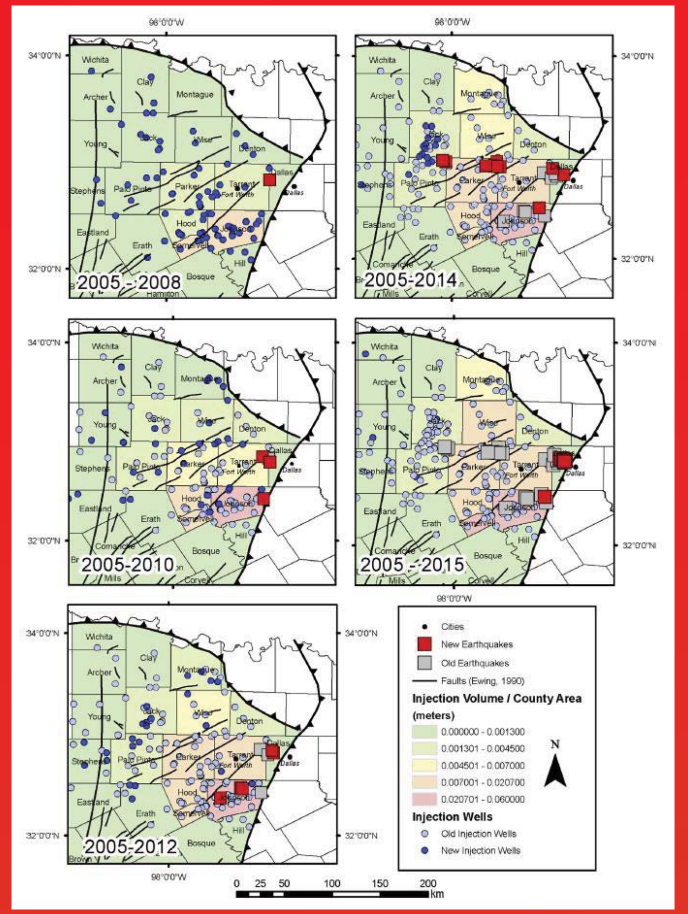
② HEAT IT UP The water flows into the fissures, creating a reservoir of very hot geothermal fluid that is continuously heated.

③ PUMP IT UP The heated fluid is pumped back up to the surface. As it rises, the pressure decreases and the fluid gives off steam.

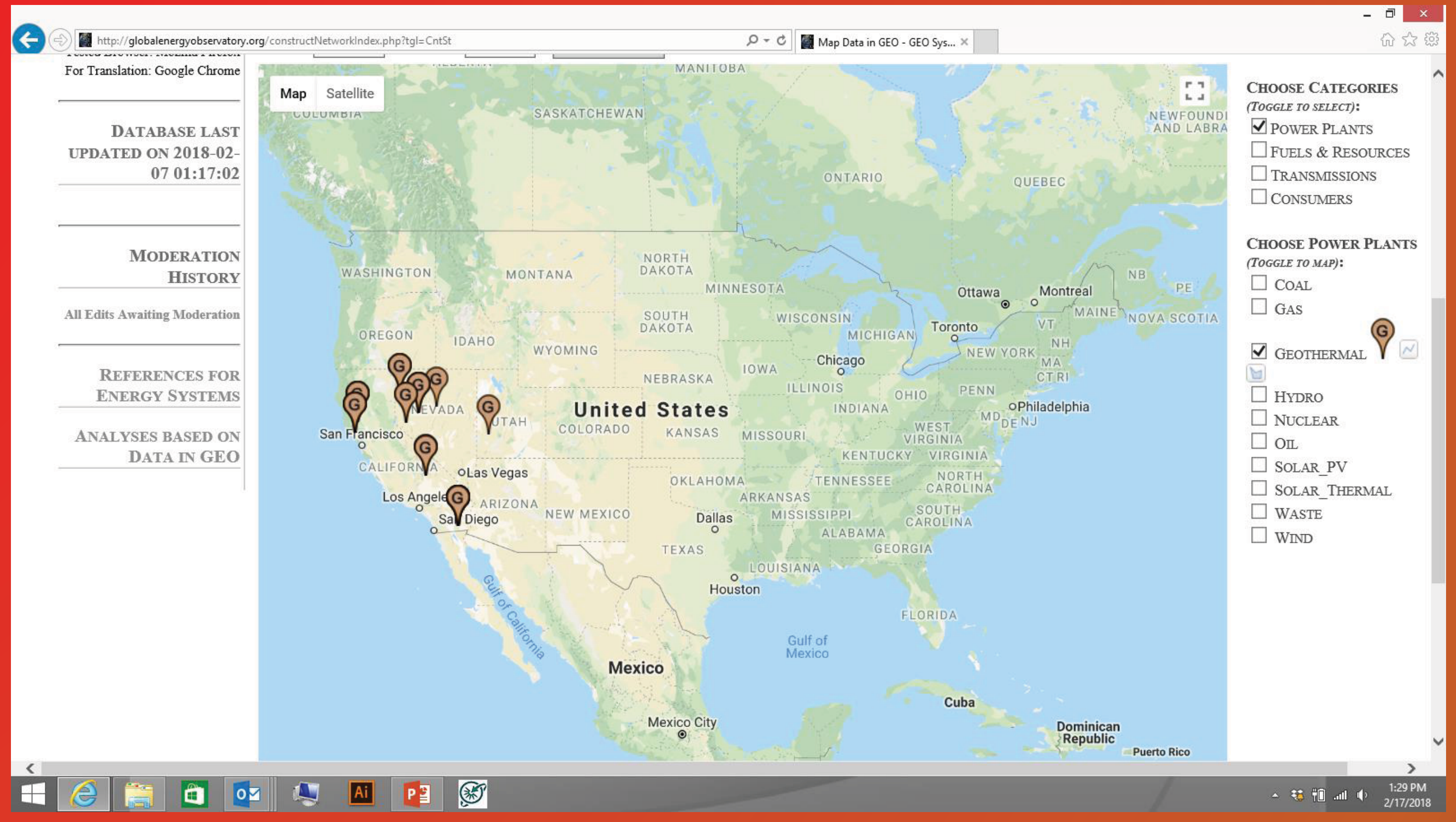
④ MAKING POWER At the power plant, the steam is pumped off and used to turn turbines, creating electricity. Water is returned to the reservoir at various steps in the process.

NOTE: Not to scale

Sources: Department of Energy, AltaRock Energy, Inc.



Where are the MegaWatt Geothermal Plants?



http://globalenergyobservatory.org/constructNetworkIndex.php?tgl=CntSt

For Translation: Google Chrome

DATABASE LAST UPDATED ON 2018-02-07 01:17:02

MODERATION HISTORY

All Edits Awaiting Moderation

REFERENCES FOR ENERGY SYSTEMS

ANALYSES BASED ON DATA IN GEO

CHOOSE CATEGORIES (TOGGLE TO SELECT):

☑ POWER PLANTS
☐ FUELS & RESOURCES
☐ TRANSMISSIONS
☐ CONSUMERS

CHOOSE POWER PLANTS (TOGGLE TO MAP):

☐ COAL
☐ GAS
☑ GEOTHERMAL
☐ HYDRO
☐ NUCLEAR
☐ OIL
☐ SOLAR_PV
☐ SOLAR_THERMAL
☐ WASTE
☐ WIND

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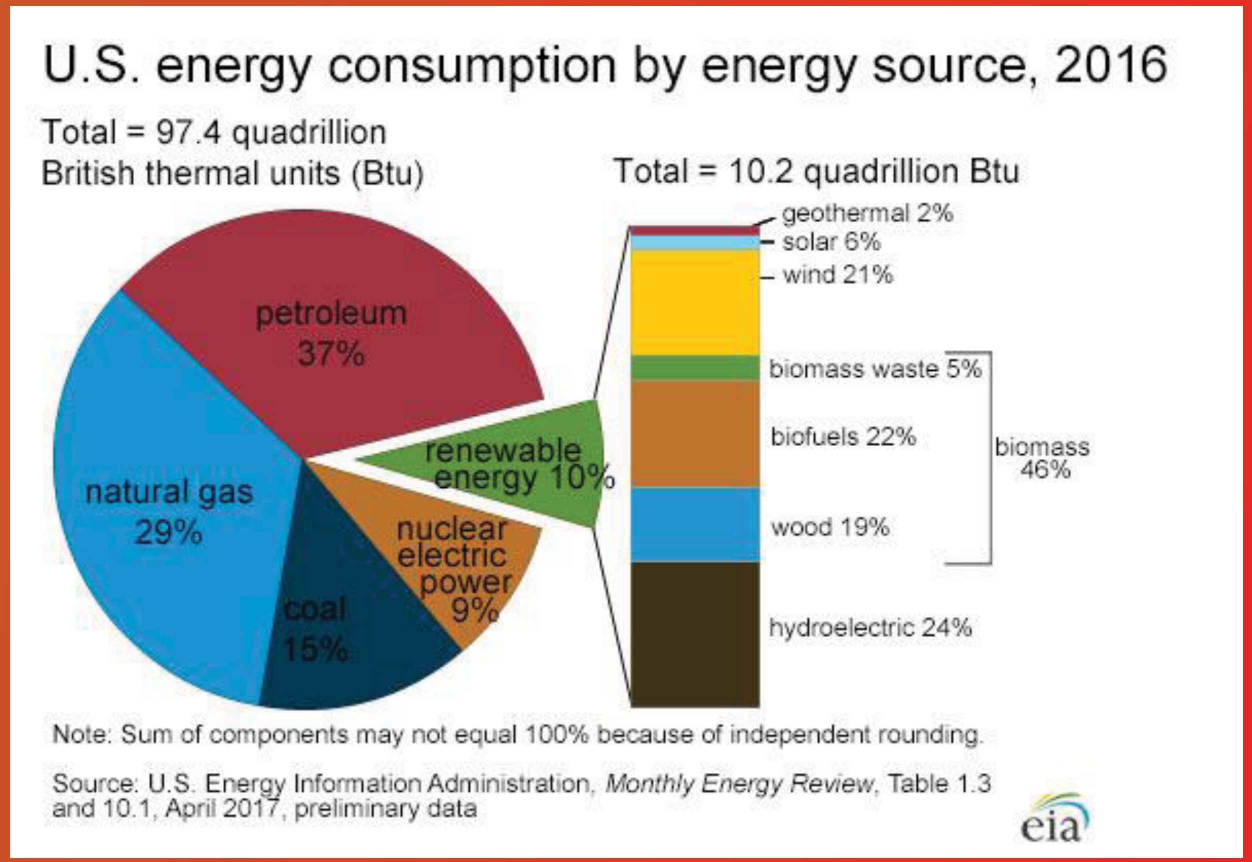
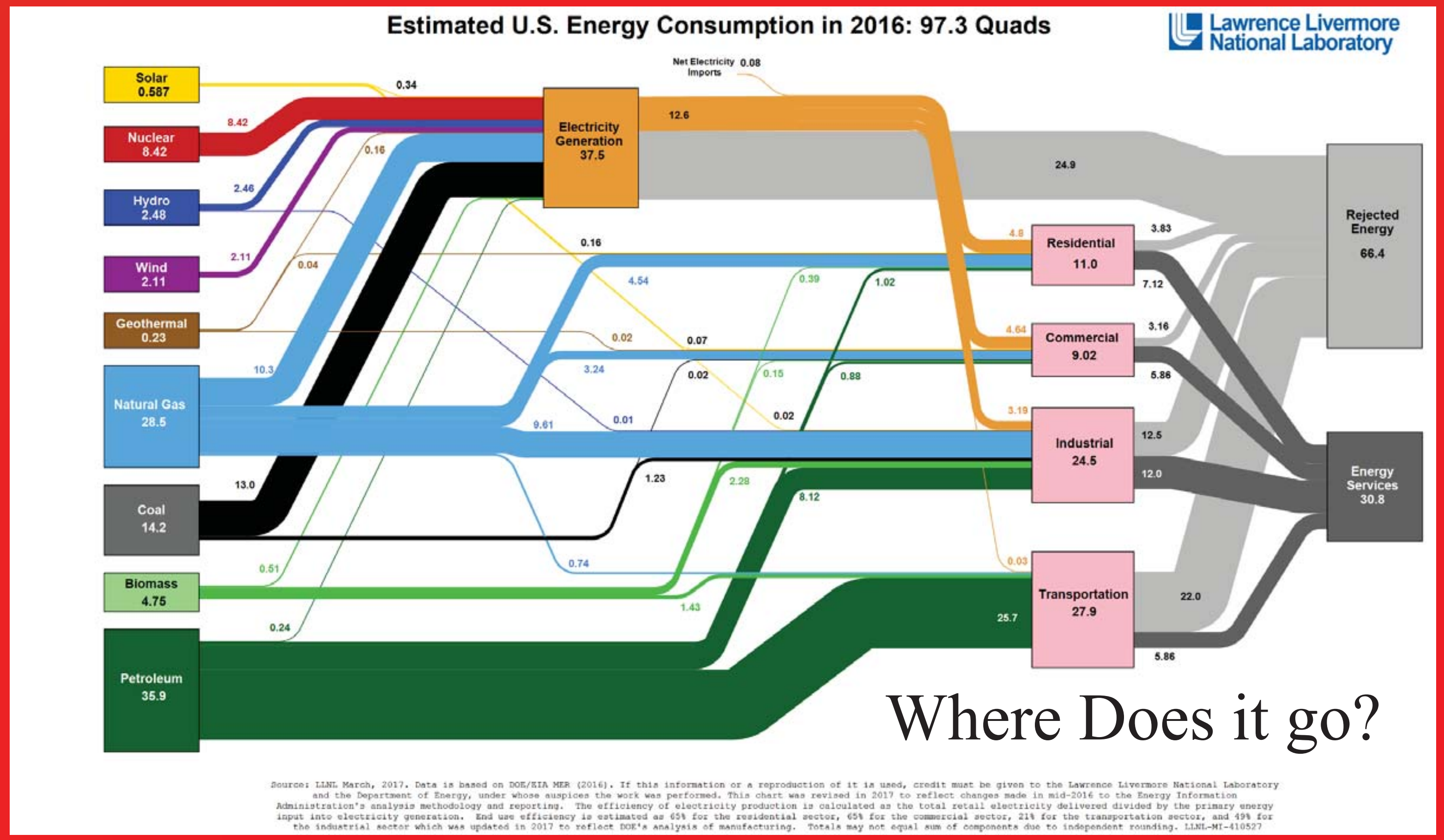
How Much Power Do We Use?



Note: Sum of components may not equal 100% because of independent rounding.

Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2017, preliminary data

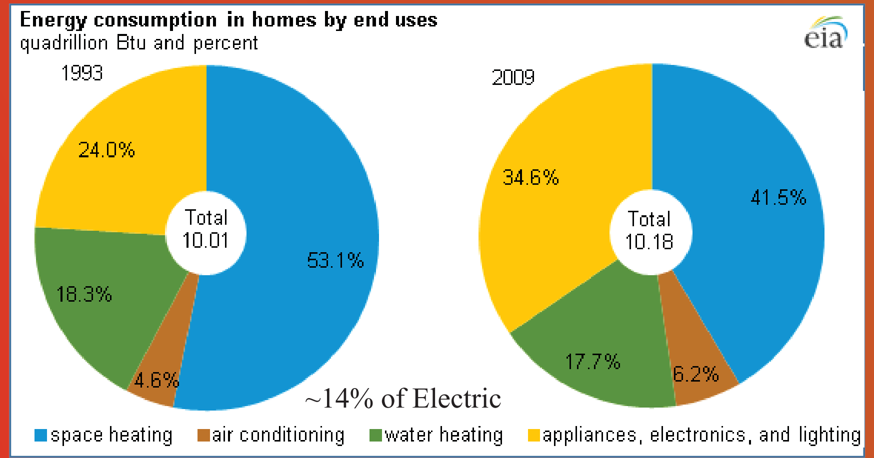


Where Does it go?

Source: LLNL March, 2017. Data is based on DOE/EIA MER (2016). If this information or a reproduction of it is used, credit must be given to the Lawrence Livermore National Laboratory and the Department of Energy, under whose auspices the work was performed. This chart was revised in 2017 to reflect changes made in mid-2016 to the Energy Information Administration's analysis methodology and reporting. The efficiency of electricity production is calculated as the total retail electricity delivered divided by the primary energy input into electricity generation. End use efficiency is estimated as 65% for the residential sector, 65% for the commercial sector, 21% for the transportation sector, and 49% for the industrial sector which was updated in 2017 to reflect DOE's analysis of manufacturing. Totals may not equal sum of components due to independent rounding. LLNL-MI-410527

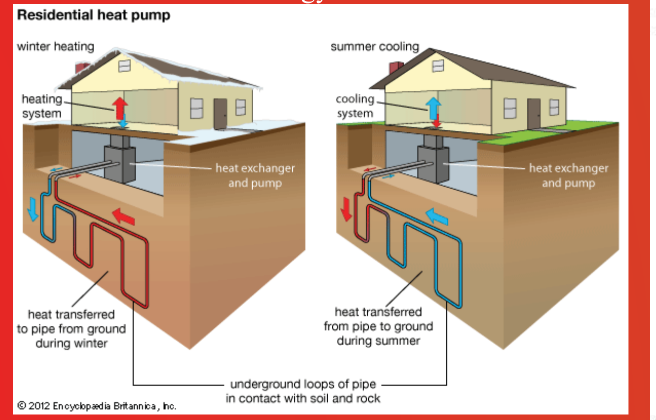
Space Heating

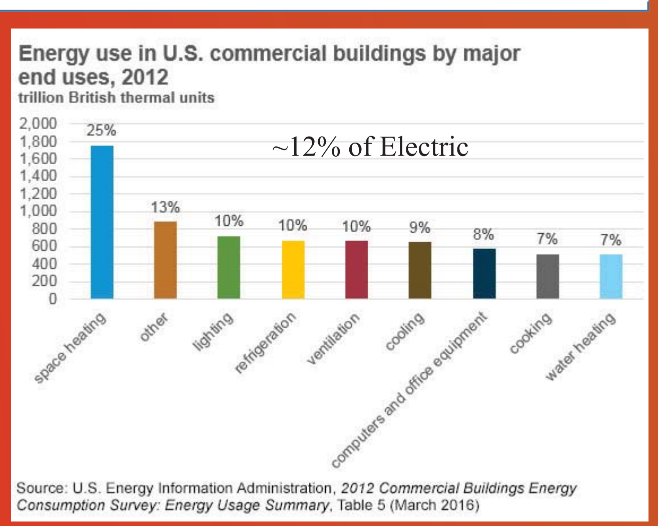
An Electron Saved is and Electron Earned



~14% of Electric

Up to ~0.08 of Electric Replacement
~0.25 of Geothermal Energy

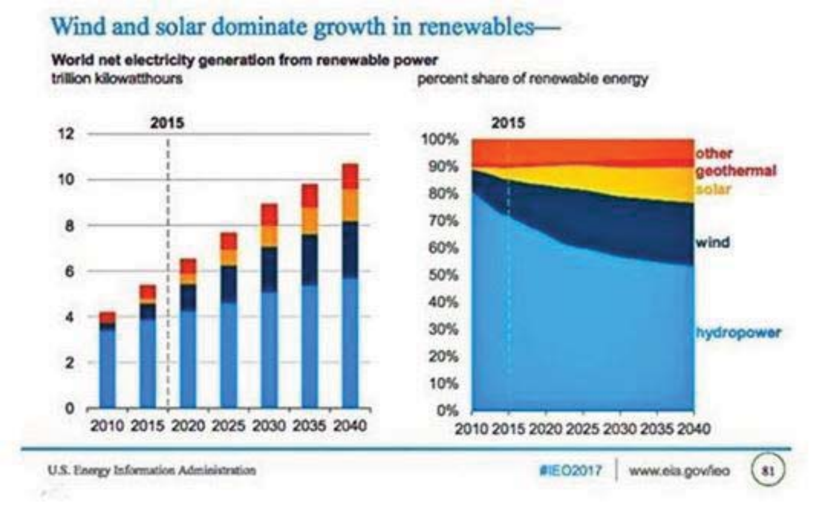


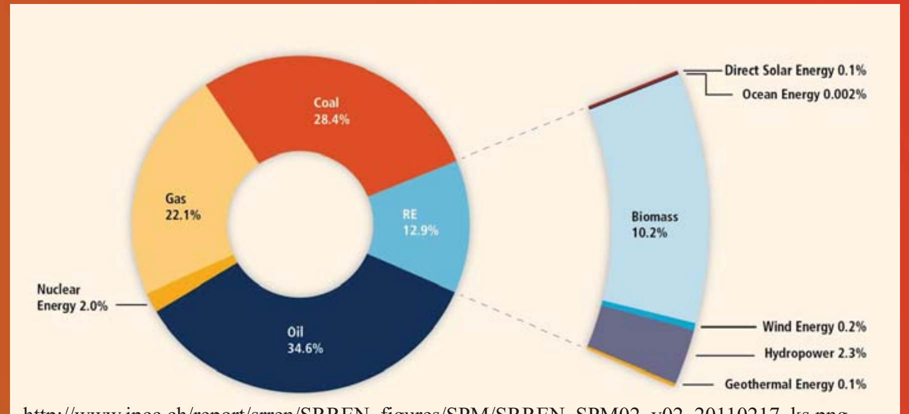


~12% of Electric

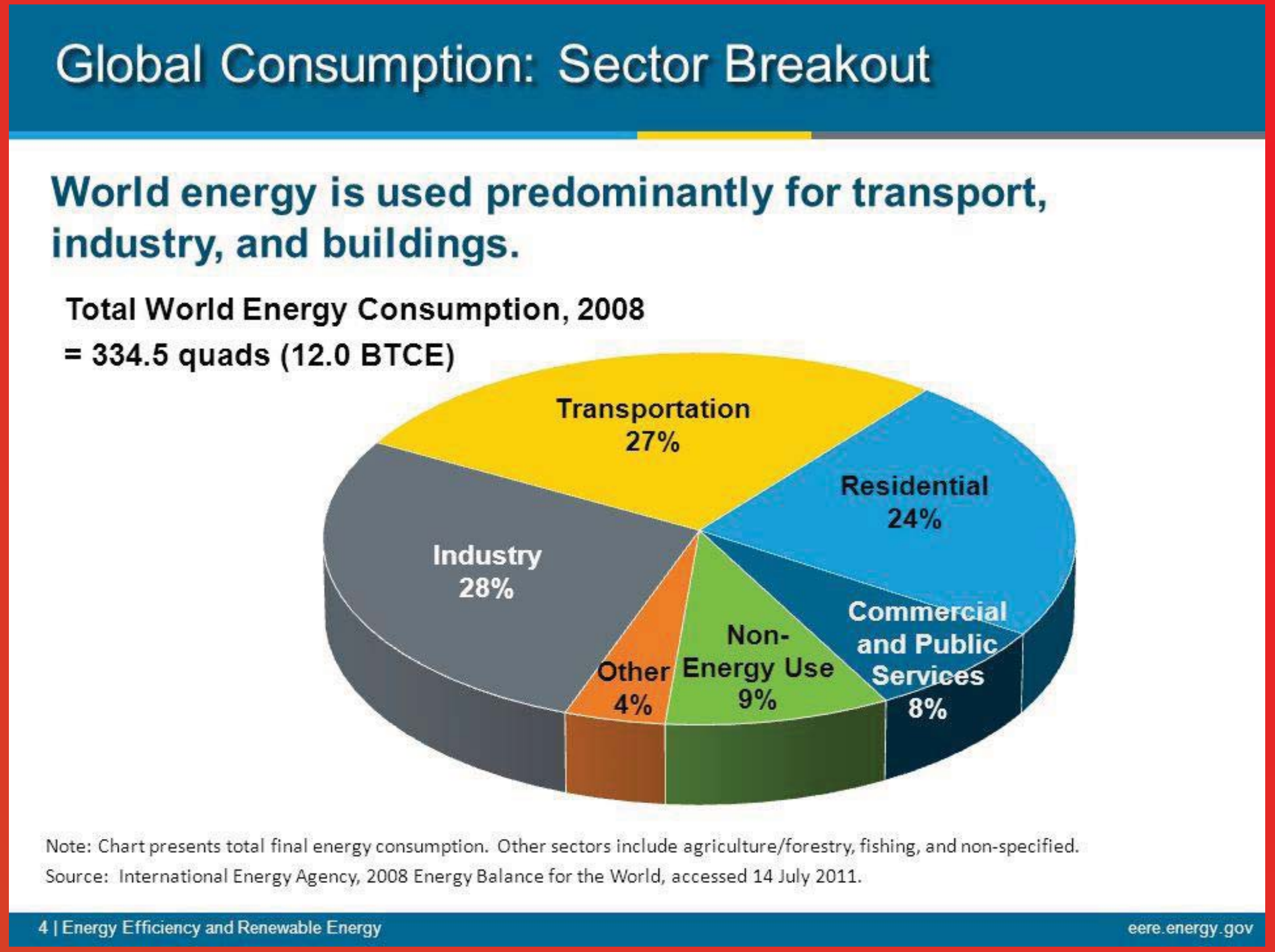
Source: U.S. Energy Information Administration, *2012 Commercial Buildings Energy Consumption Survey: Energy Usage Summary*, Table 5 (March 2016)

World Renewable Use and Projections





http://www.ipcc.ch/report/srren/SRREN_figures/SPM/SRREN_SPM02_v02_20110217_ks.png



Global Consumption: Sector Breakout

World energy is used predominantly for transport, industry, and buildings.

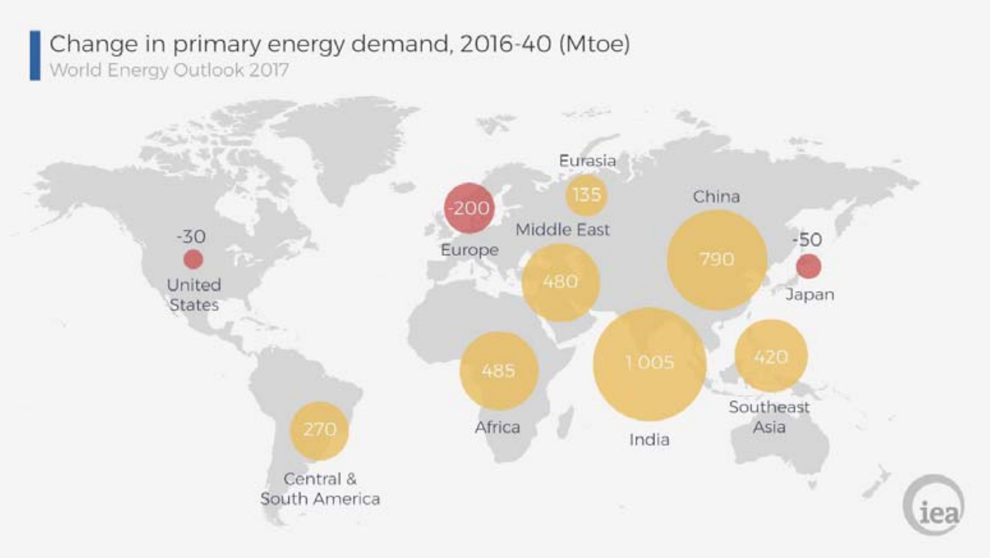
Total World Energy Consumption, 2008
= 334.5 quads (12.0 BTCE)

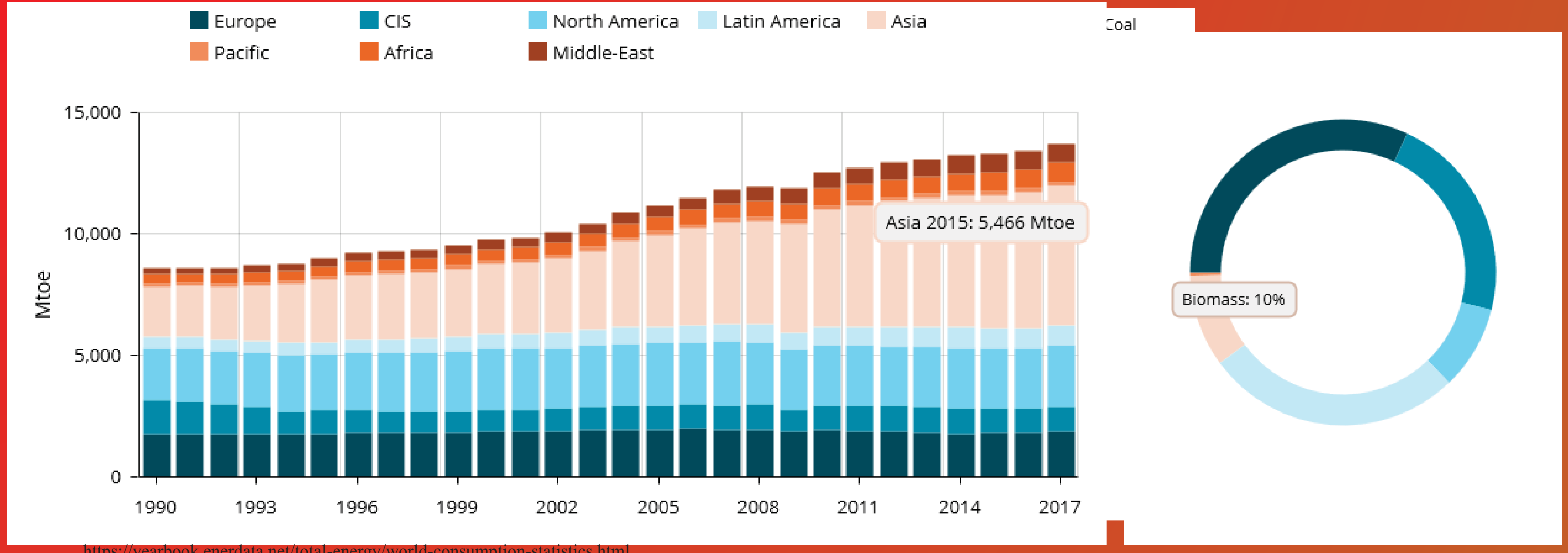
Note: Chart presents total final energy consumption. Other sectors include agriculture/forestry, fishing, and non-specified.
Source: International Energy Agency, 2008 Energy Balance for the World, accessed 14 July 2011.

4 | Energy Efficiency and Renewable Energy

eere.energy.gov

World Energy by Use and Change





https://yearbook.enerdata.net/total-energy/world-consumption-statistics.html

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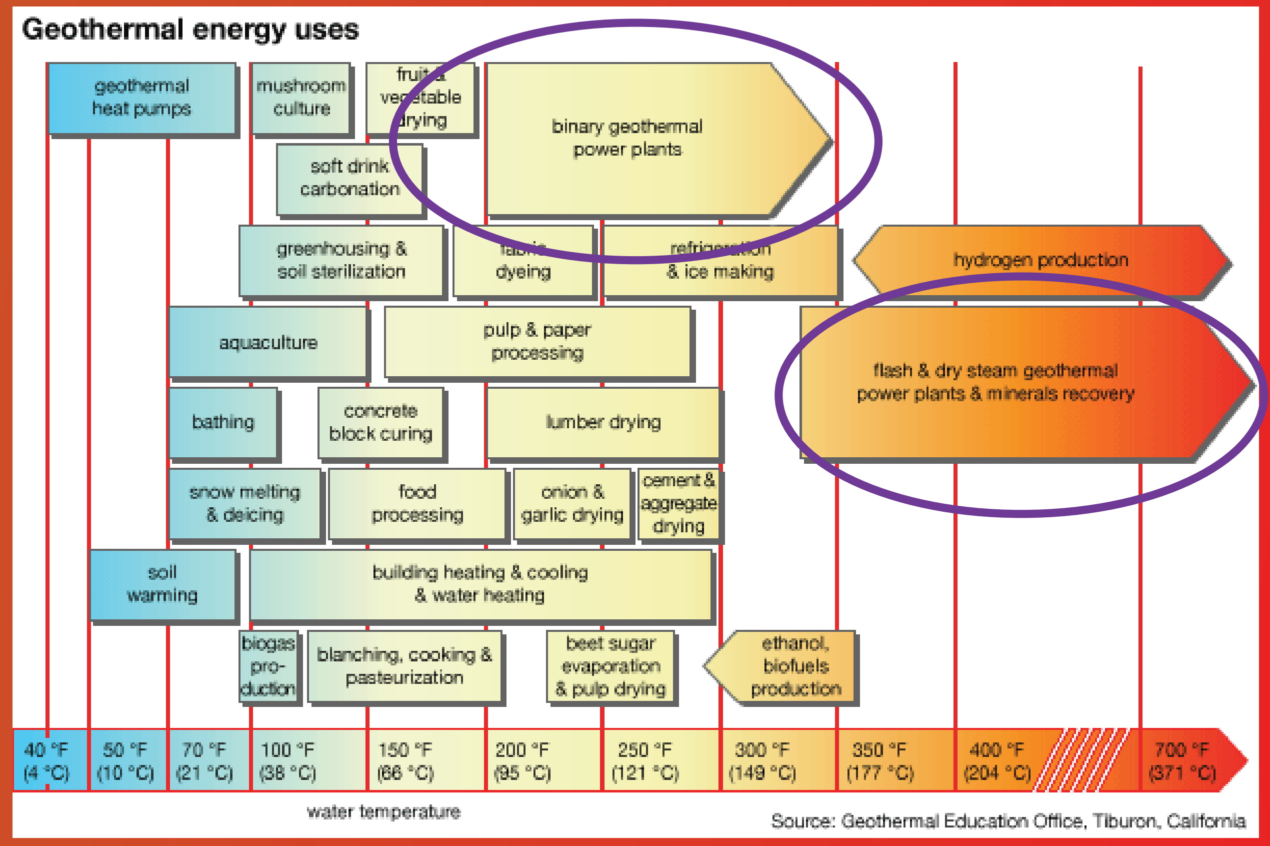
Co-Producing From Your Well?

Rankin cycle turbines can produce heat economically from wast heat from wells. There are a lot of wells.

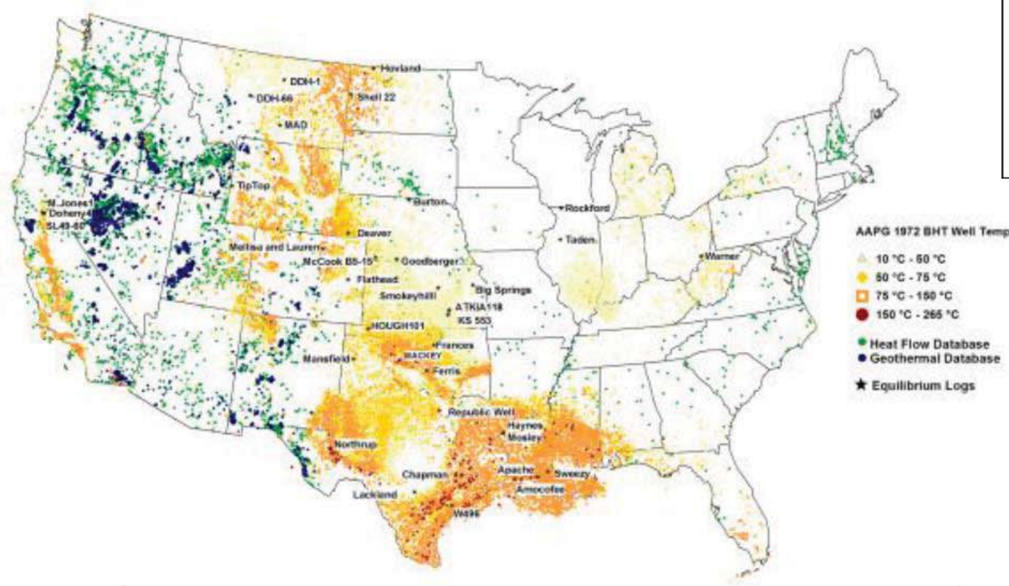
Low Heat Power



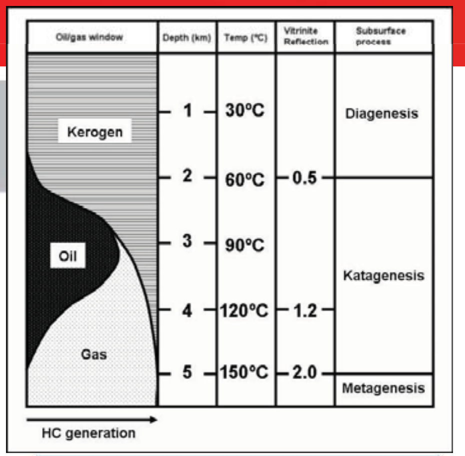
Source: Geothermal Education Office, Tiburon, California

The Opportunity

Co-Produced Water from Existing Wells



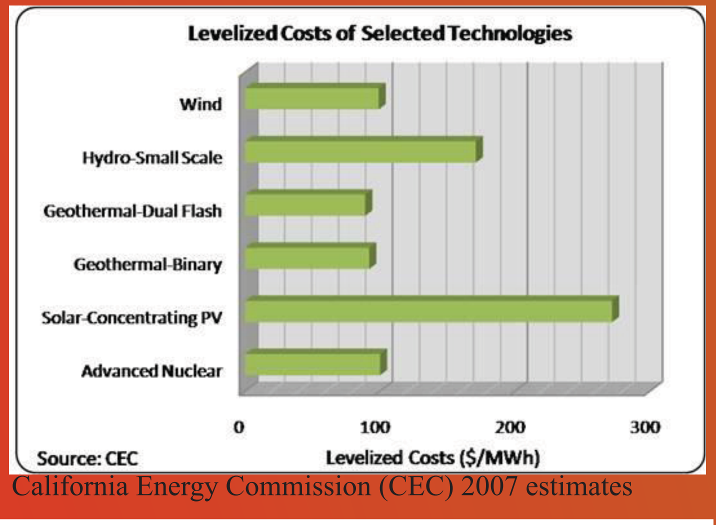
823,000 active oil & gas wells in the U.S.
3 million GPM of hot water in top 8 states
3GW power at 212°F
Sources: The Future of Geothermal Energy – 2006 MIT Report
U.S. Energy Information Administration - 2008



1.2M-1.5M active & inactive wells in Texas alone – USGS has characterized 17,000 wells above 200°F and on the way to 25,000 before year's end.

1. Disposal well 2. Enhanced oil recovery 3. Production well 4. Injected brine 5. Injected fluid 6. Oil

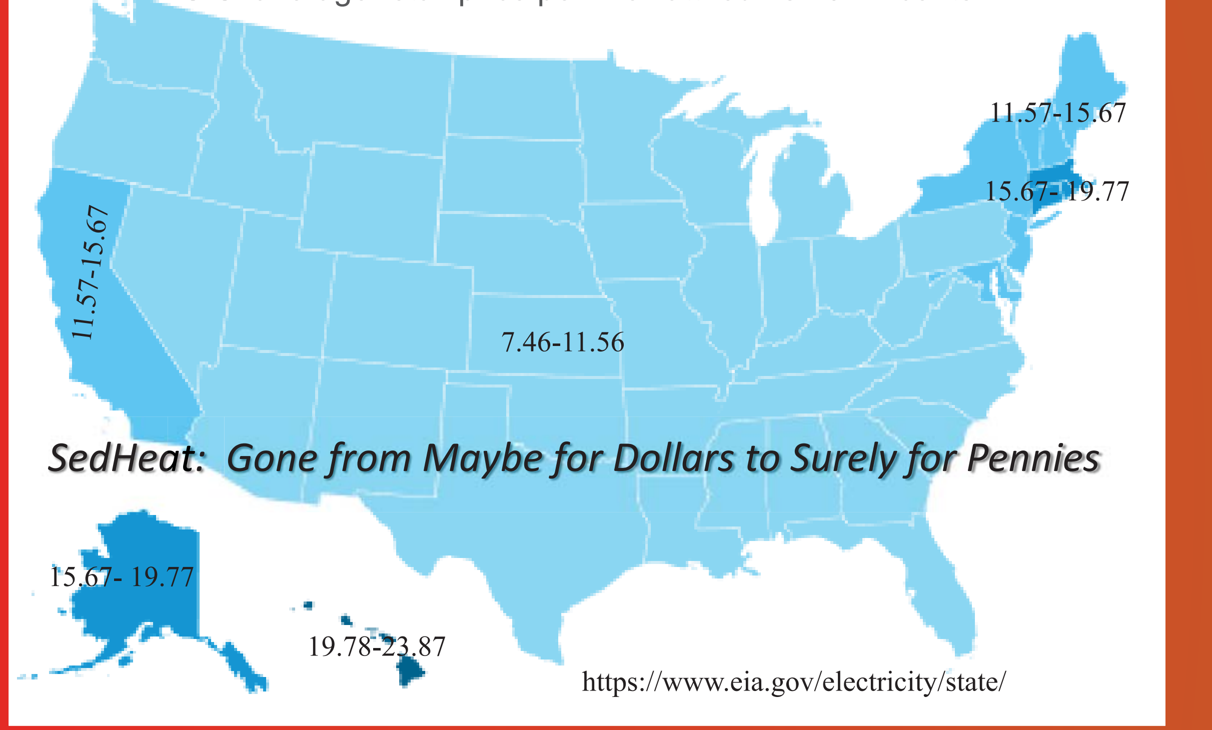
What do We Pay for Power?



Source: CEC

California Energy Commission (CEC) 2007 estimates

U.S. average retail price per kilowatthour is 10.41 cents

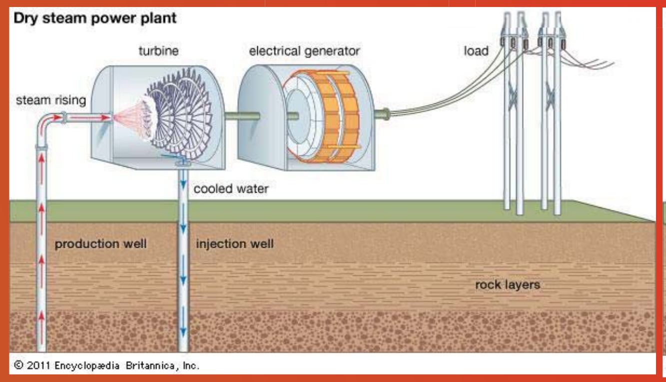


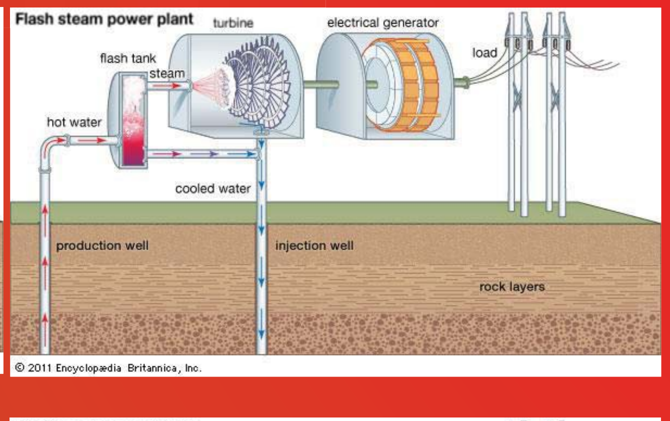
SedHeat: Gone from Maybe for Dollars to Surely for Pennies

https://www.eia.gov/electricity/state/

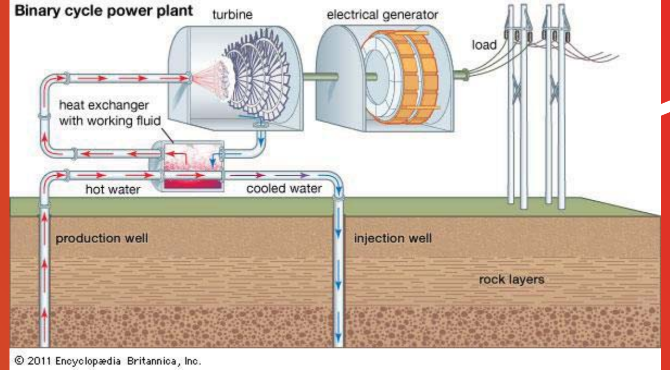
Electricity from Heat

Turbines - The Reigning Champs

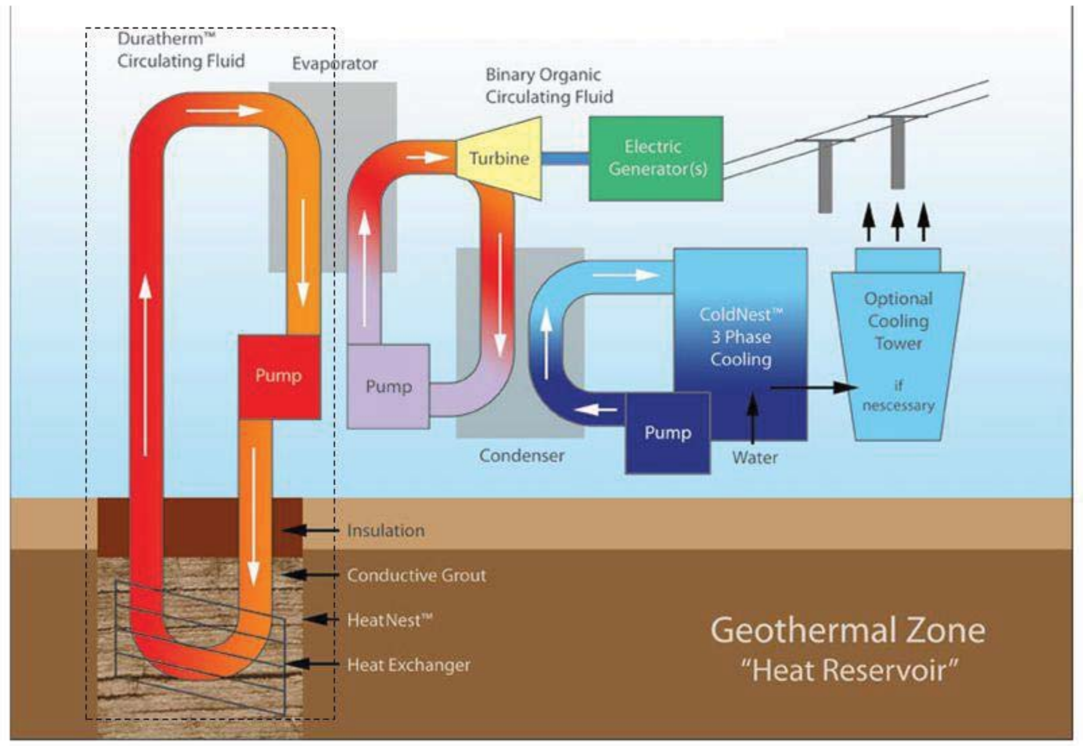




The Low-Heat Challenger



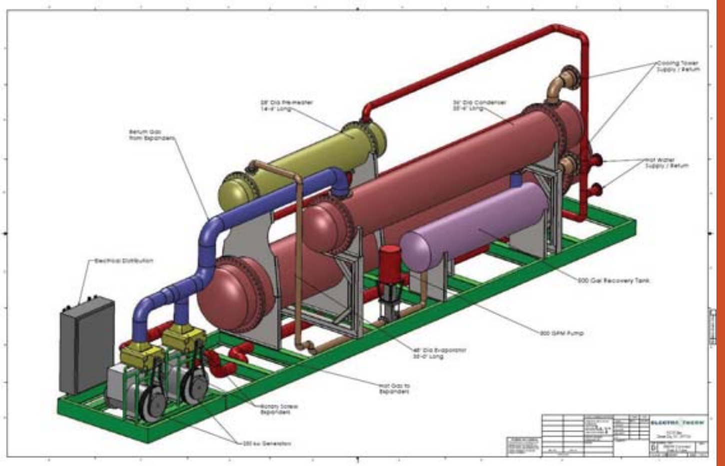
Rankine Cycle for Geothermal Power Plant



The Green Machine Example

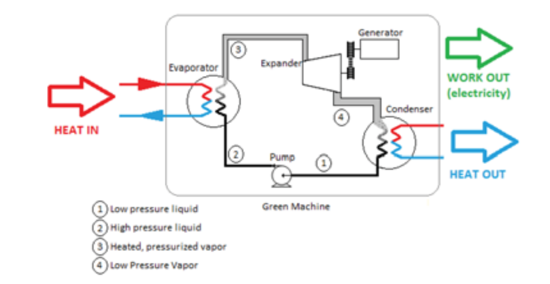
(You can Buy This)

≤ $0.10/kwh From <100 C



The Organic Rankine Cycle (ORC) technology used in the Green Machine is demonstrated in the visual graph below:

Refrigerant - Honeywell R245FA - Charge (lbs): 700 lbs.
Expander - 75% Expansion Efficiency
Electric Generator - Marathon Prime Line Efficiency 91%
System Efficiencies - 6% - 10% (Resource temperature dependent)
Basic Cycle - Organic Rankine Cycle (ORC) Twin Screw



https://www.businesswire.com/news/home/20090604005254/en/ElectraTherm-Green-Machine-Turns-Geothermal-Heat-Electricity

Building a Geothermal Future on a Sedimentary Foundation

John Holbrook, Texas Christian University, Dept. of Geological Sciences and Energy Institute

SEDHEAT

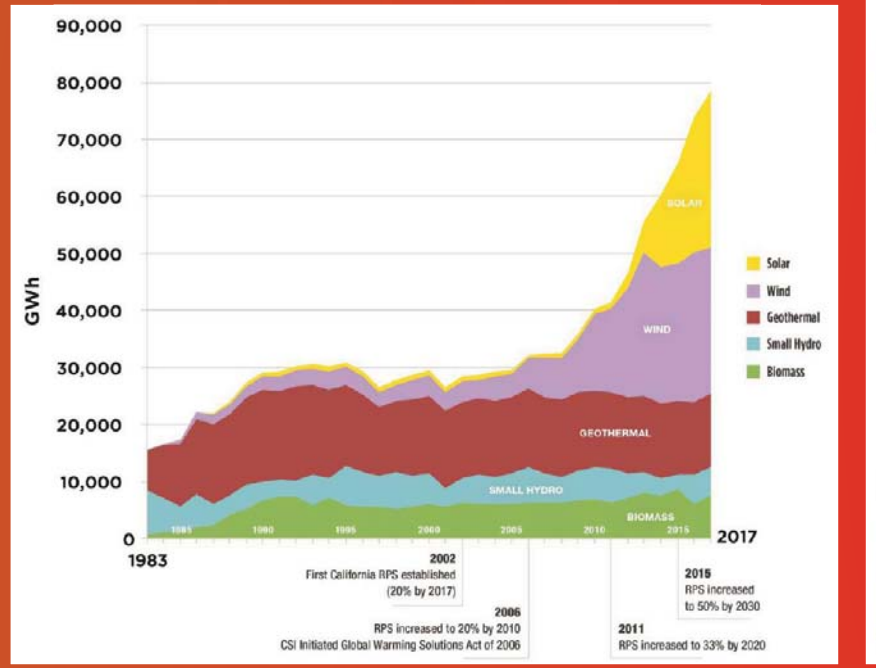
The Sustainable Energy Problem Solved?

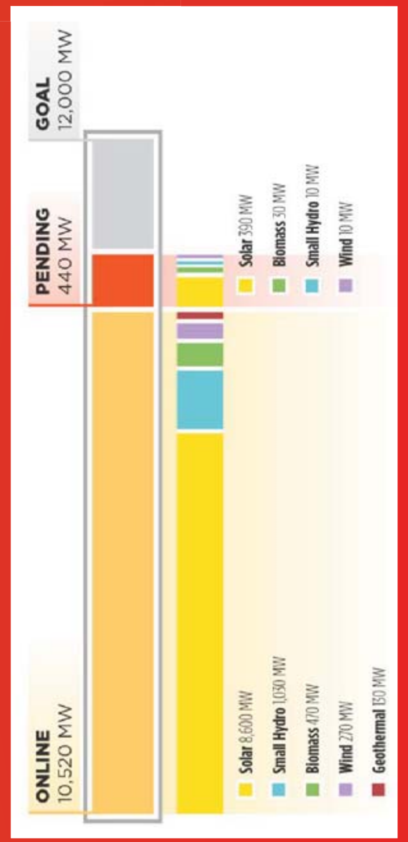
A bold new direction for geothermal is using intermittent solar energy to spike heat in any of the many sedimentary with marginal heat resources by spiking heat of injectors with intermittent solar energy. The stored heat is then used to generate power from geothermal pumping. This ultimately turns intermittent solar energy into more useable baseload energy.

So Why Does Storage Matter?

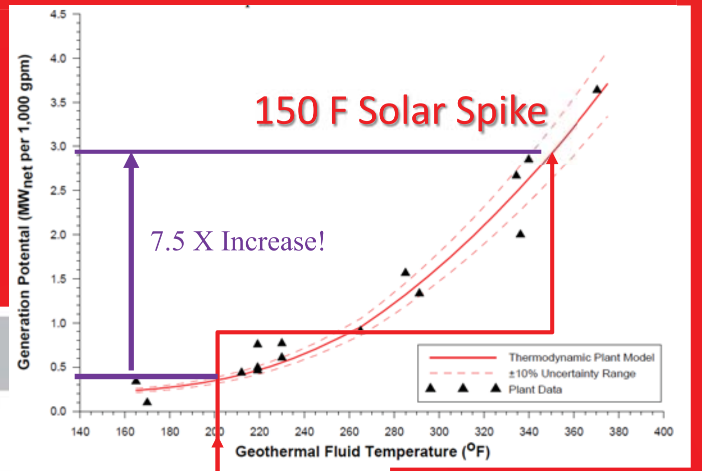
California Power

A Solar Wind With no Sign of Slowing

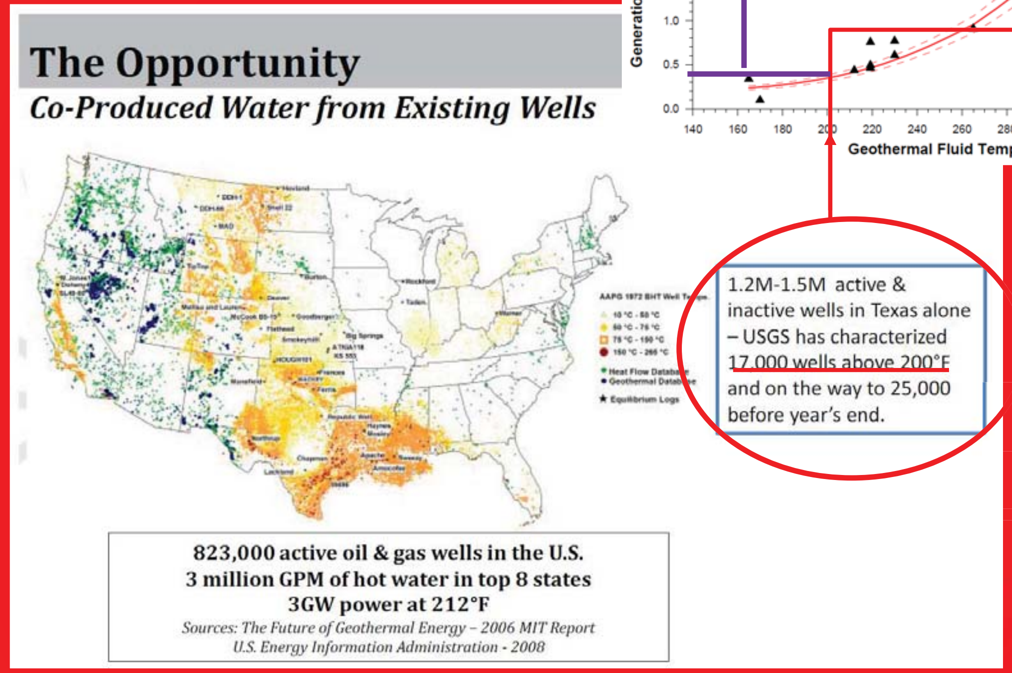




Geothermal as Power Storage and the Way Forward



(Sanyal and Butler, 2010)



The Opportunity

Co-Produced Water from Existing Wells

823,000 active oil & gas wells in the U.S.
3 million GPM of hot water in top 8 states
3GW power at 212°F

Sources: The Future of Geothermal Energy – 2006 MIT Report
U.S. Energy Information Administration - 2008

1.2M-1.5M active & inactive wells in Texas alone – USGS has characterized 17,000 wells above 200°F and on the way to 25,000 before year's end.

Coupled Geothermal Systems?

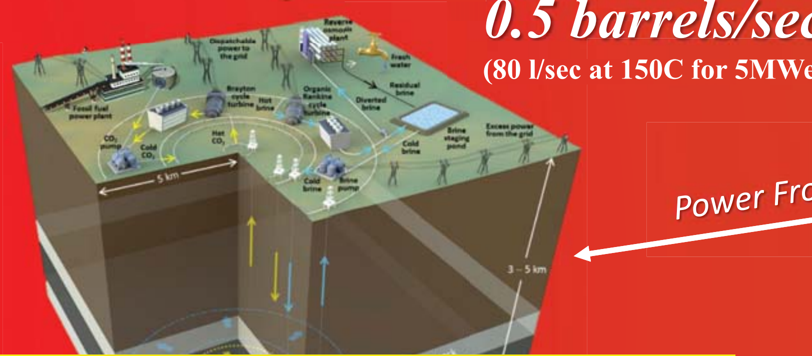
Convert your Wastewater to a Power Plant?

Spike It

Typical Injection well at about 100C

Earth Battery

Economic Sedheat
0.5 barrels/sec at 150C
(80 l/sec at 150C for 5MWe; MIT Panel, 2005)



Power From the Battery

Solar Base Load!!

The "Duck" Dilemma

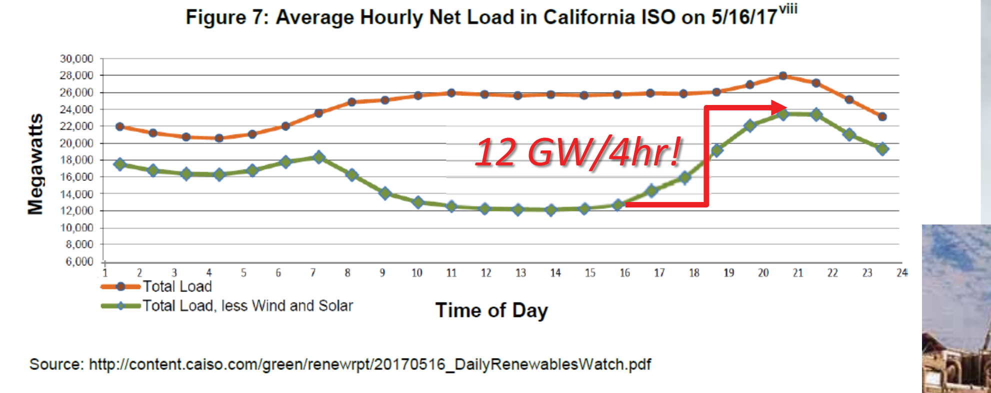


Figure 7: Average Hourly Net Load in California ISO on 5/16/17[viii]

Source: http://content.caiso.com/green/renewrpt/20170516_DailyRenewablesWatch.pdf

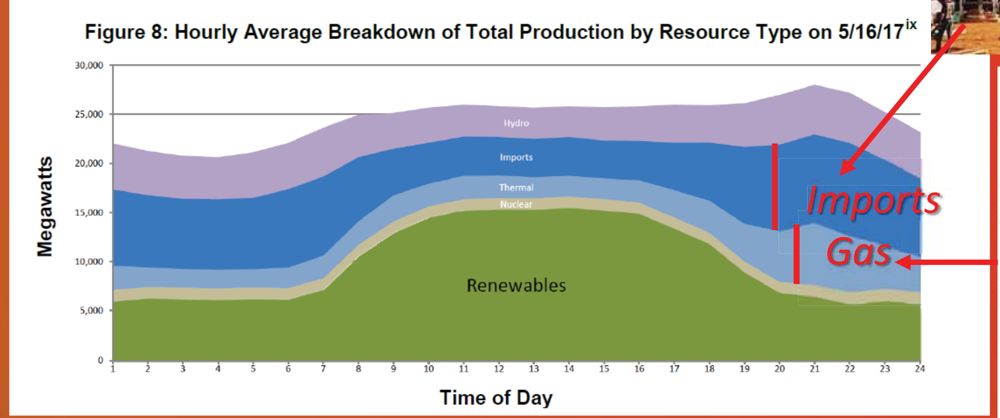
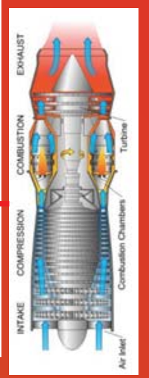


Figure 8: Hourly Average Breakdown of Total Production by Resource Type on 5/16/17[ix]



The Hybrid Plant Model

Stillwater Plant, Fallon, NV

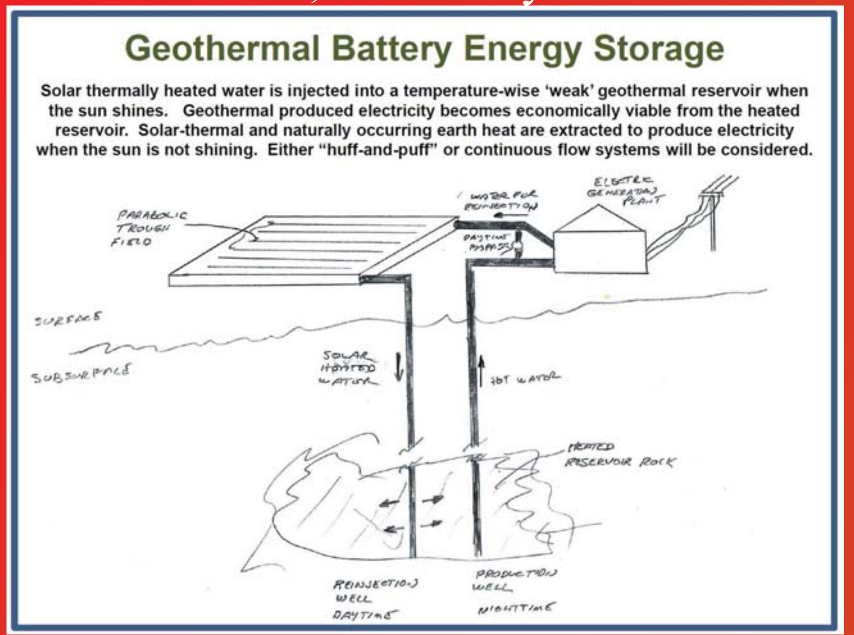
Enel Green Power North America's Stillwater Solar Geothermal Hybrid Project in Fallon, Nevada is a first of its kind renewable energy power plant.

Stillwater integrates 33 MW of geothermal power with 26.4 MW of solar photovoltaic and 2 MW of solar thermal capacity.

http://www.thinkgeoenergy.com/video-enels-stillwater-hybrid-geothermal-solar-plant-in-nevada/

Who's Working on This?

EGI, University of Utah

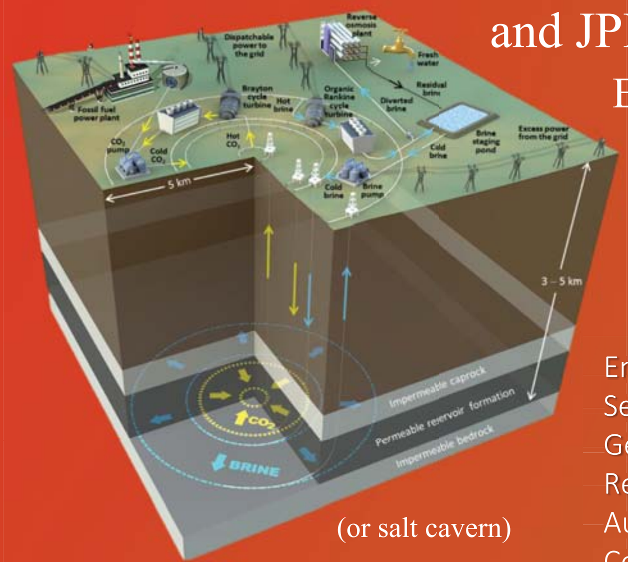


Geothermal Battery Energy Storage

Solar thermally heated water is injected into a temperature-wise 'weak' geothermal reservoir when the sun shines. Geothermal produced electricity becomes economically viable from the heated reservoir. Solar-thermal and naturally occurring earth heat are extracted to produce electricity when the sun is not shining. Either "huff-and-puff" or continuous flow systems will be considered.

Ohio University and JPL

Earth Battery Incubator Workshop 2016



(or salt cavern)

CO$_2$-Geothermal Bulk Energy Storage System

Buscheck, T., Bielicki, J., et al. (2016). "Multi-Fluid Geo-Energy Systems: Using Geologic CO$_2$ Storage for Geothermal Energy Production and Grid-Scale Energy Storage in Sedimentary Basins." *Geosphere,* 12(3), 1-19.

Energy Sustainability Research Laboratory

Energy Storage in Sedimentary Basin Geothermal Resources
August 15-16, 2016 |
Columbus, OH
Jeff Bielicki and Tom Buscheck