

Geothermal Energy Now:
Opportunities in grid power, direct
heat, and energy storage

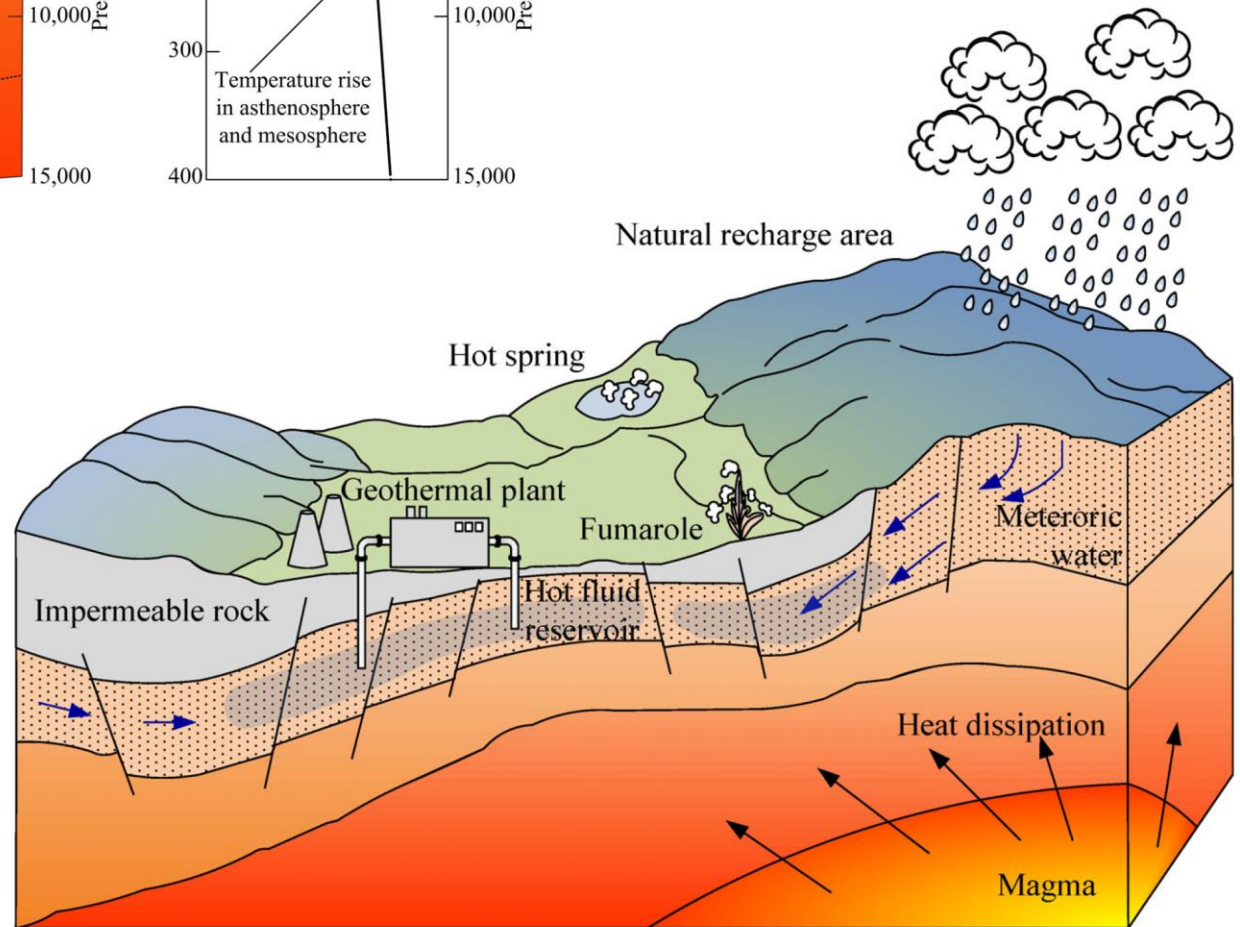
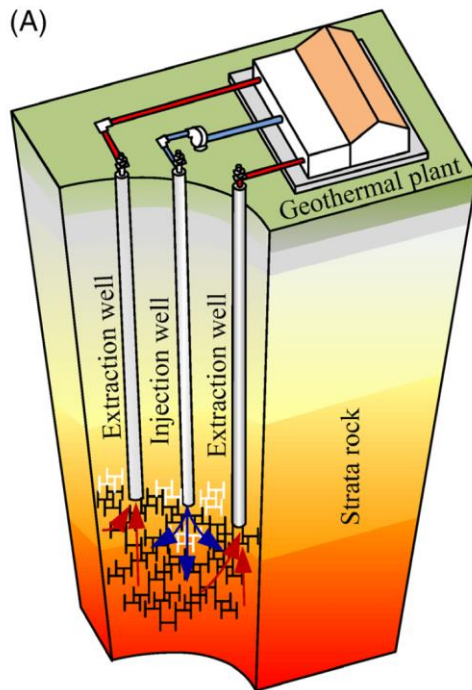
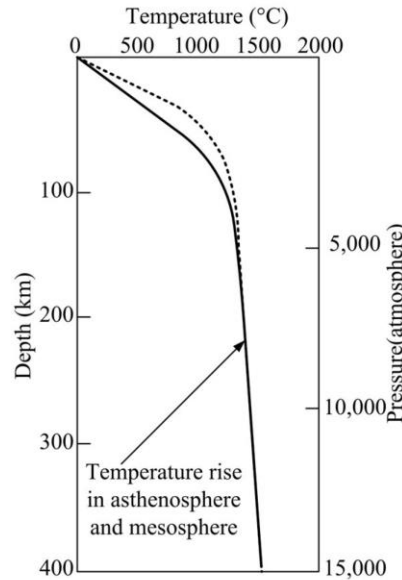
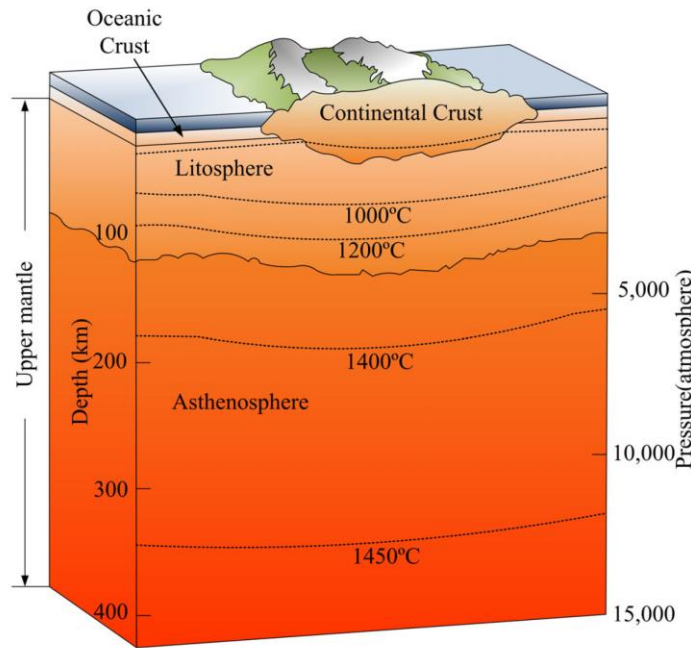
John Holbrook
Texas Christian University

SEDHE  T



GEO THERMAL

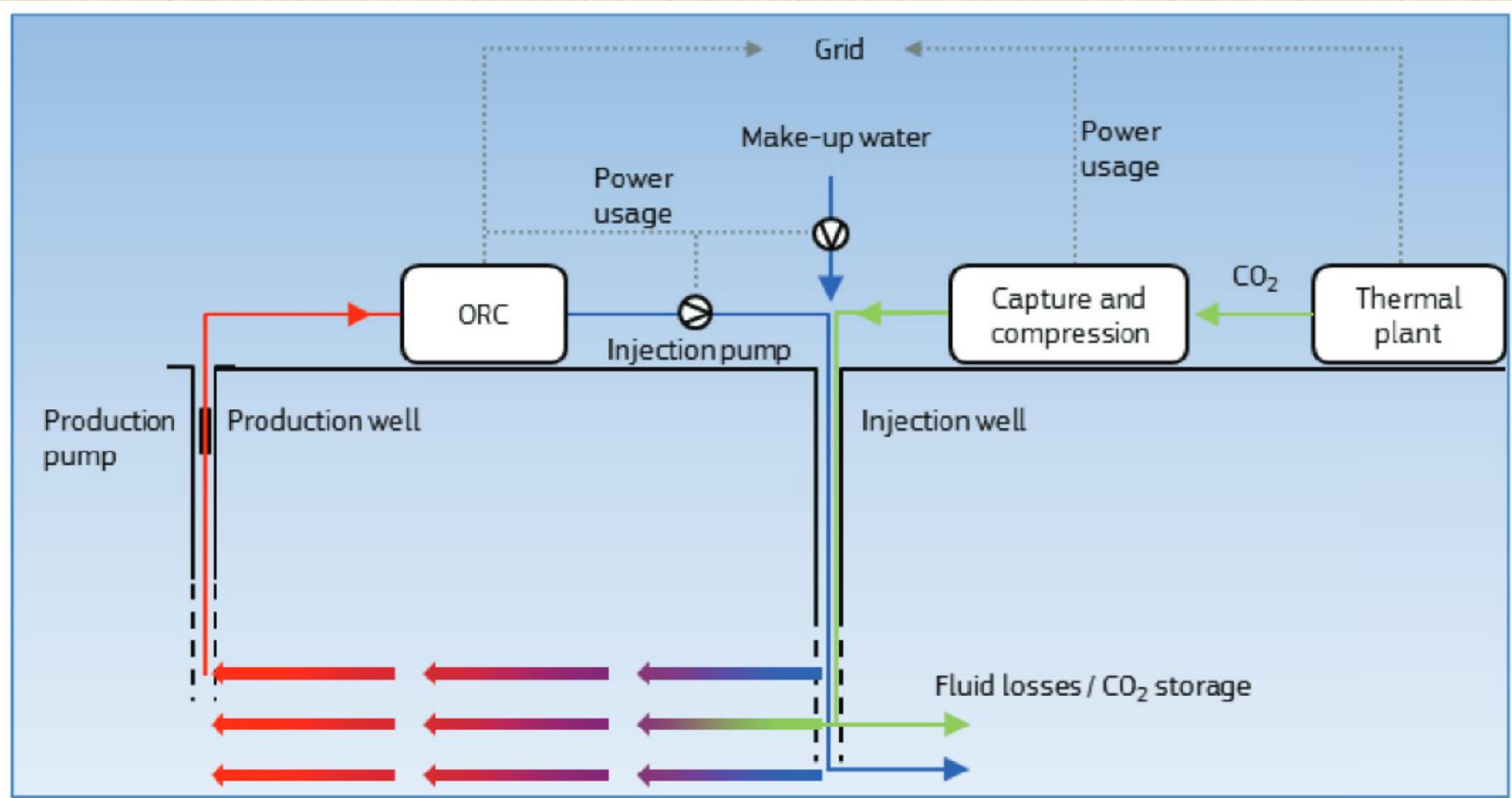
The General Idea



(Kurnia et al., 2020)

Couple it with Carbon Sequestration and Storage

CO₂ as the Working Fluid



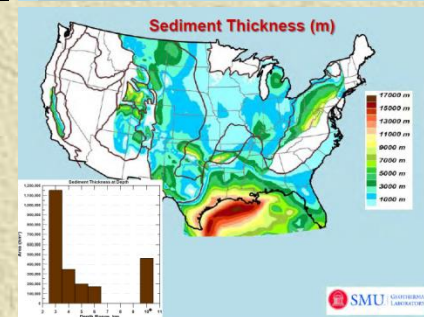
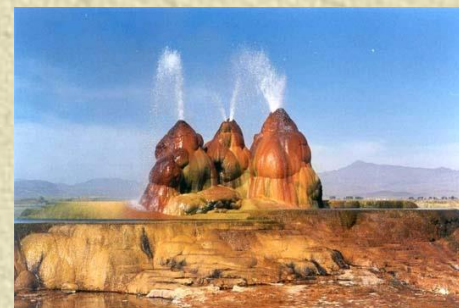
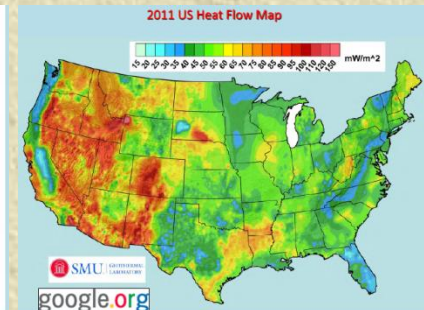
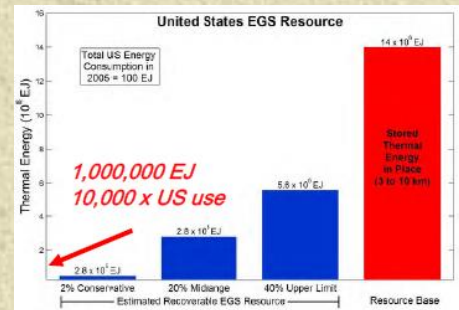
SEDHEAT

The goal of this RCN
*“To form a
central point of unity, exchange, and education to exceed the
science and engineering challenges of
sedimentary-basin geothermal energy.”*

Steering Committee

John Holbrook, TCU
Derek Elsworth, Penn
State

Karen Block, CUNY
Joseph Moore, U Utah
David Blackwell, SMU
Herbert Einstein, MIT





What did we do?

**Build and Sustain a Research Community
-Conferences, shortcourses, publications, grants,
and assorted get togethers'**

4 Large Conferences

ARMA-AAPG-SEDHEAT WORKSHOP

SUCCESSFUL ENGINEERING OF SEDIMENTARY GEOTHERMAL SYSTEMS

Friday June 24th and
Saturday June 25th, 2016
50th Rock
Mechanics/Geomechanics
Symposium
Westin Galleria, Houston,
Texas
[http://armasymposium.org/
workshops](http://armasymposium.org/workshops)

Conveners: Derek Elsworth,
John Holbrook, Charles
Fairhurst, Sid Green

**PENROSE
CONFERENCE**

THE GEOLOGICAL SOCIETY
OF AMERICA®

CONVENERS:
John Holbrook
Texas Christian University
Fort Worth, Texas 76129
Rick Allis
Utah Geological Survey
Salt Lake City, Utah 84114
Derek Elsworth
Penn State University
University Park, Penn. 16802
Sidney Green
Schlumberger / Univ. of Utah
Salt Lake City, Utah 84105
Joseph Moore
Energy & Geoscience Institute
University of Utah
Salt Lake City, Utah 84198

**Predicting and
Detecting Natural and
Induced Flow Paths
for Geothermal Fluids
in Deep Sedimentary
Basins**

19–23 October 2013 • Park City, Utah, USA
<http://www.geosociety.org/penrose/13utah.htm>
<http://www.sedheat.org/>
[National Science Foundation Sponsored Conference]

Unlocking the Energy Elephant

SEDHEAT
NATIONAL SCIENCE FOUNDATION-SPONSORED CONFERENCE

*SedHeat Workshop: Science and Engineering
for Geothermal Energy in Sedimentary Basins*

March 2nd and 3rd, 2017

Marriott University Park Hotel, Salt Lake City,
Utah, USA

www.shutterstock.com • 400212811

One-day workshop

American Rock Mechanics
Association (ARMA) 49th Symposium
in Minneapolis (June 1, 2014)

The Role of Geomechanics in Geothermal Reservoir Engineering

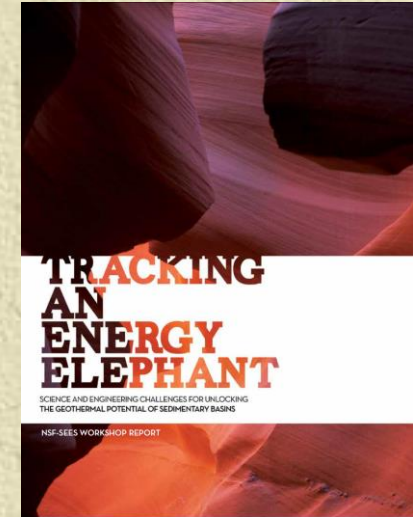
Leaders- Azaden Riahi; Branko
Damjanac and Will Pettitt, (ITASCA).

12 Incubator Workshops!

CO₂-Geothermal Bulk
Energy Storage System

Buscheck, T., Bielicki, J., et al. (2016). "Multi-Fluid Geo-Energy
Systems: Using Geologic CO₂ Storage for Geothermal Energy
Production and Grid-Scale Energy Storage in Sedimentary
Basins." *Geosphere*, 12(3), 1-19.

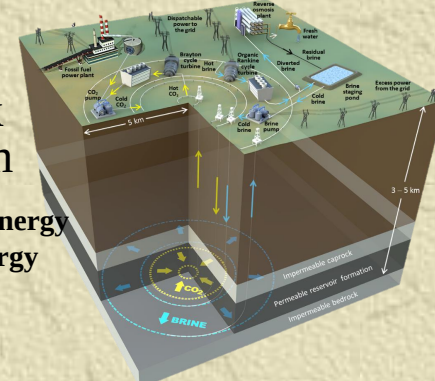
Energy Sustainability Research Laboratory



Theme Issue: Geothermal Energy
from Sedimentary Basins:
Challenges, Potential, and Ways
Forward



Eds: John Holbrook, Anna
Crowell, Herbert Einstein
Five papers published and three in
final stages



The Sedimentary Basin

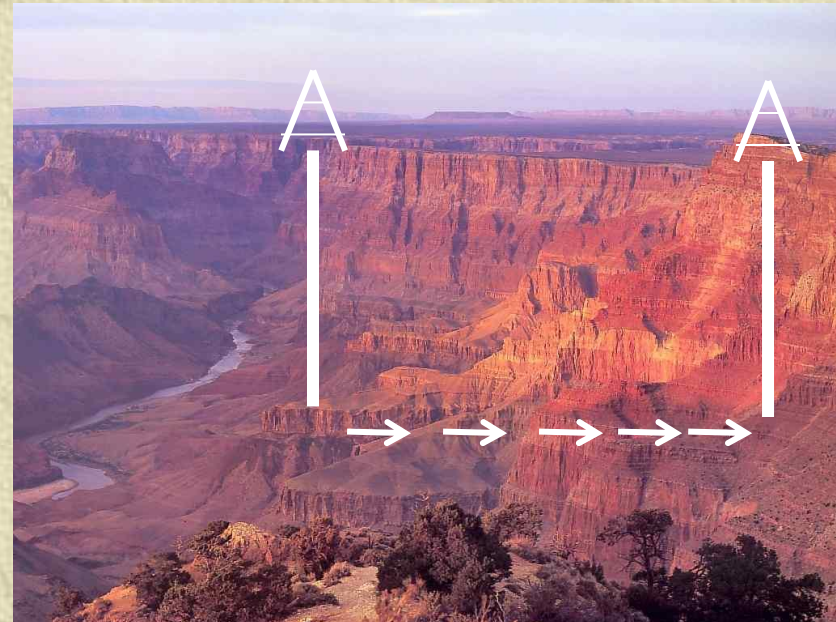
Fluid flow



What are the fundamental sedimentary processes that control the filling of sedimentary basins across all scales, and how do they impact permeability, connectivity, and heterogeneity of deep-basin flow paths?

What are the diagenetic processes that operate in deep sedimentary basins and how do they augment or deduct permeability as they evolve?

What controls the natural processes whereby fractures form and evolve within basin sediments, and what is the impact of these fractures on the transmission of fluid flow?



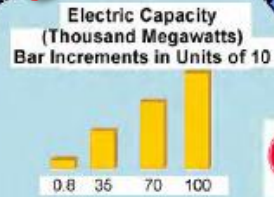
Question #1

Why Bother?



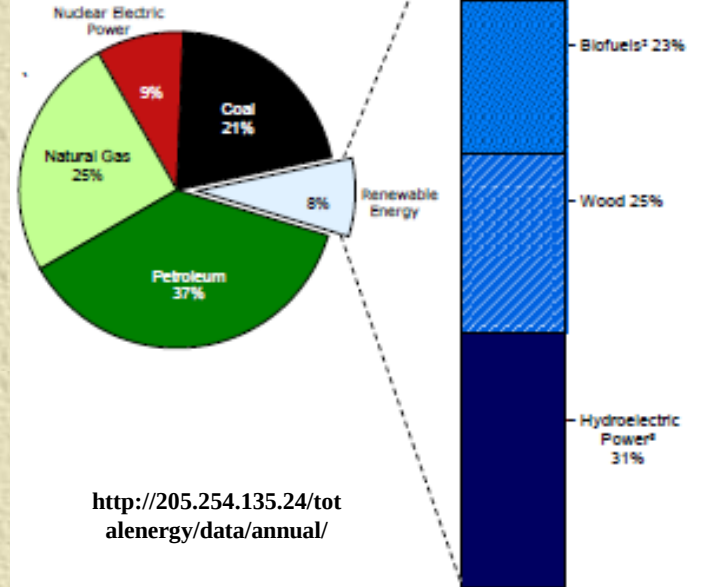
Why Geothermal?

Installed Capacity -- 980,000 MW (EIA)



Renewable Energy as Share of Total Primary Energy Consumption, 2010

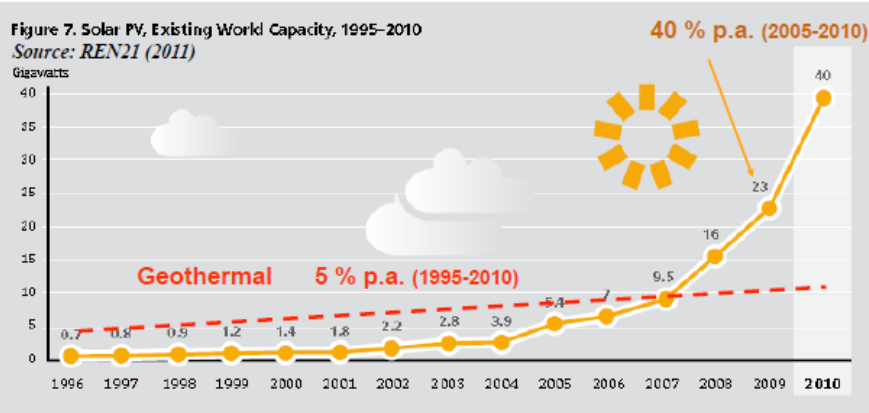
Geothermal
3% of 8%!
<3000MWe



<http://205.254.135.24/totalenergy/data/annual/>

Global PV capacity growth vs. Geothermal power growth

Figure 7. Solar PV, Existing World Capacity, 1995-2010
Source: REN21 (2011)

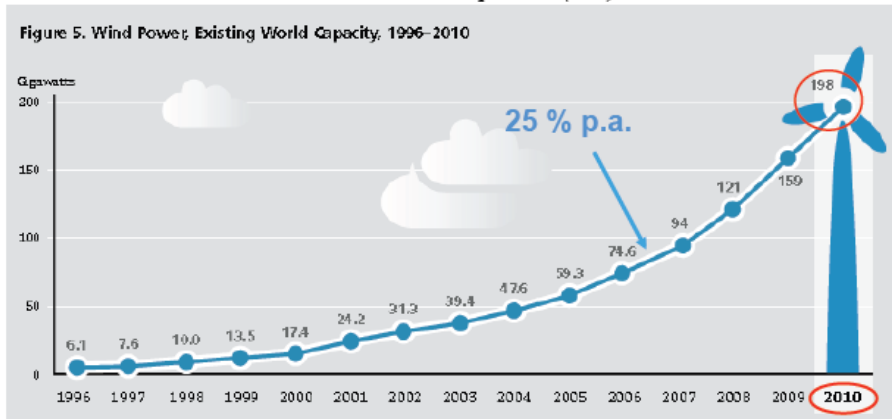


Geothermal growth: all hydrothermal!

Global wind power growth

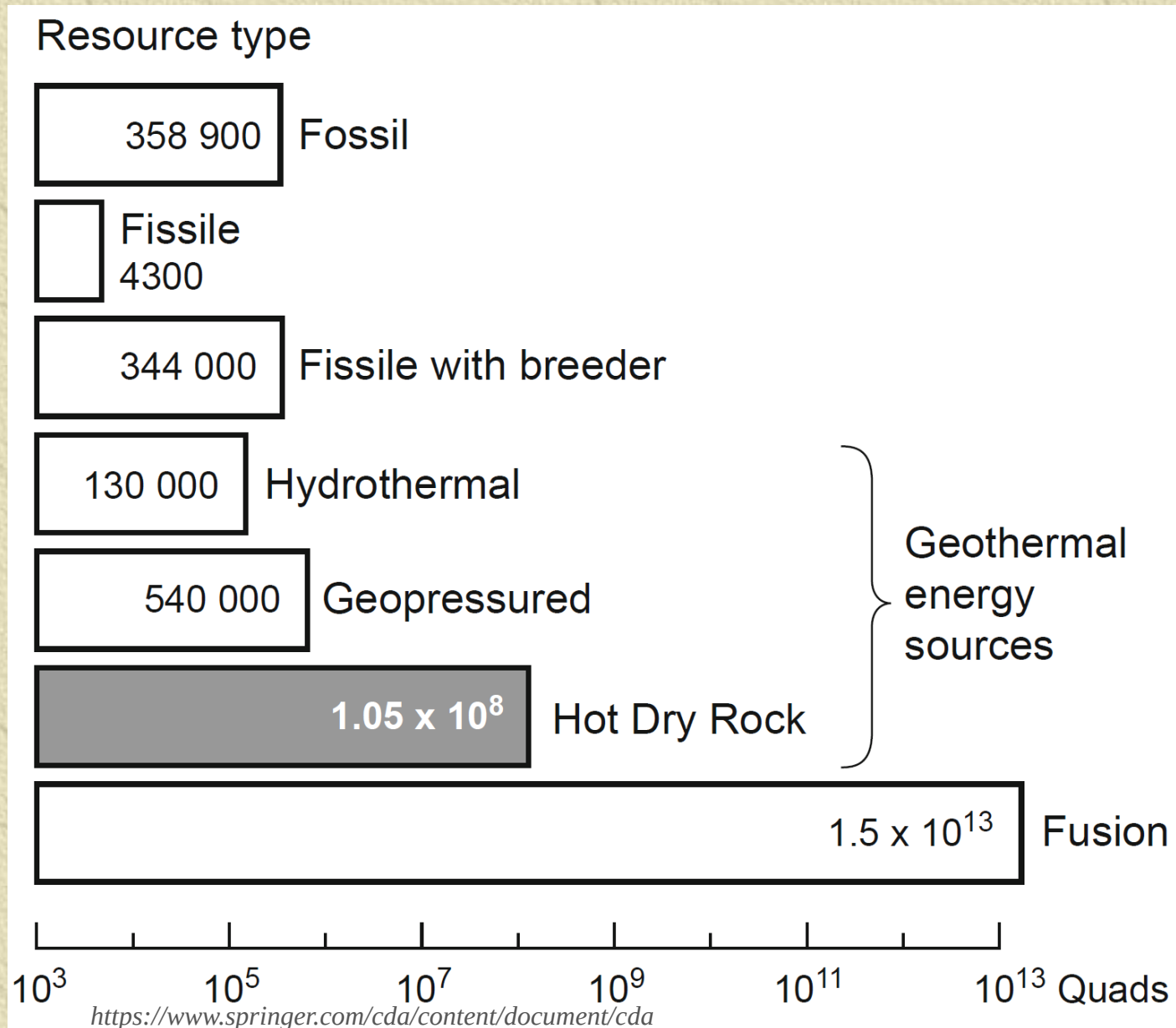
Source: REN21 Global Status Report 2010 (2011)

Figure 5. Wind Power, Existing World Capacity, 1996-2010



C.O. Ladsy Rybach Source: REN 21 Global Status Report 2010

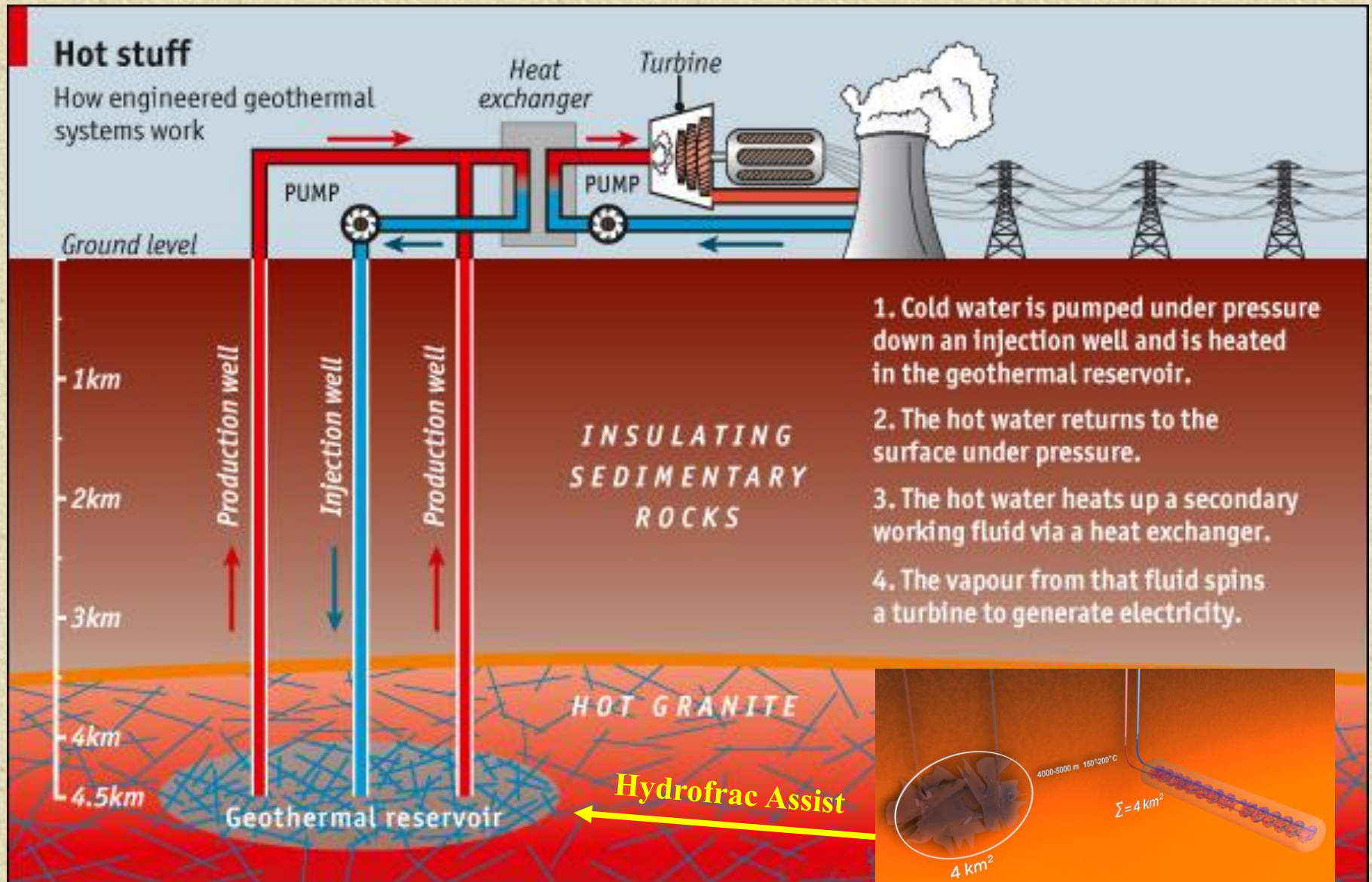
Energy in the Continental Crust



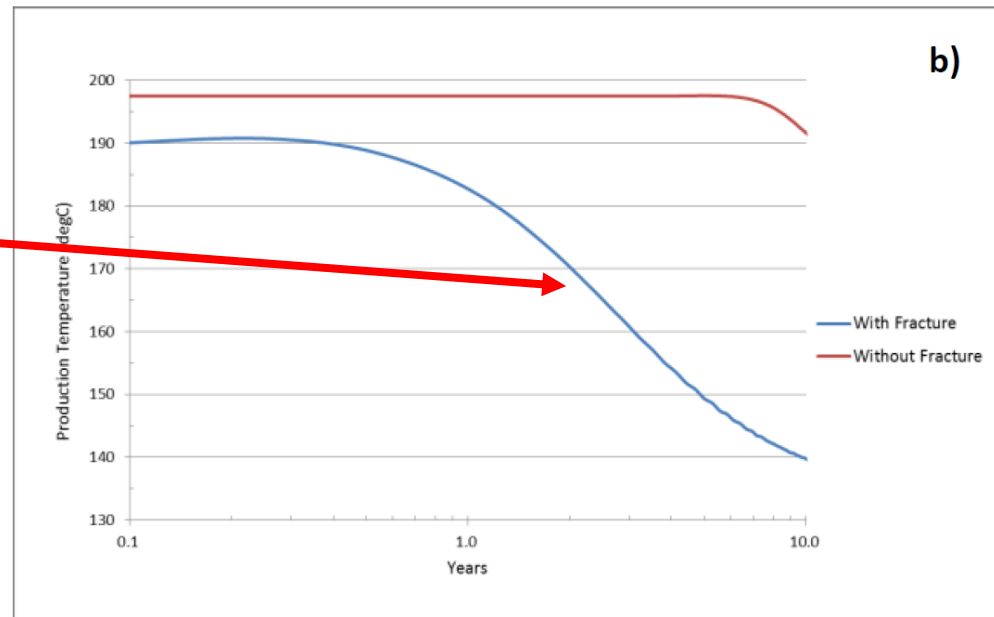
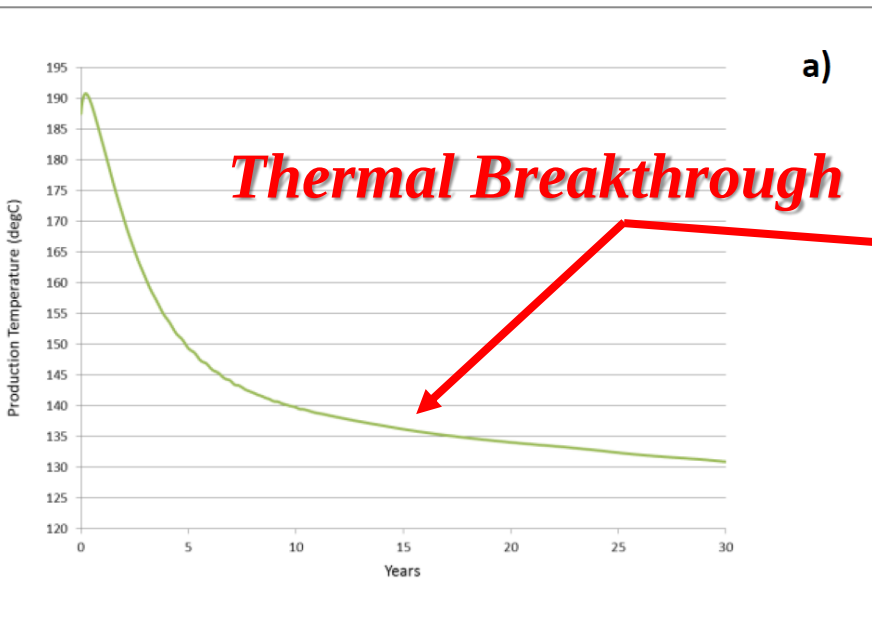
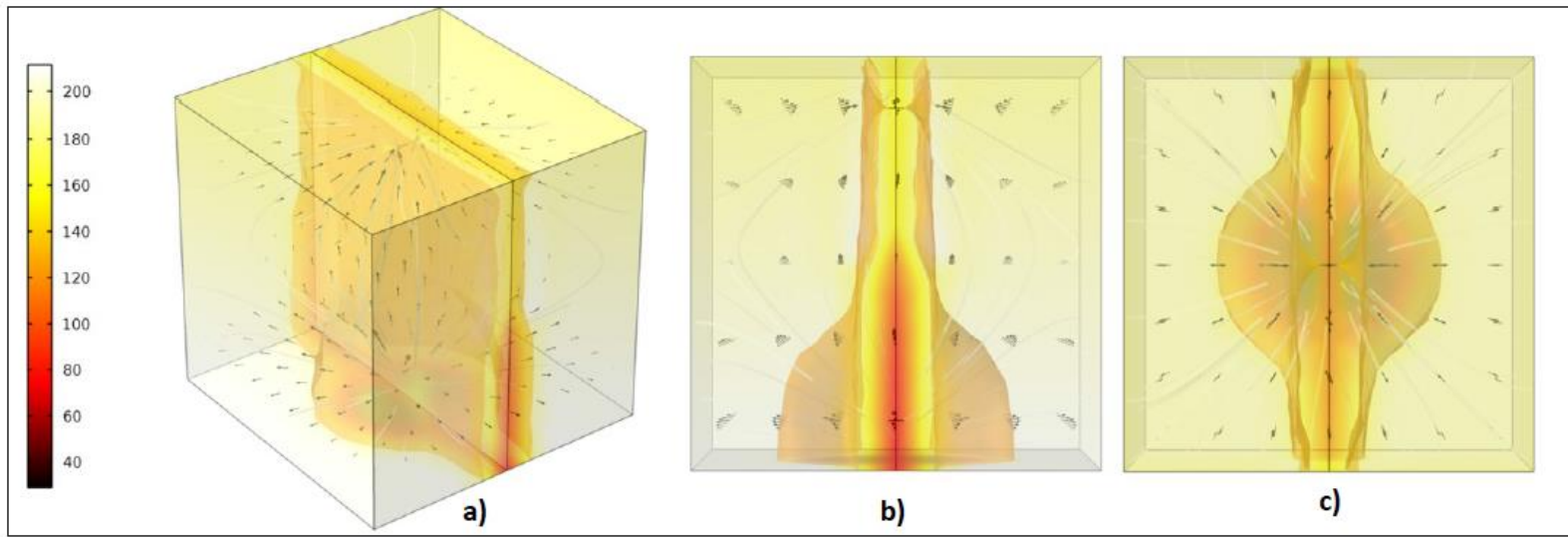
EGS/Hot Dry Rocks Approach

Hot stuff

How engineered geothermal systems work

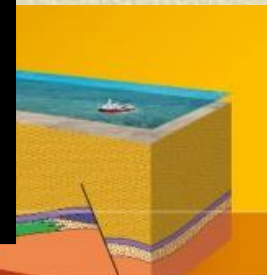
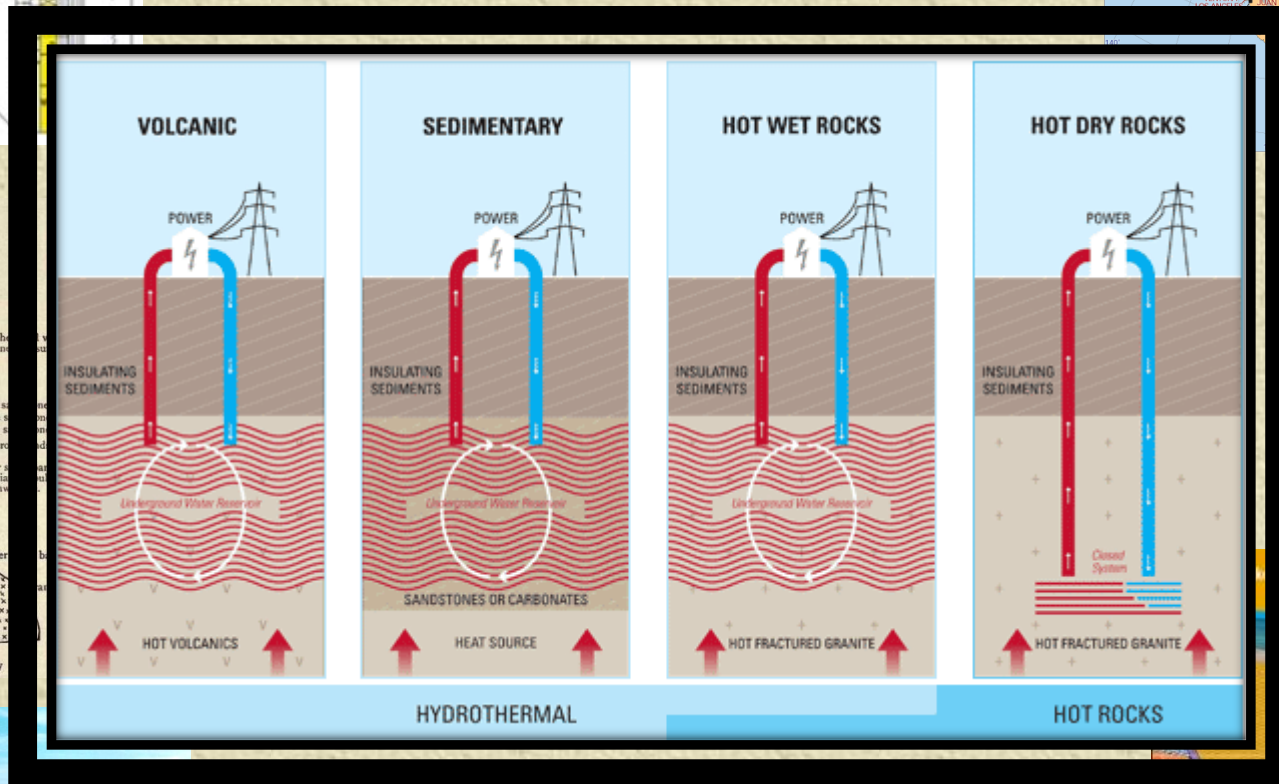
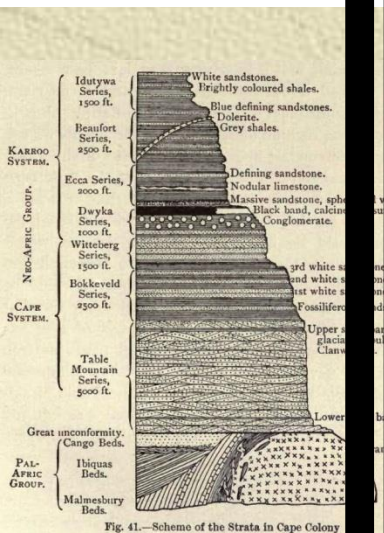


Why Not EGS/Hot Dry Rocks Approach?



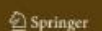
(Bakhsh, 2016)

Sedheat, What's New?



Petroleum Geoscience

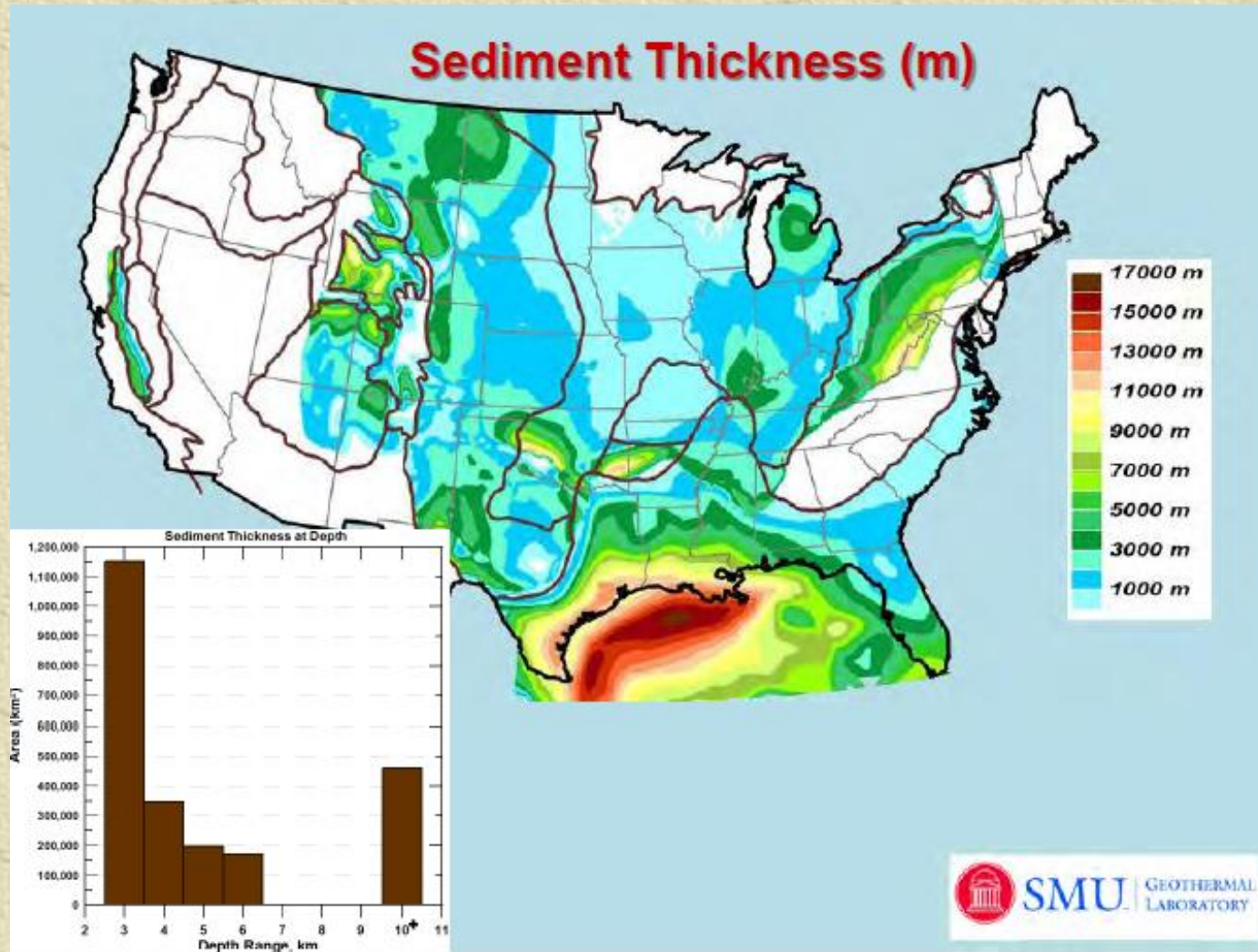
From Sedimentary Environments
to Rock Physics



<http://www.bing.com/images/search?q=sedimentary+basins&qpv=tsedimentary+basins&FORM=IGRE#x0y3653>

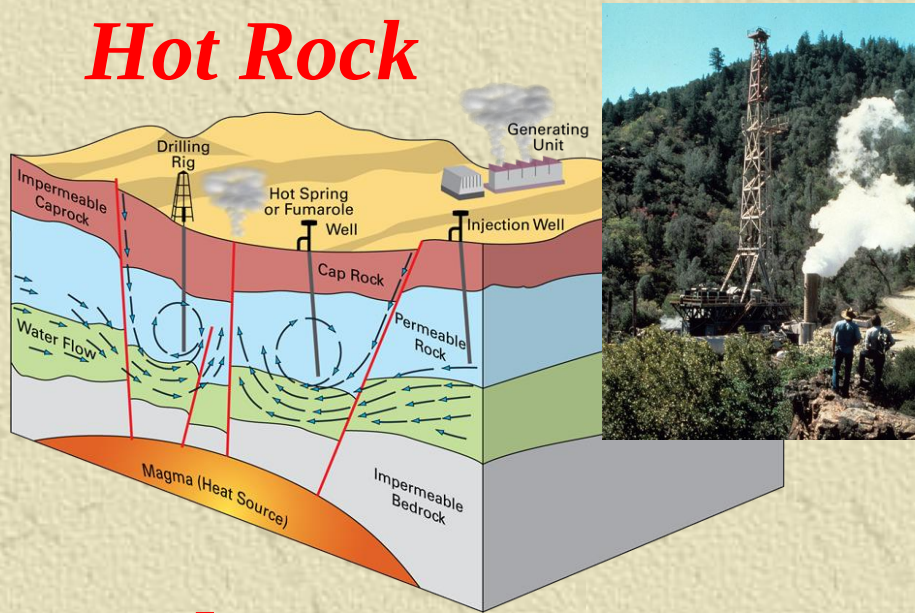
Category of Resource	Thermal Energy, in Exajoules (1EJ = 10^{18} J)	Reference
Conduction-dominated EGS		
Sedimentary rock formations	100,000	MIT, 2006
Crystalline basement rock formations	13,300,000	MIT, 2006
Supercritical Volcanic Systems	74100 excludes Yellowstone NP, Hawaii	USGS Circular 790
Hydrothermal	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

(C.O. Joe
Moore)

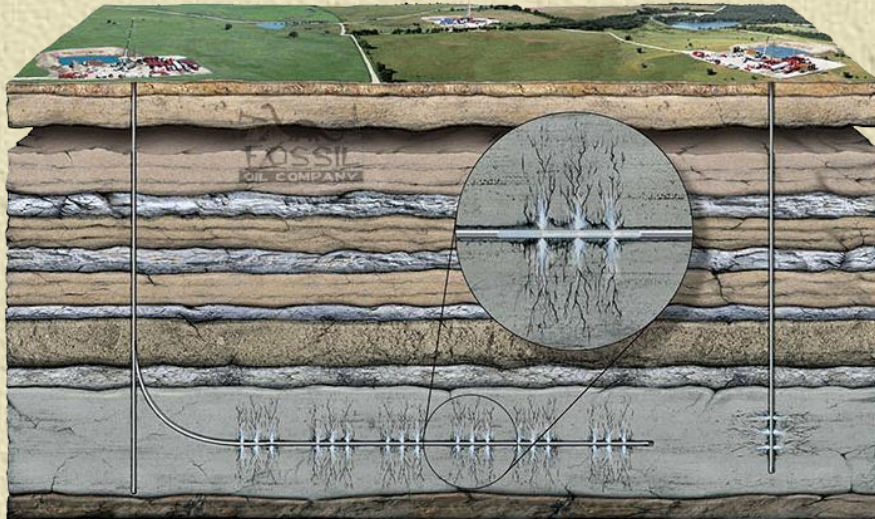


The Big Difference

Hot Rock



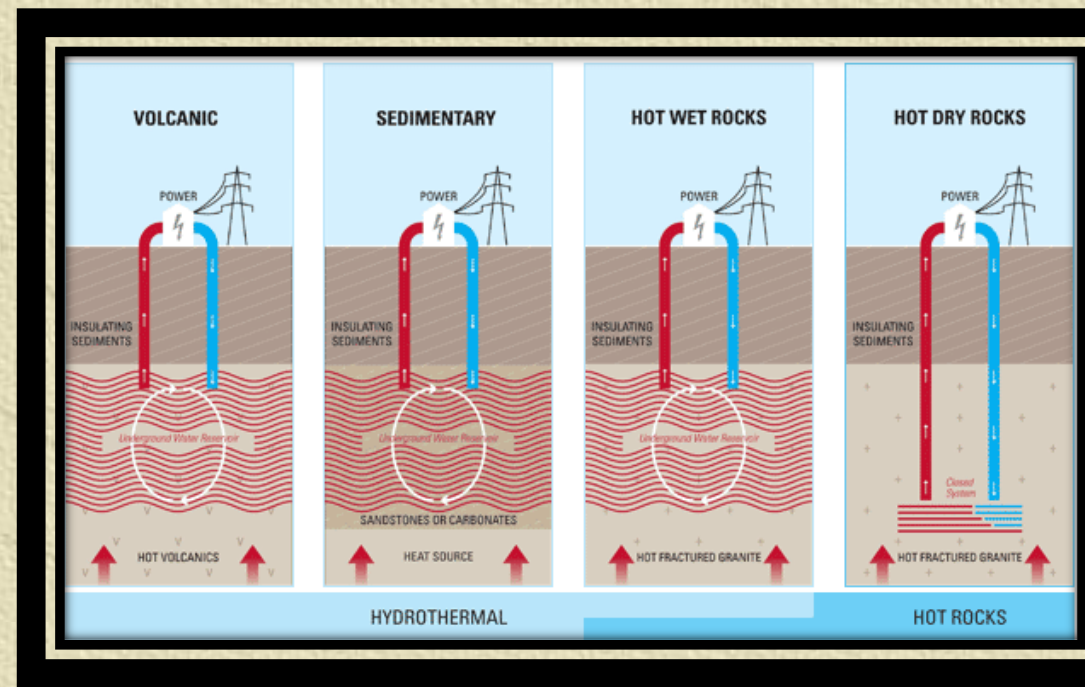
SedHeat



Flow Rates

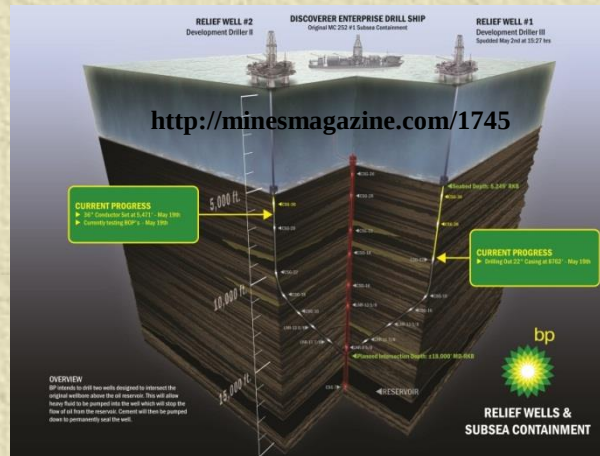
Economic Sedheat 150C - 0.5 barrels/sec

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

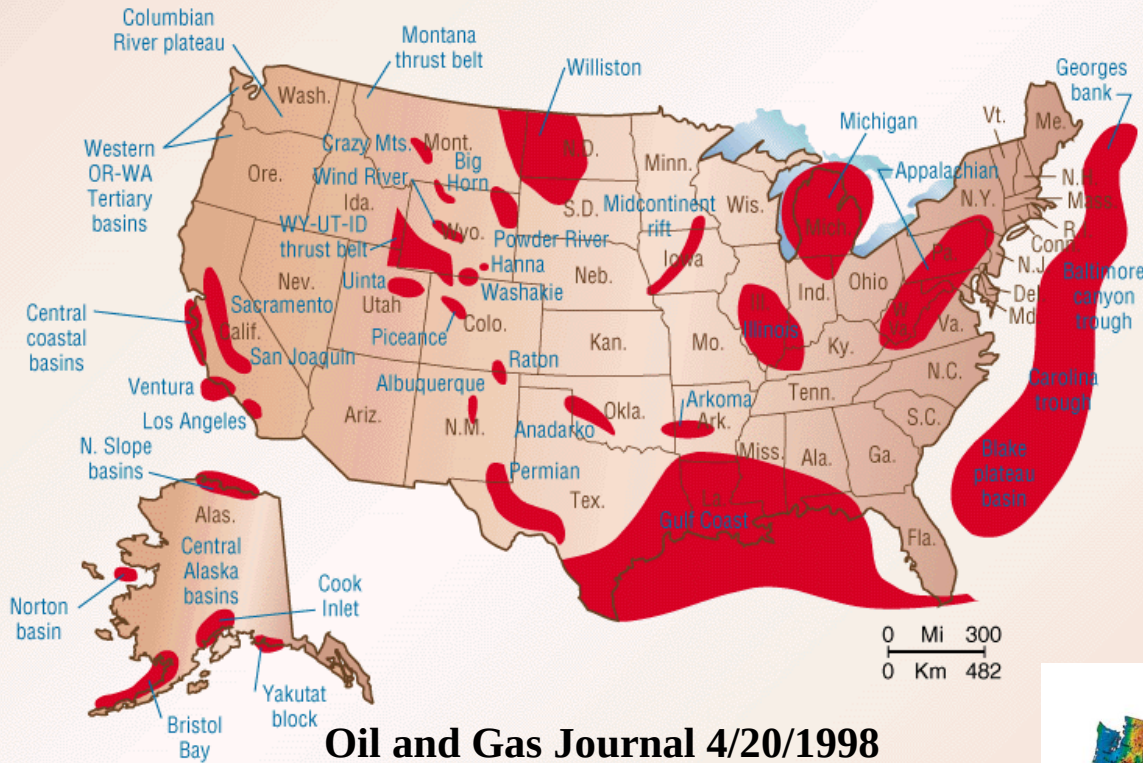


Gulf/Macondo Spill 0.6-0.7 barrels/sec

(62k-53k bpd; Flow Rate Technical Group 2010)

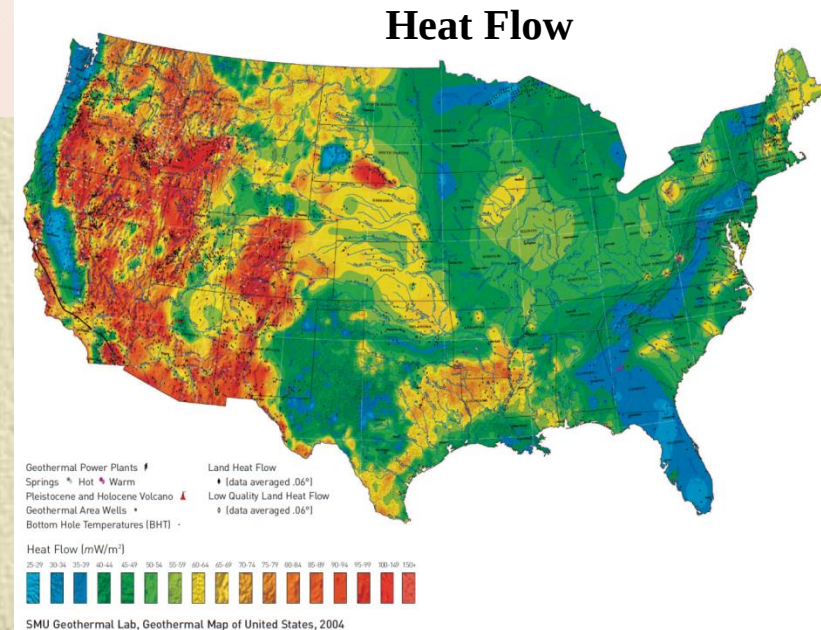


BASINS WITH SEDIMENTARY ROCKS DEEPER THAN 15,000 FT (4,600 M)



Where's the Heat?

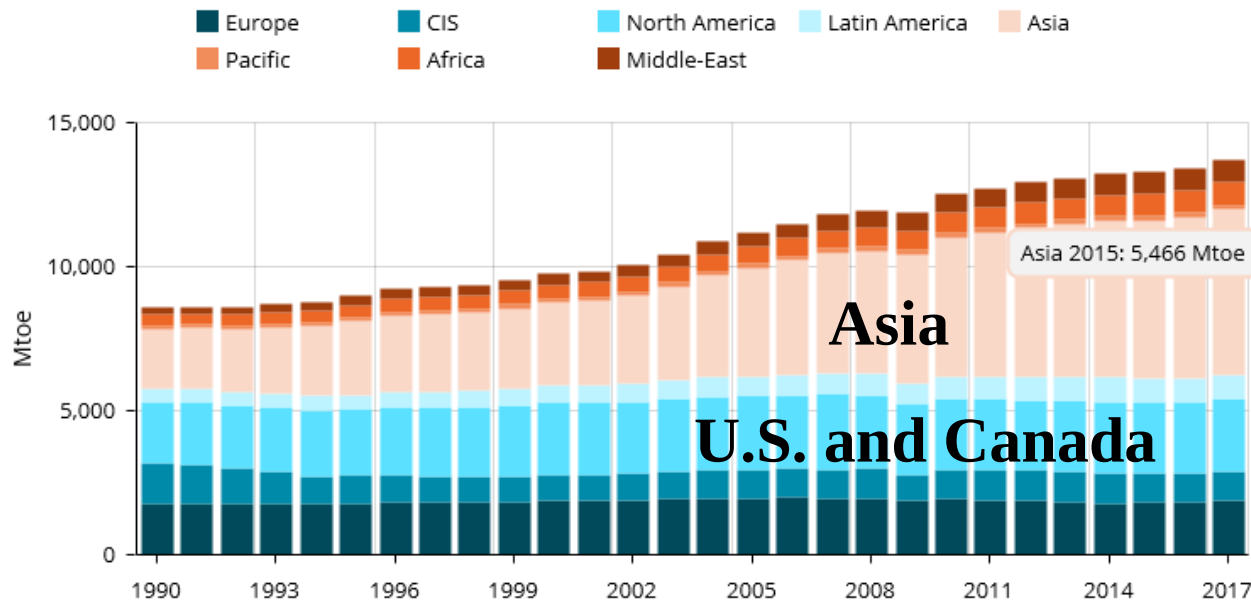
Basins and Heat Resources



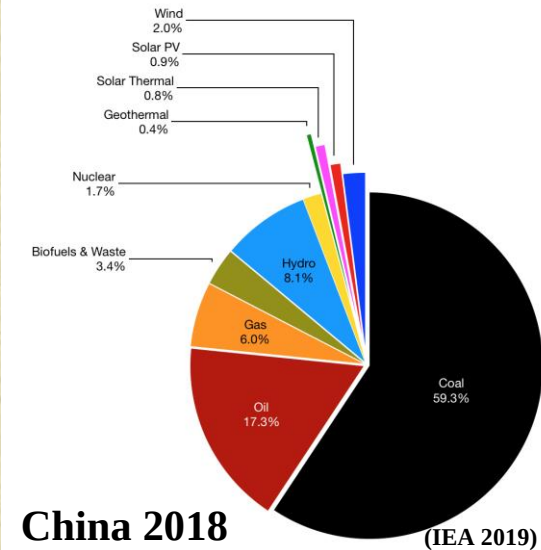
Why Does it Matter?

World Energy by Use and Change

Change in primary energy demand, 2016-40 (Mtoe)
World Energy Outlook 2017



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

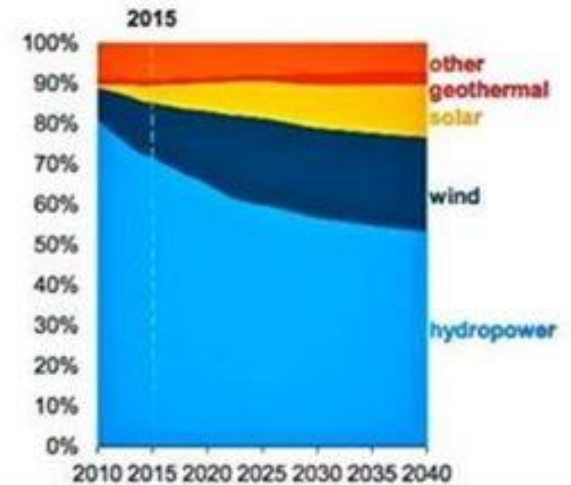
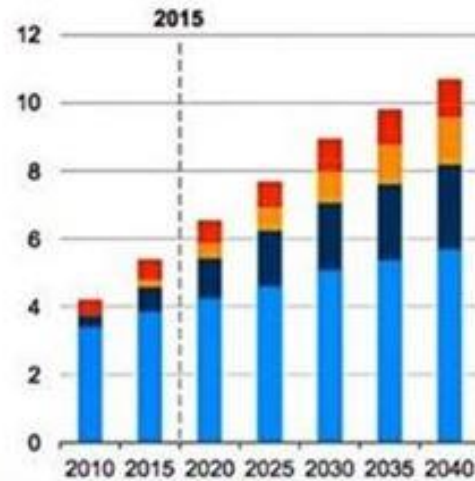


World Renewable Use and Projections

Wind and solar dominate growth in renewables—

World net electricity generation from renewable power
trillion kilowatthours

percent share of renewable energy

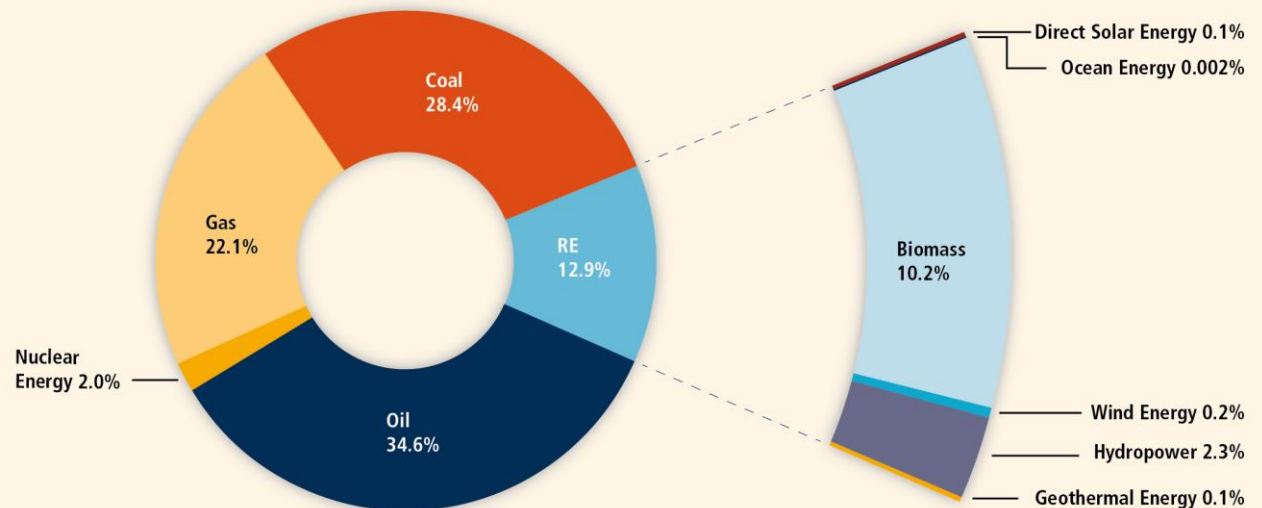


U.S. Energy Information Administration

#IEO2017

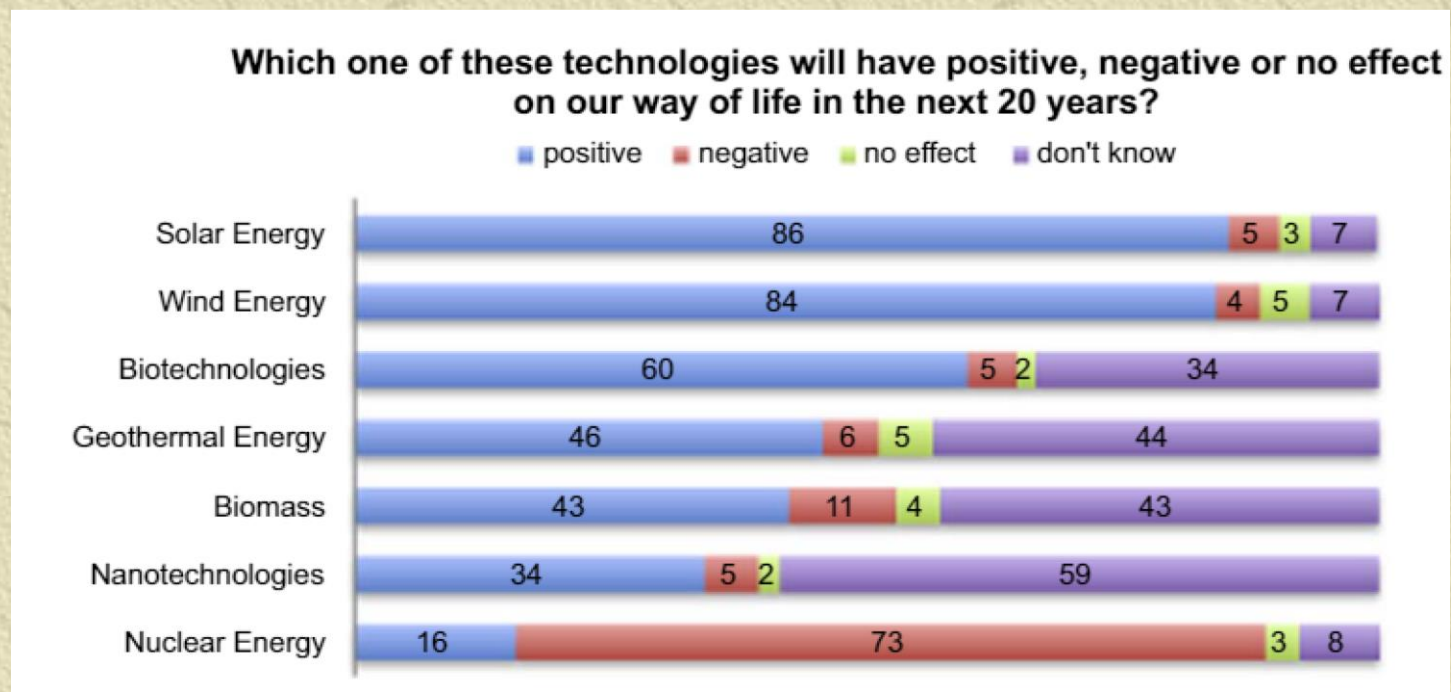
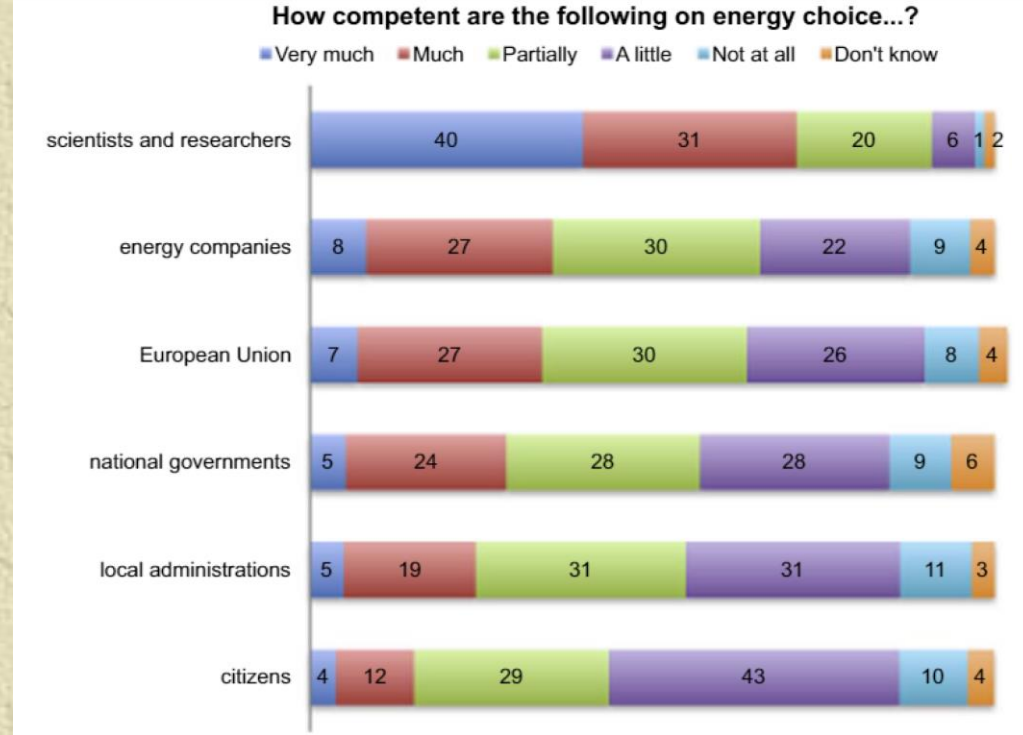
www.eia.gov/ieo

81



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

An Italian Point of View



So What Have We Learned?



Opportunities for O & G Industry

✧ **The Grid**

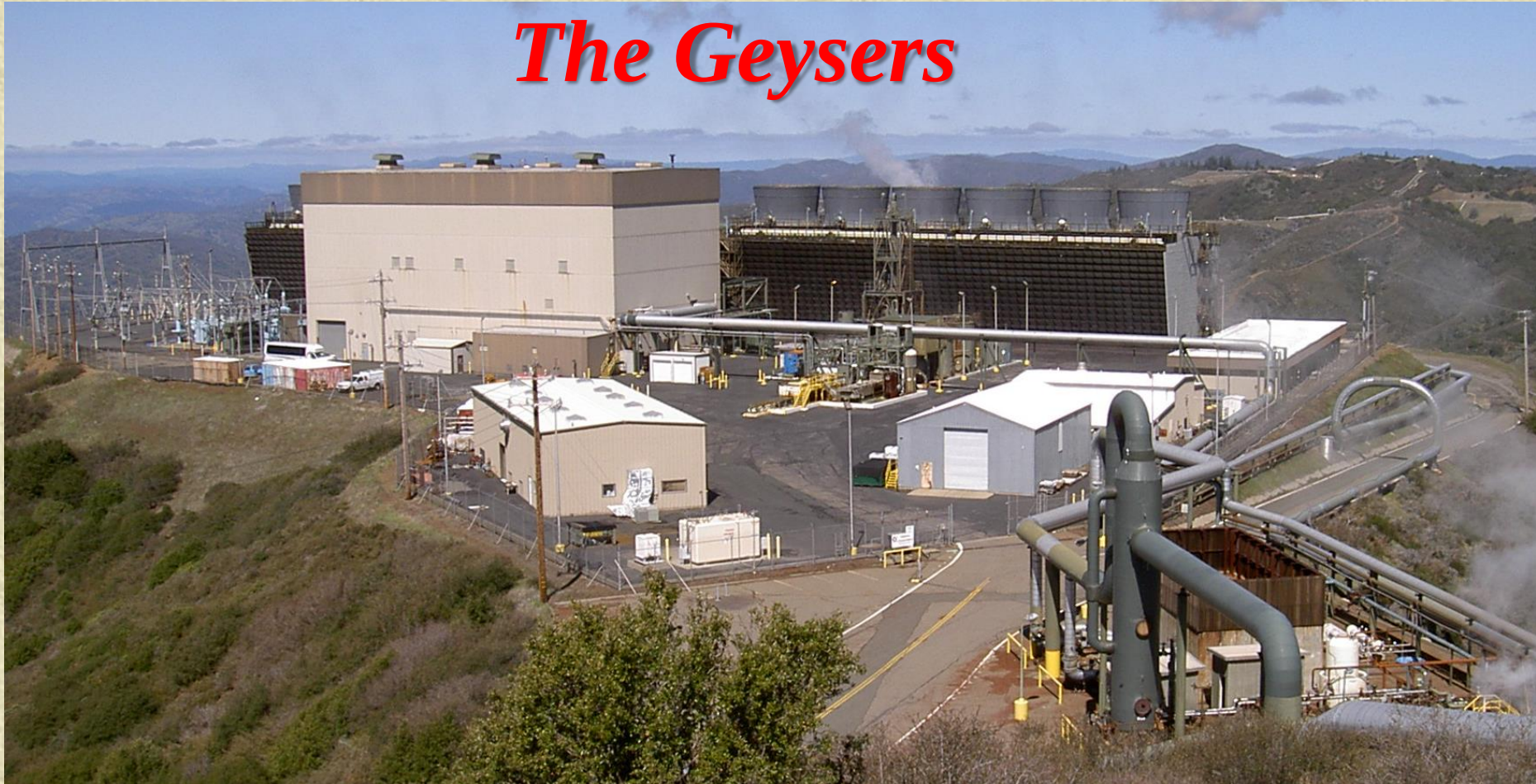
✧ Direct Heat

✧ Energy storage/Earth battery

Opportunities on the Grid

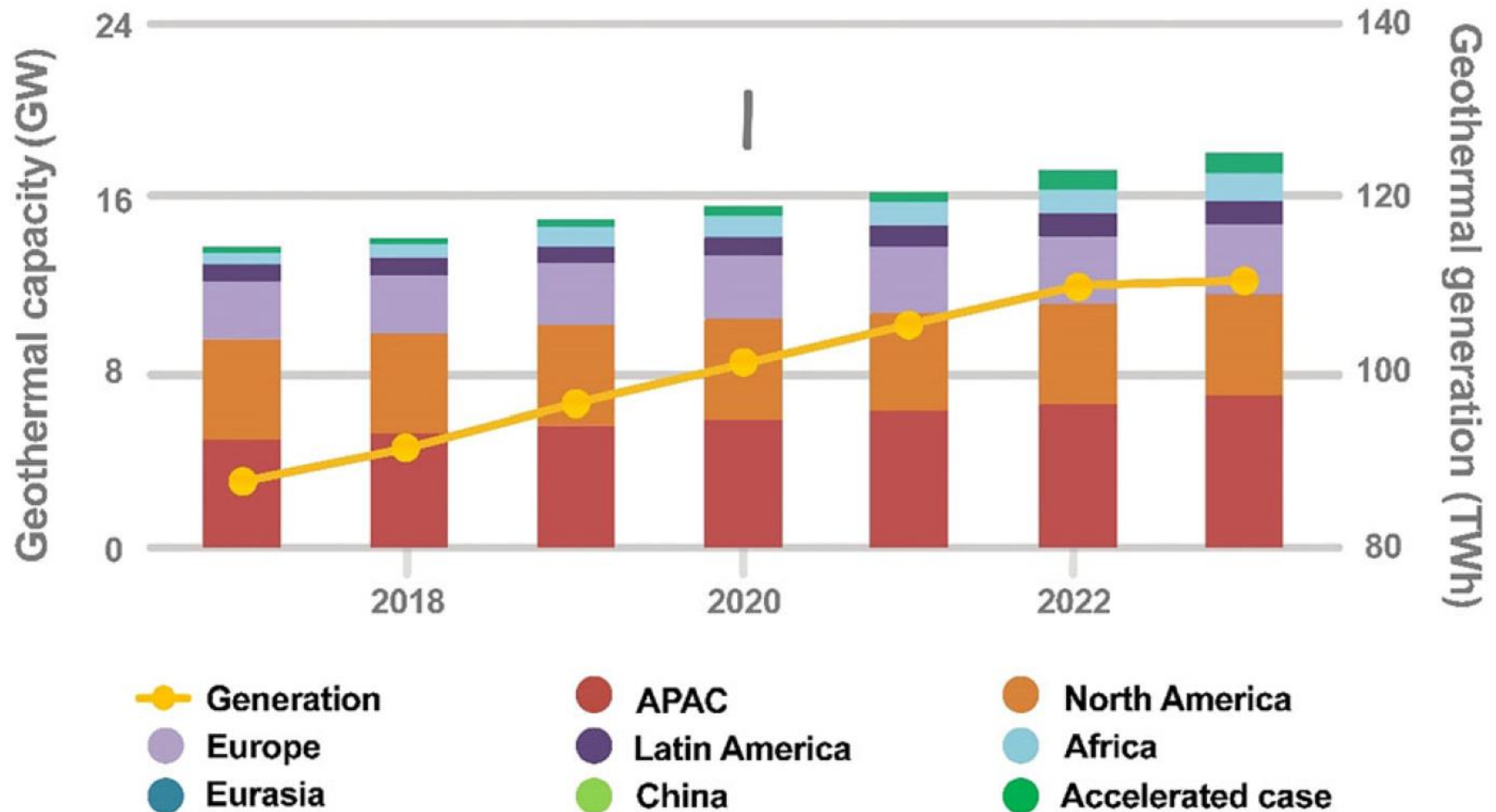
MegaWatt Power Generation

The Geysers



https://en.wikipedia.org/wiki/The_Geysers#/media/File:Sonoma_Plant_at_The_Geysers_4778.png

Who's turning Geoheat into Electrons?

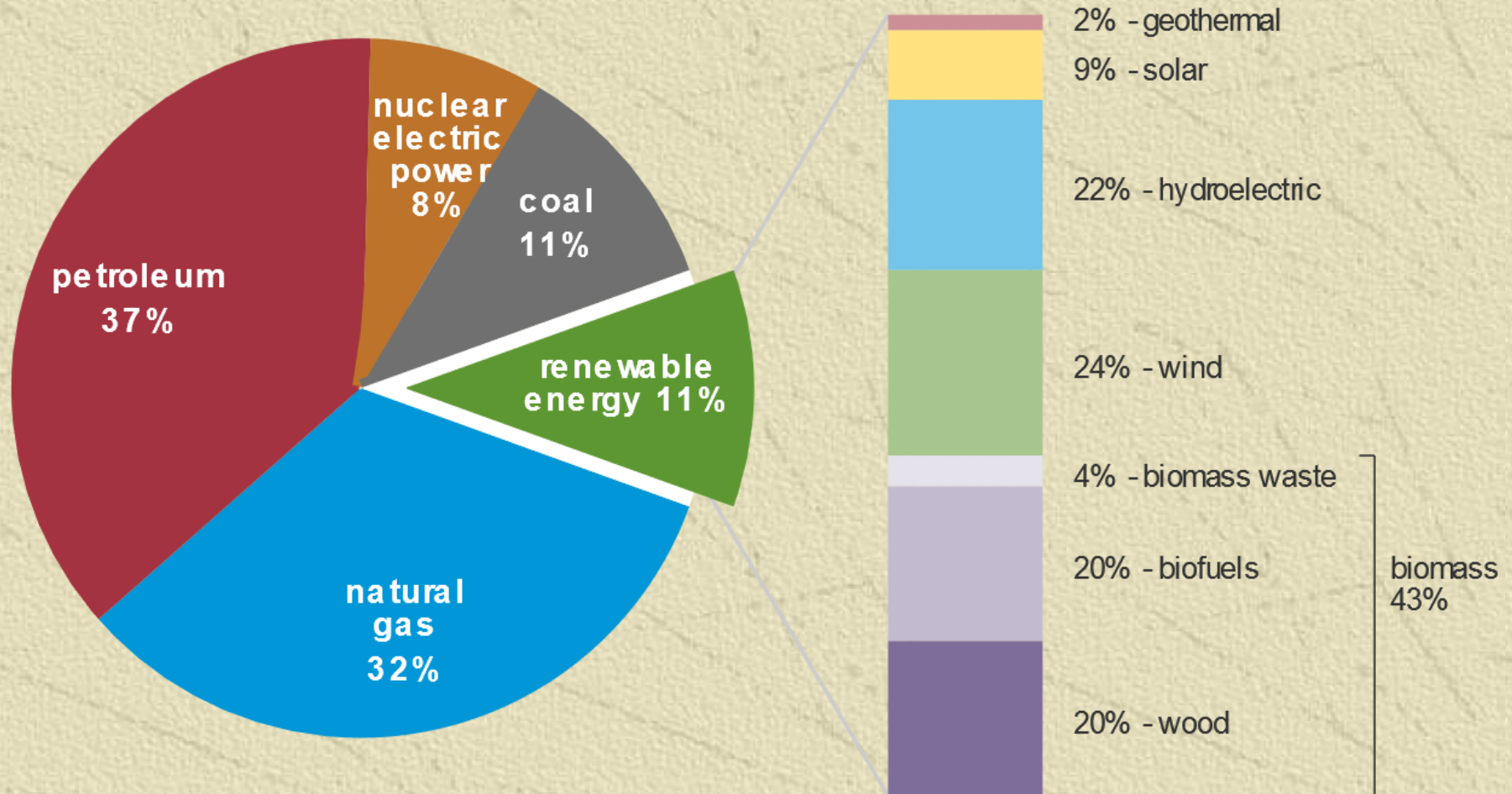


(Ghazvini, et al., 2019)

U.S. primary energy consumption by energy source, 2019

total = 100.2 quadrillion
British thermal units (Btu)

total = 11.4 quadrillion Btu

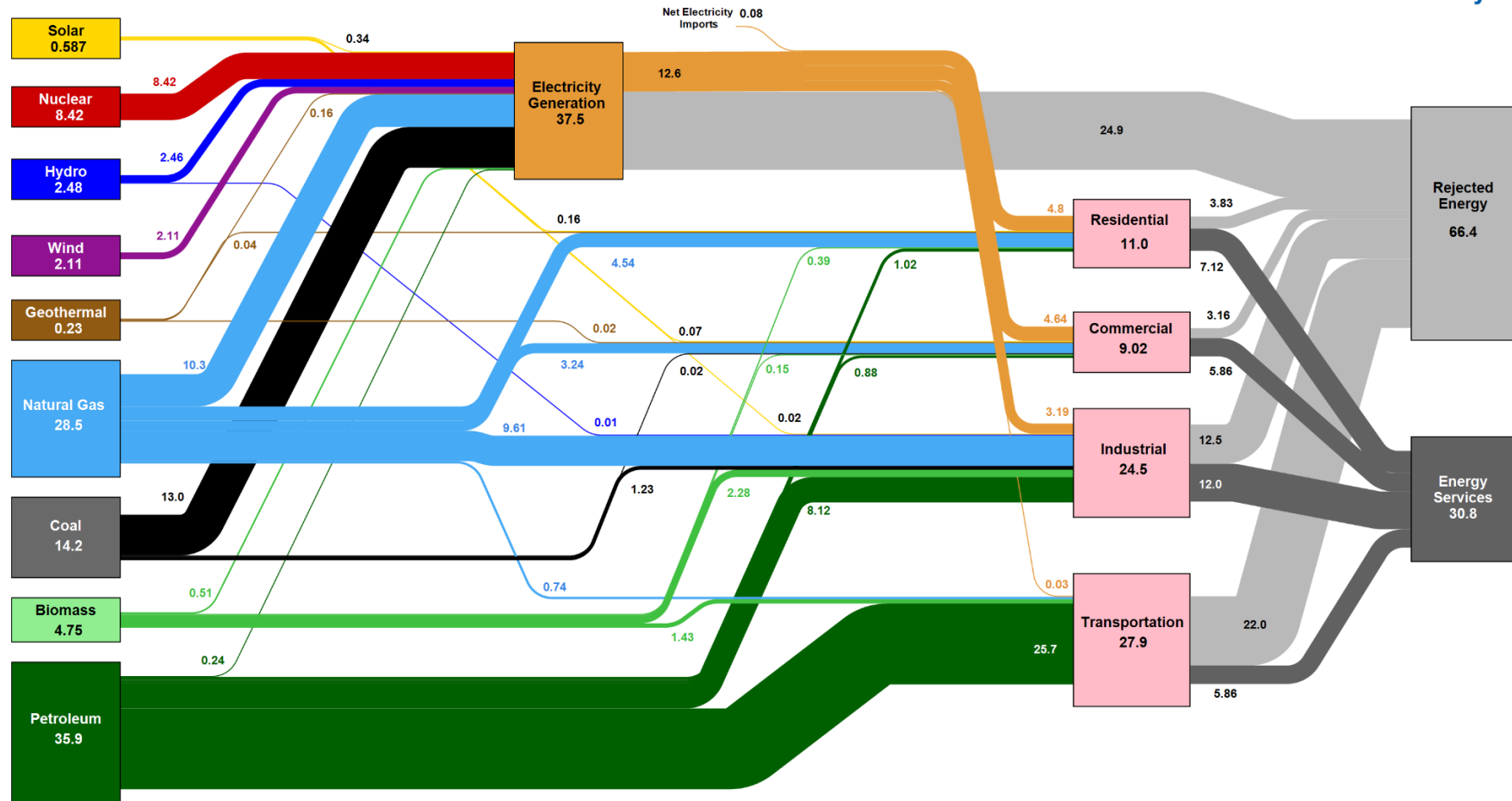


Note: Sum of components may not equal 100% because of independent rounding.

Source: U.S. Energy Information Administration, *Monthly Energy Review*, Table 1.3 and 10.1, April 2020, preliminary data

Where Does it go?

Estimated U.S. Energy Consumption in 2016: 97.3 Quads



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

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} @ 100 kg/s	\$24k @ 10c/kWh
Ground Water	2000 gpm (150 kg/s)	no pump needed	\$3k @ \$1/1000 gal
Oil	6,000 bbl/d (100 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 million on top of drilling costs

C.O Rick Allis

Hurdles!



© Roddy Smith

Challenges!



Heat and Water!

Risk-reward equation is challenging when thinking of geothermal developments (e.g., 5 km for high temperature stratigraphic targets); geothermal developments need both injection and production wells. Note Mansure (2011 GRC) recommends using multiplier of 2 to adjust from 2003 to 2010.

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

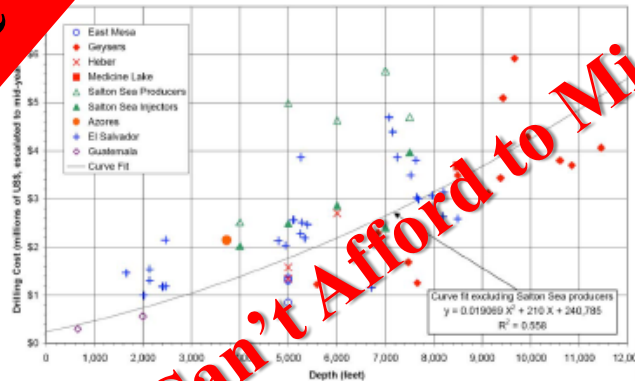


Figure 8. Correlation of drilling cost versus well depth (as of 2003) (from GeothermEx, 2004).

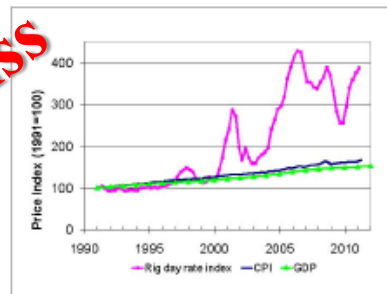


Figure 4. Index of recent rig day rate vs. CDP and CPI. (Note: rig day rate data runs as much as 3 months in arrears.)

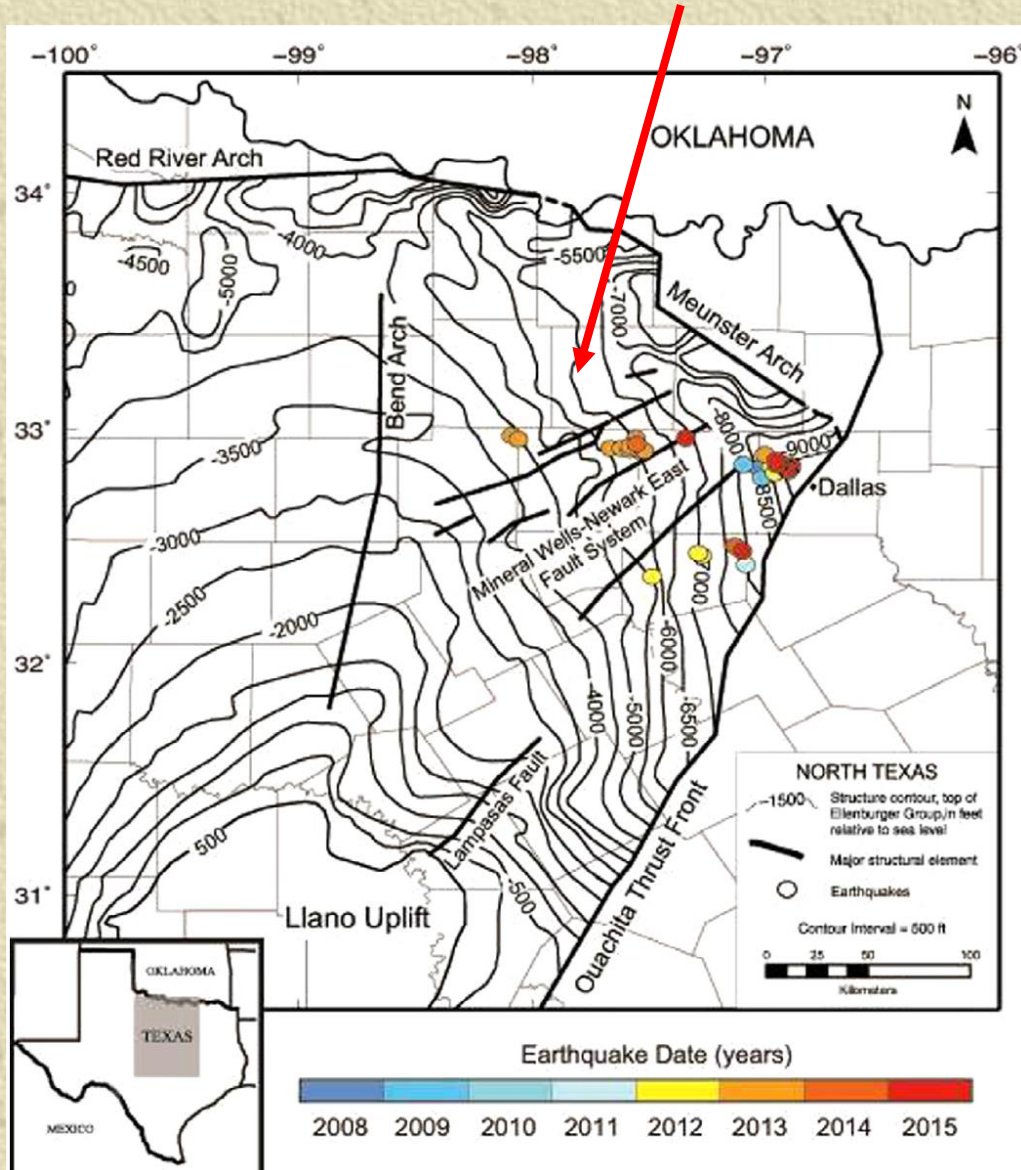
Mansure & Blankenship, 2011

C.O Rick Allis

The Water Challenge

Ft Worth Basin - A Production and Injection Experiment

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



Upper Pennsylvanian 305 - 303.7 Ma	Cisco	$\phi = 17\%$	$\kappa = 1.78 \times 10^{-13} \text{ m}^2$
	Canyon	$\phi = 15\%$	$\kappa = 2.47 \times 10^{-13} \text{ m}^2$
Middle Pennsylvanian 310 - 305 Ma	Strawn ~300 m	$\phi = 15\%$	$\kappa = 2.49 \times 10^{-13} \text{ m}^2$
	Wichita (Caddo)	$\phi = ?$	$\kappa = ?$
	Bend (Atoka)	$\phi = 15\%$	$\kappa = 2.99 \times 10^{-13} \text{ m}^2$
Lower Pennsylvanian 323.2 - 310 Ma	Marble Falls (Morrow) max 182 m	$\phi = ?$	$\kappa = ?$
Mississippian 359 - 332 Ma	Barnett Shale	<i>Production Horizon</i>	
	Mississippian Lime	<15 m	$\phi = 10\%$ $\kappa = 2.96 \times 10^{-14} \text{ m}^2$
	Viola Limestone	<15 m	$\phi = ?$ $\kappa = ?$
Ordovician 485.4 - 443.8 Ma	Ellenburger 1000 m	$\phi = 4\%$	$\kappa = 9.87 \times 10^{-14} \text{ m}^2$
	<i>Wastewater Injection Horizon</i>		
Precambrian 4.6 Ga - 541 Ma	Granite Basement	$\phi < 5\%$	$\kappa < 3 \times 10^{-19} \text{ m}^2$

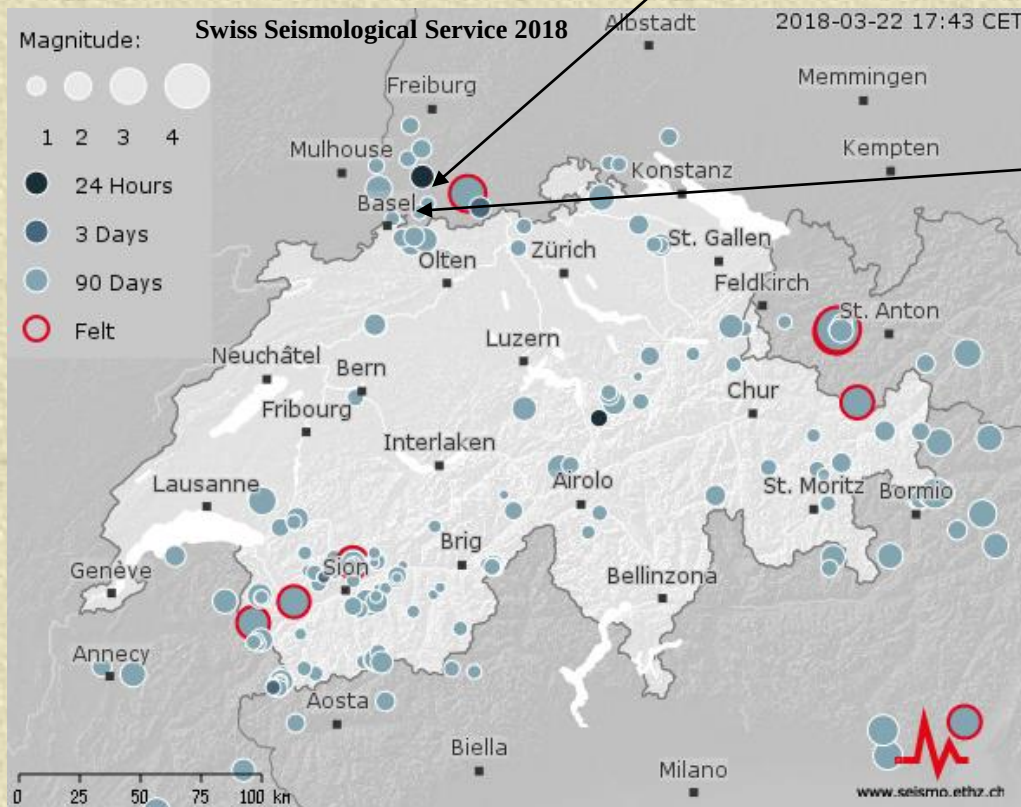
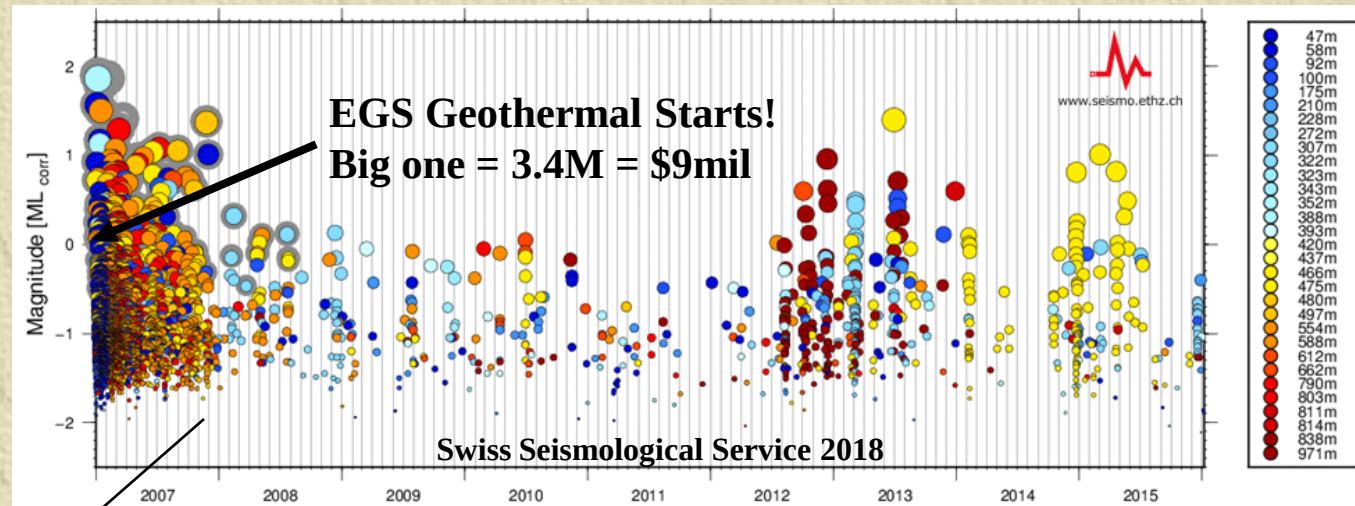
reactivated seismic zone

(Hornbach, et al., 2016)

The Bazel Catastrophe

Quake Threat Leads
Swiss to Close
Geothermal Project

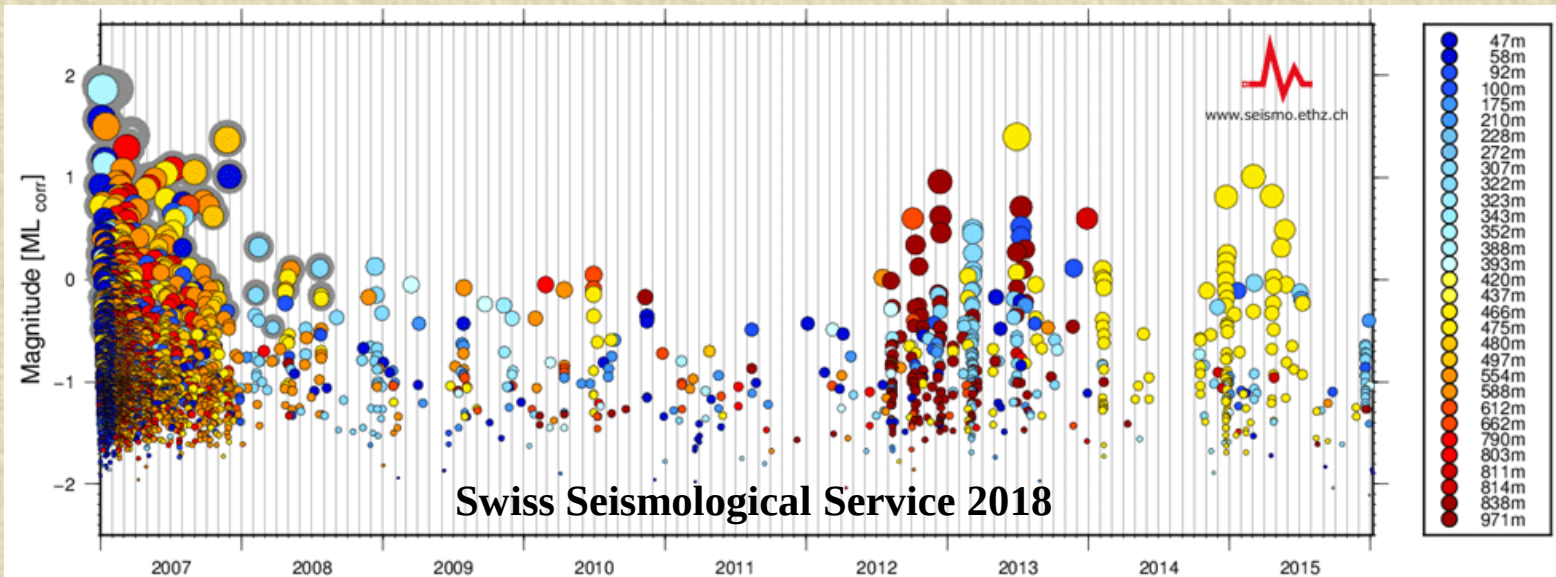
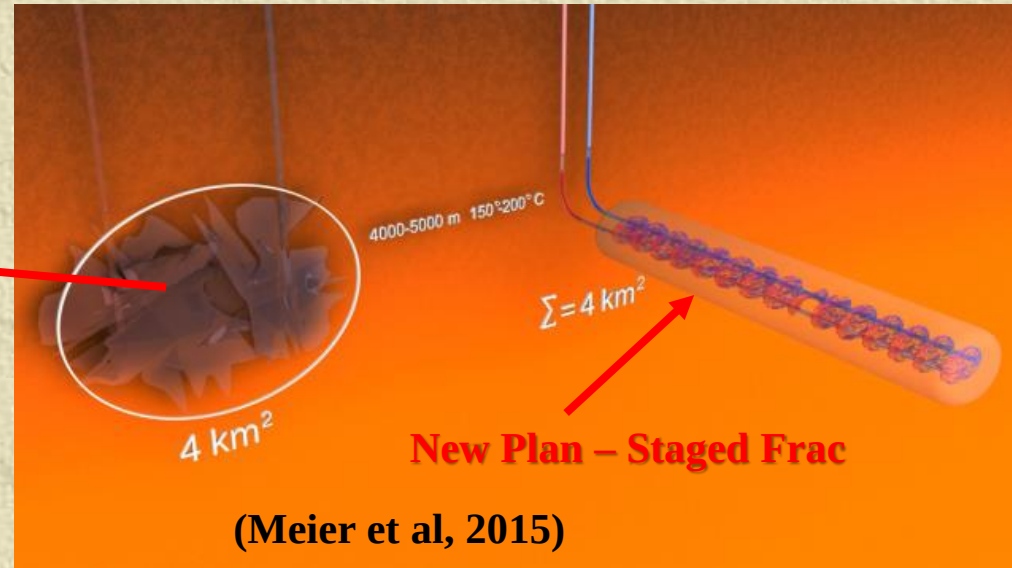
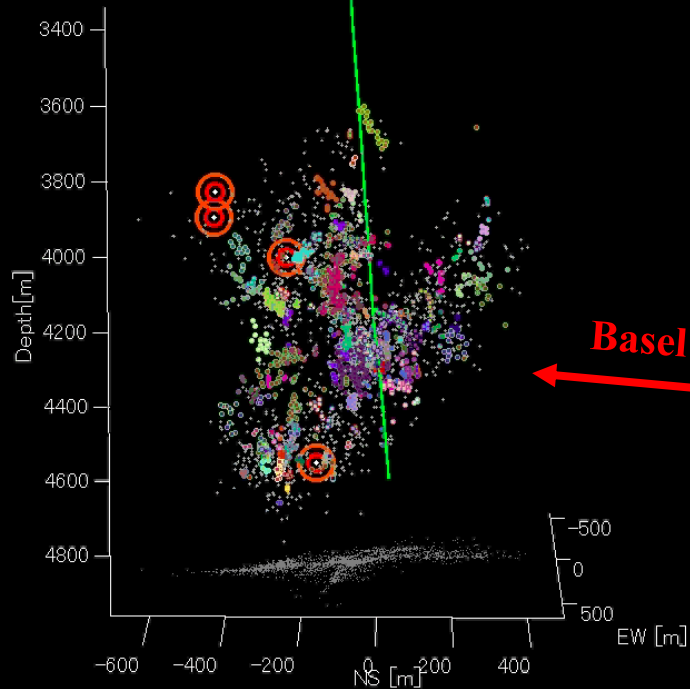
New York Times



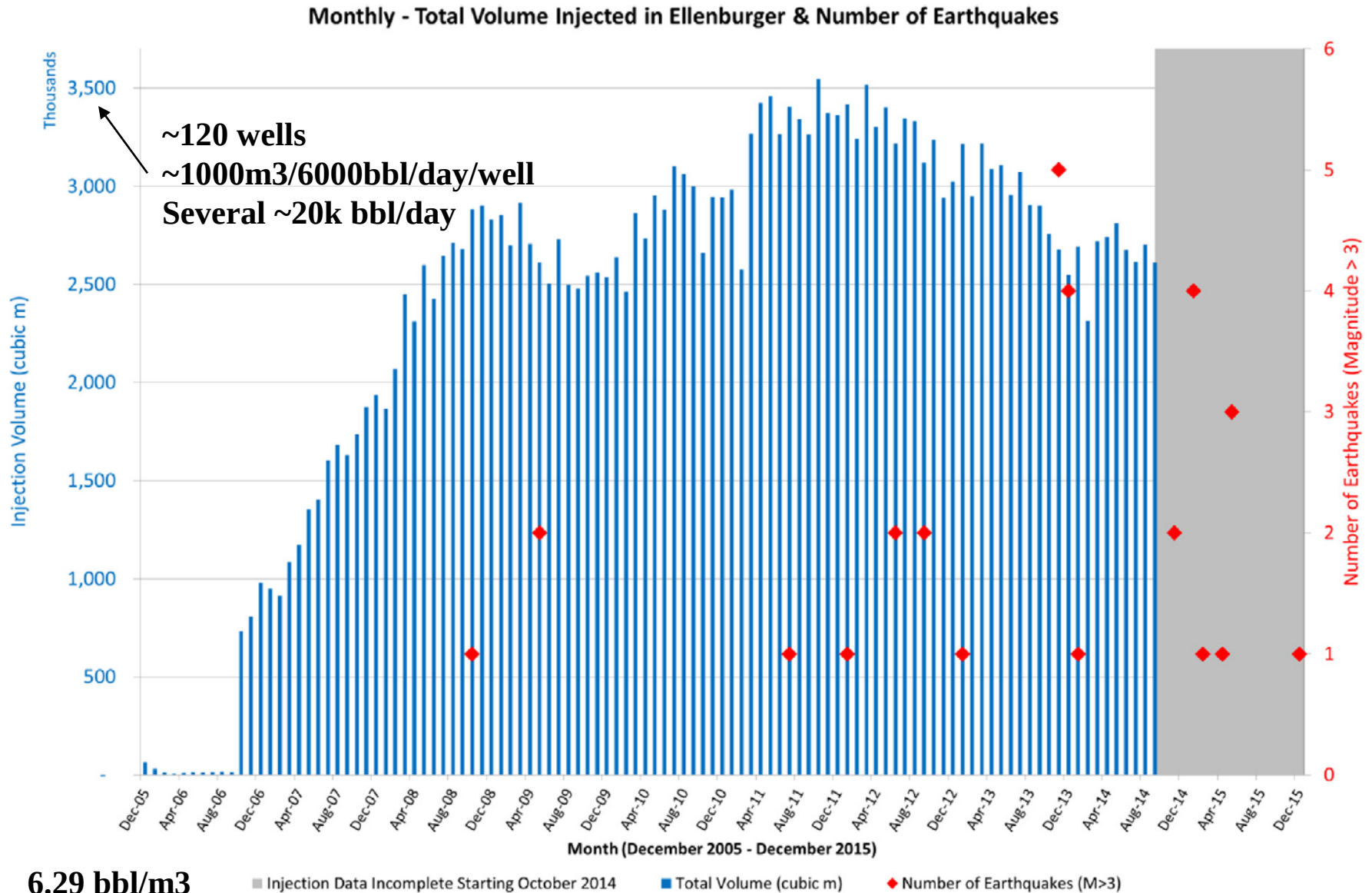
<http://bigthink.com/1000-words/on-this-day-in-1356-a-major-earthquake-destroyed-the-town-of-basel-switzerland>

The Bazel Solution

Swiss Cheese; the Swiss Answer

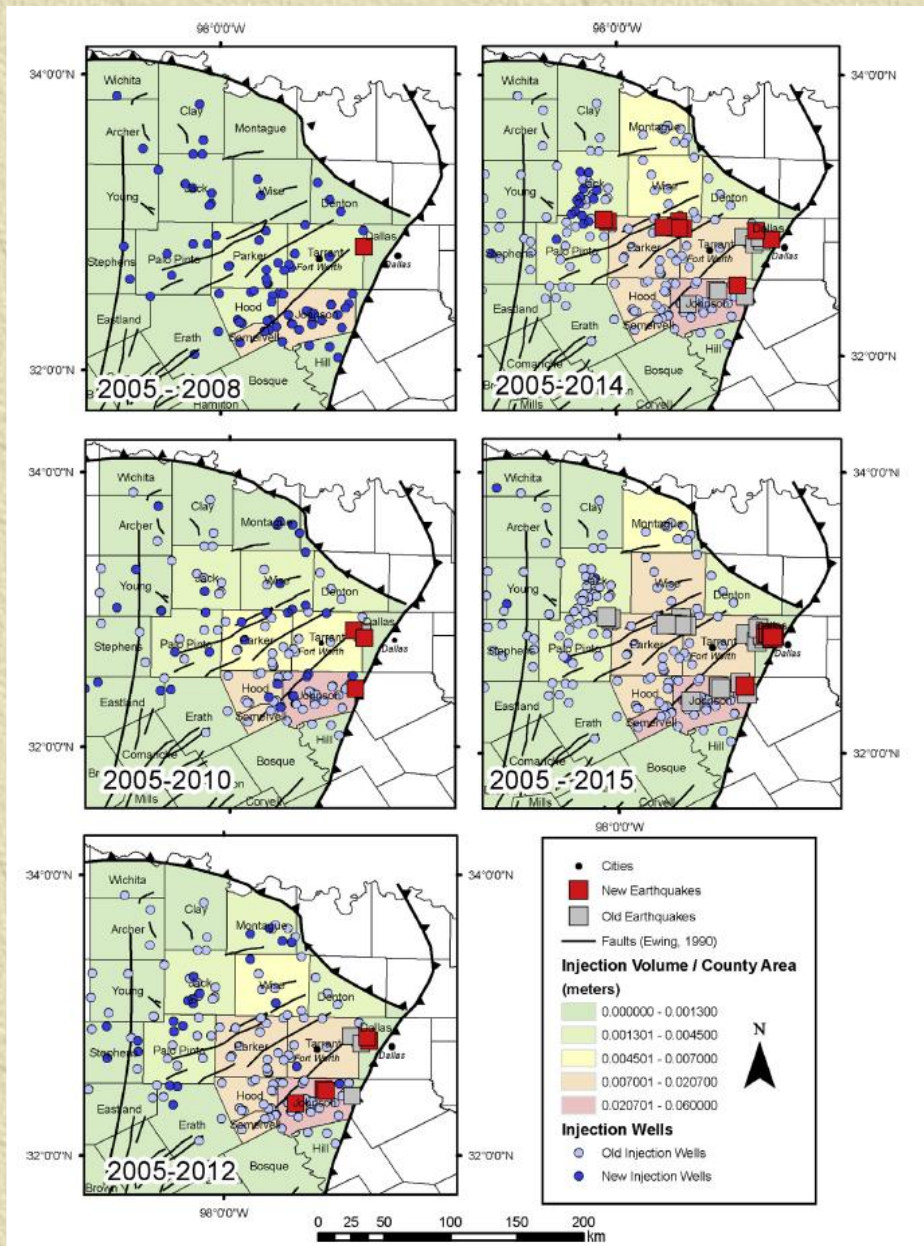
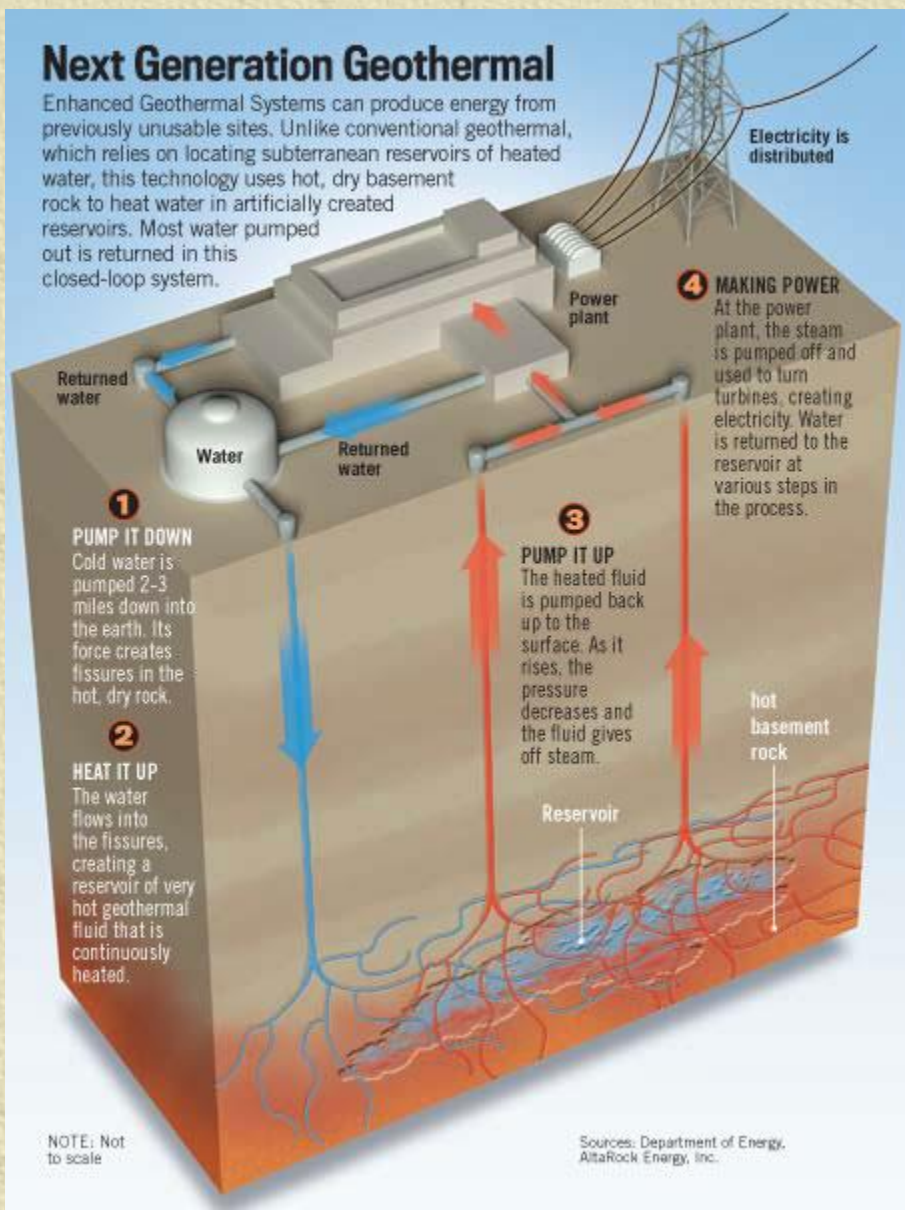


The Ft Worth Basin – Injection Rates



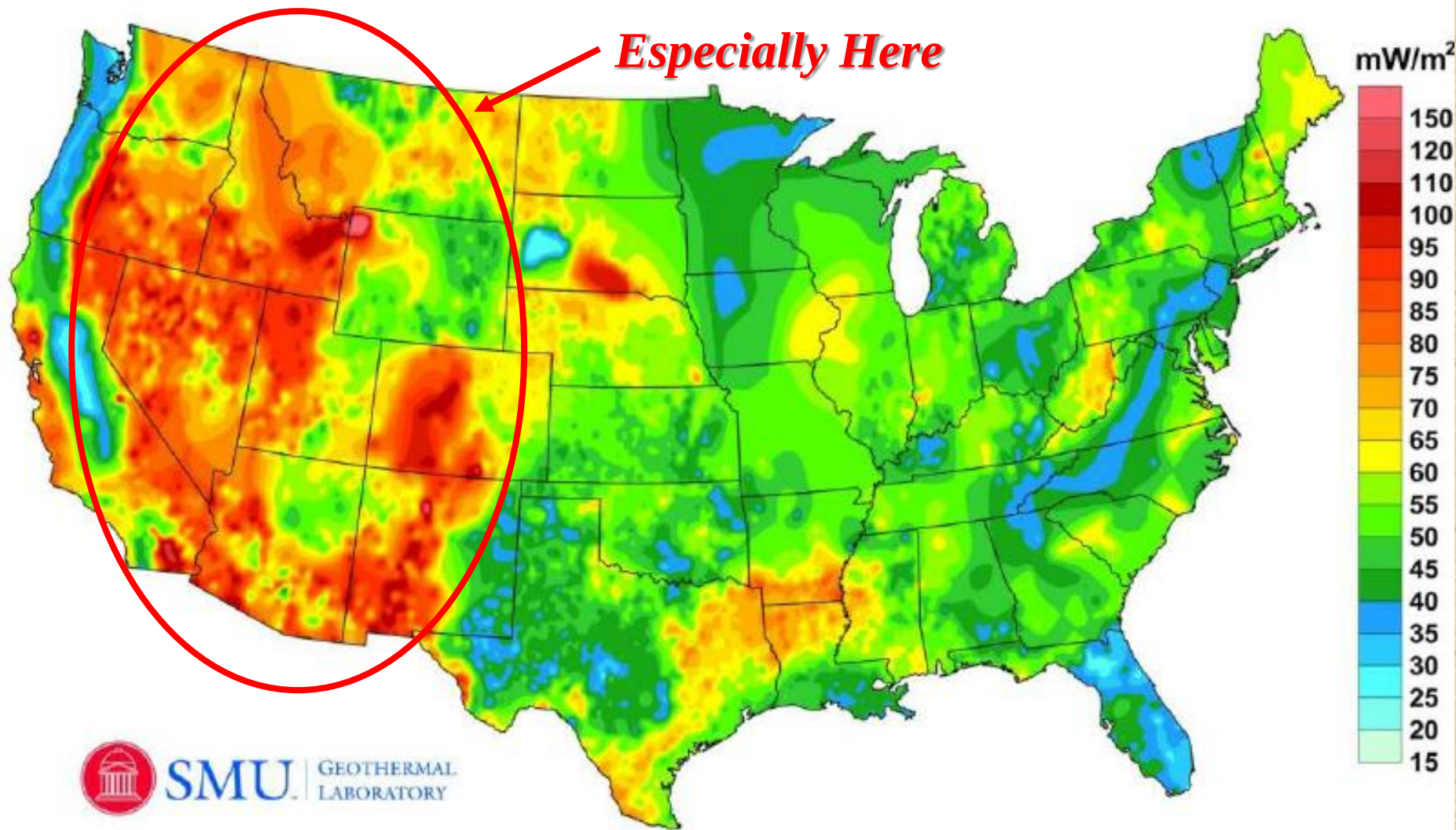
(Hornbach, et al., 2016)

The Geothermal Difference? Extraction During Injection

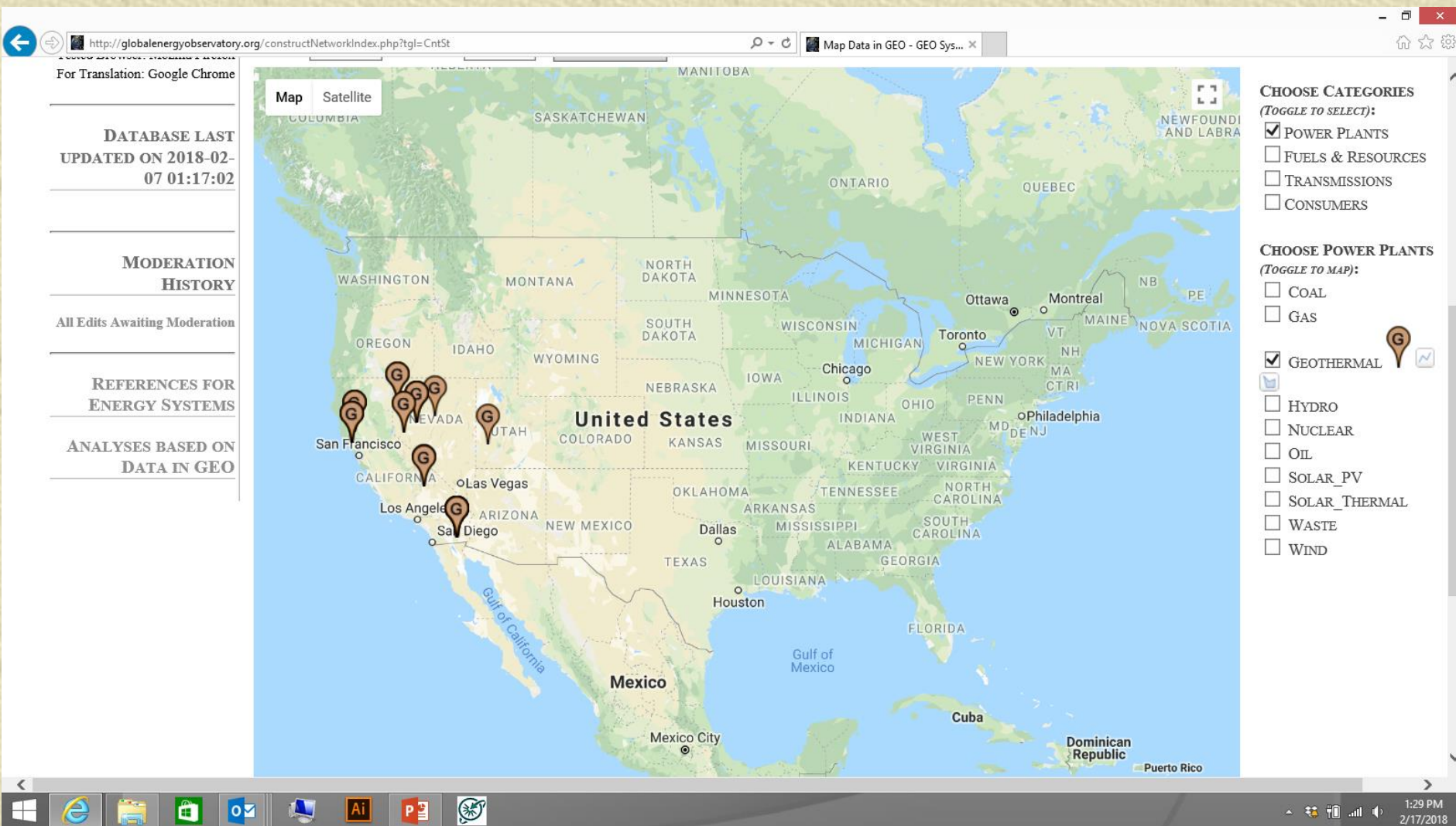


The Heat Challenge

Got Alotta Heat



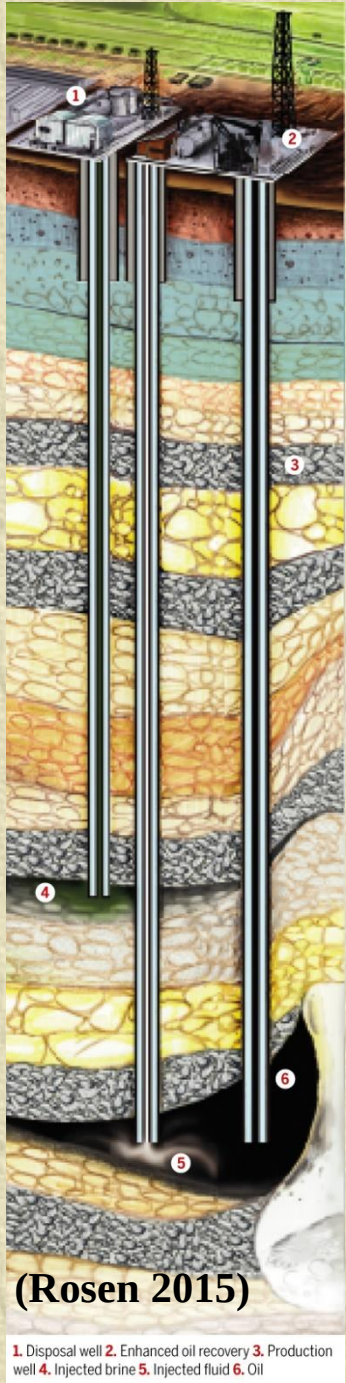
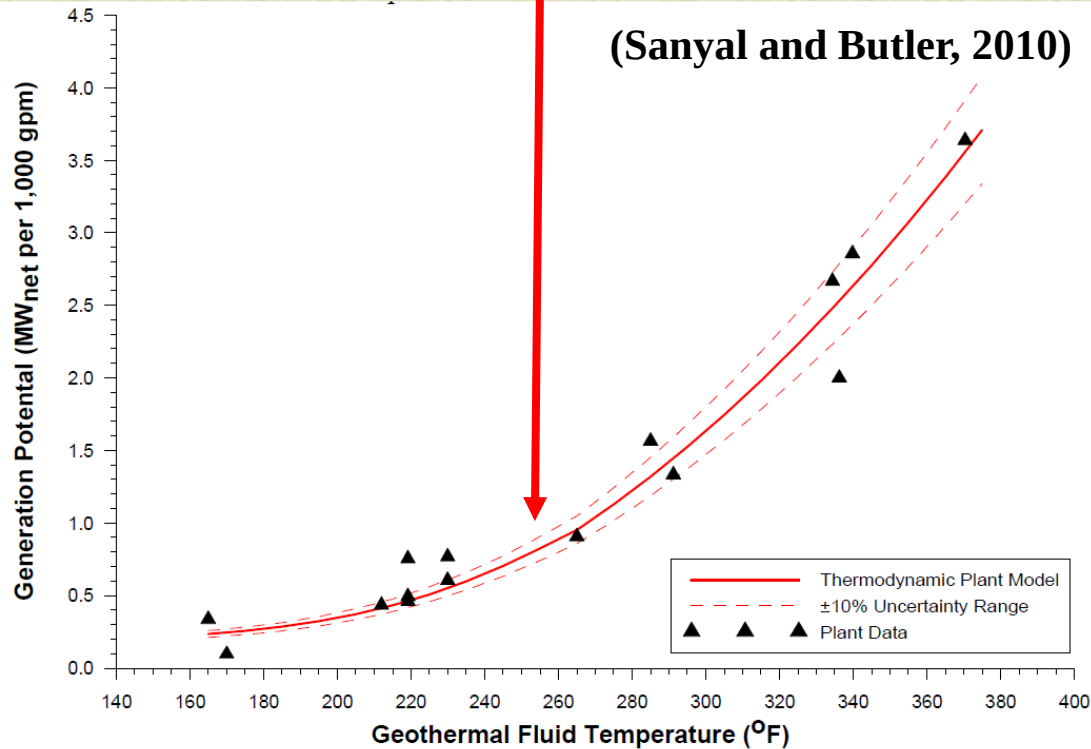
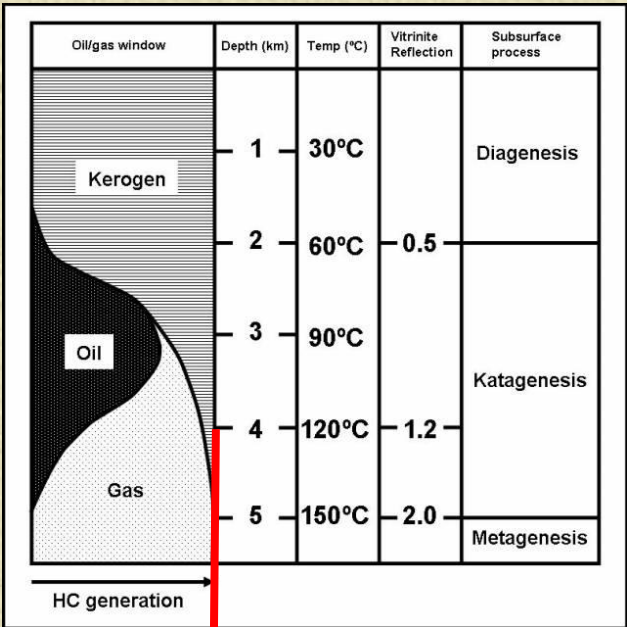
Where are the MegaWatt Geothermal Plants?



[illegible]

The Petro Problem

*Why Drill a
Deep Hot Well?*



Basins Vs. Heat?

US Geothermal Potential

Temperature at 6km

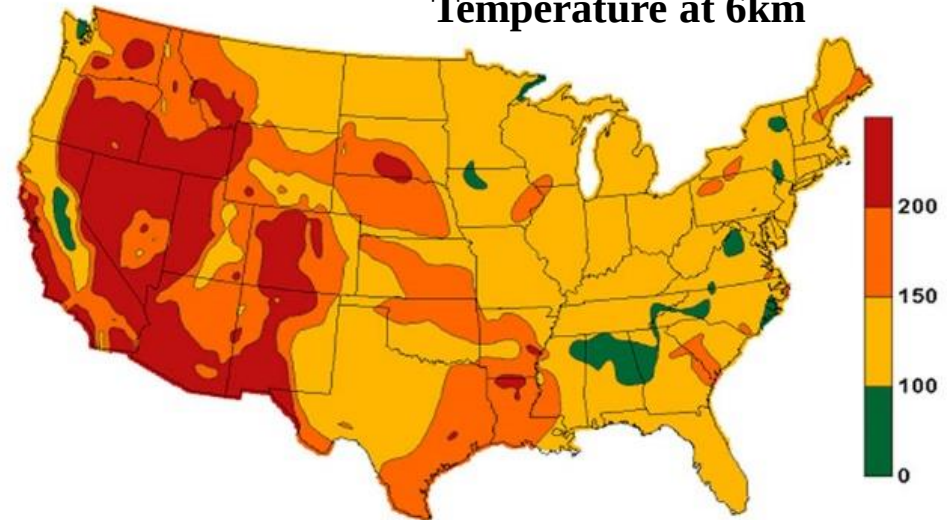
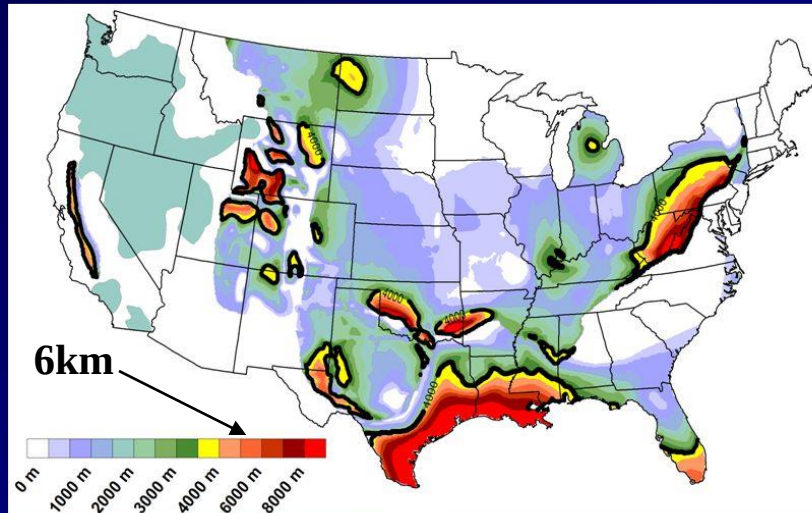


Figure 1: Estimated Earth Temperatures (°C) at 6 km Depth

Sediment thickness in the continental United States

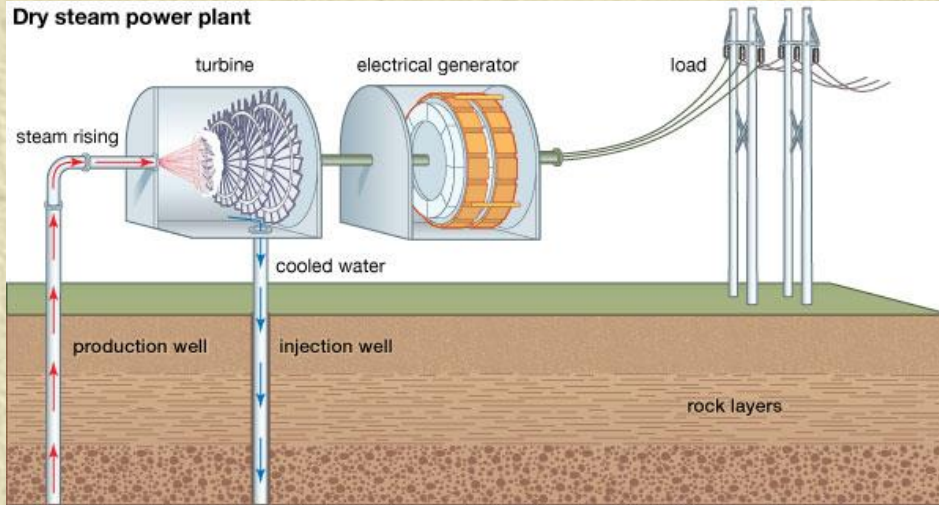


Need a low heat Solution

Electricity from Heat

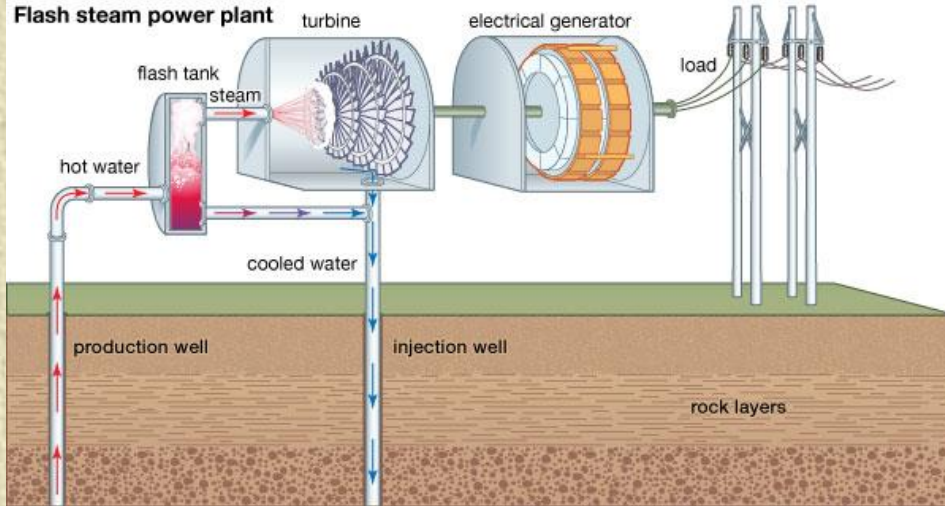
The Reigning Champs

Dry steam power plant



© 2011 Encyclopædia Britannica, Inc.

Flash steam power plant

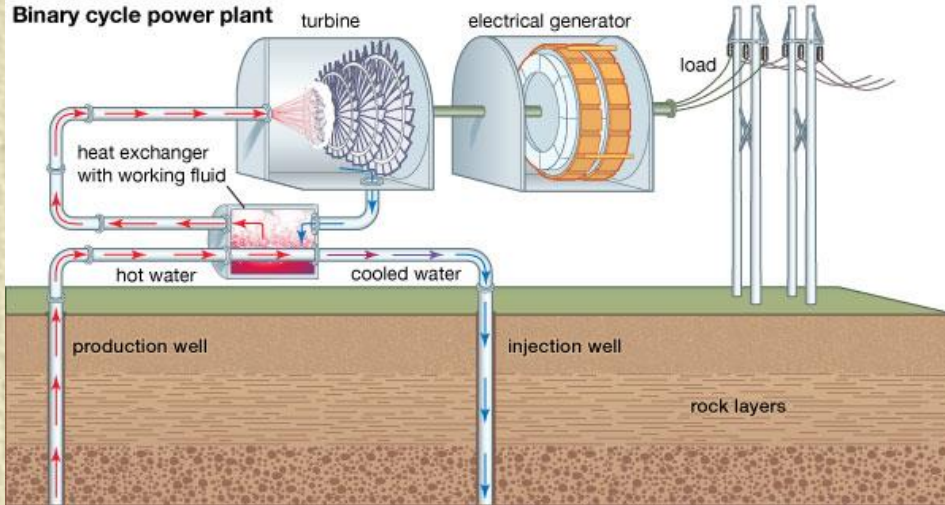


© 2011 Encyclopædia Britannica, Inc.

The Low-Heat Challenger



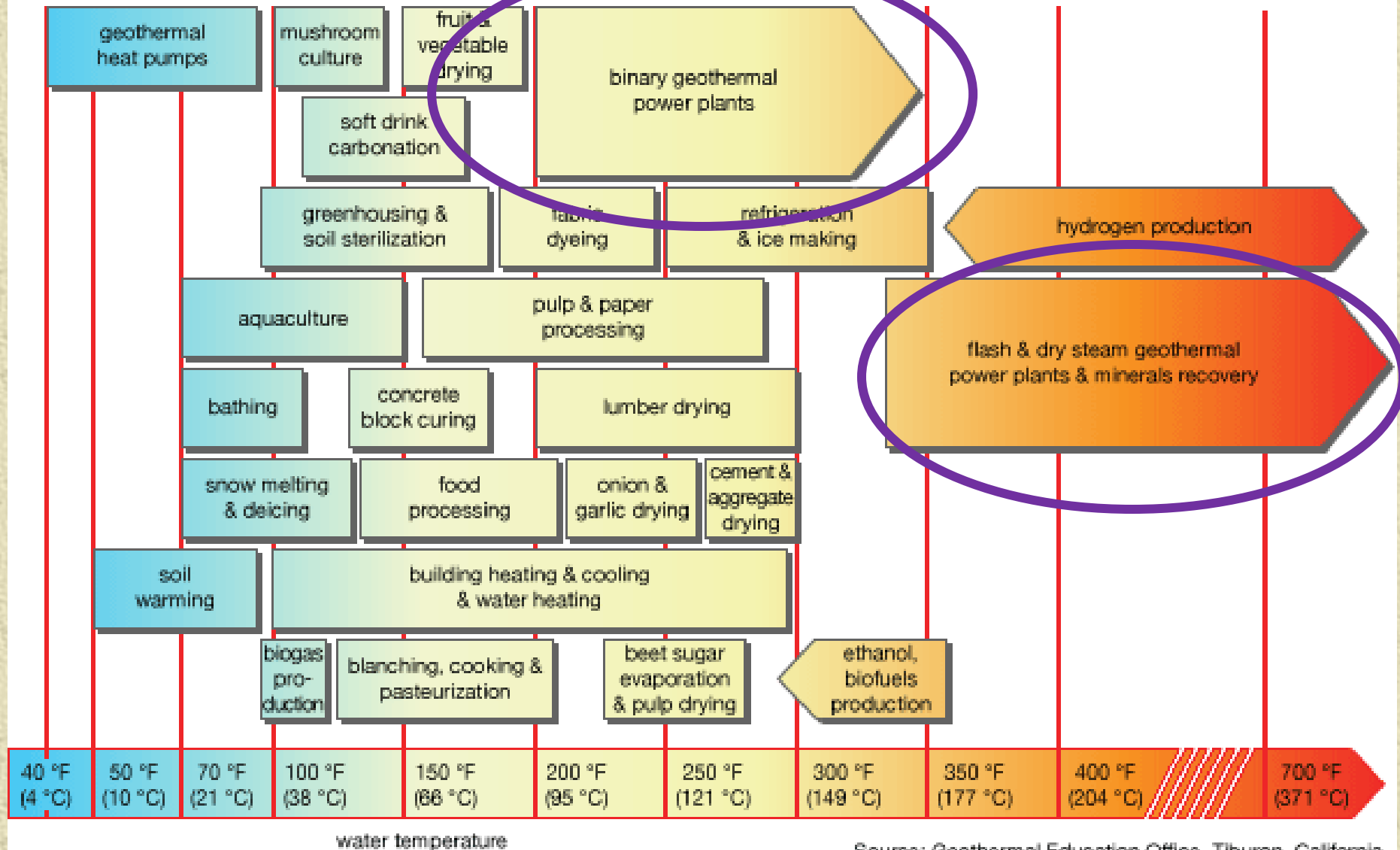
Binary cycle power plant



© 2011 Encyclopædia Britannica, Inc.

Low Heat Power

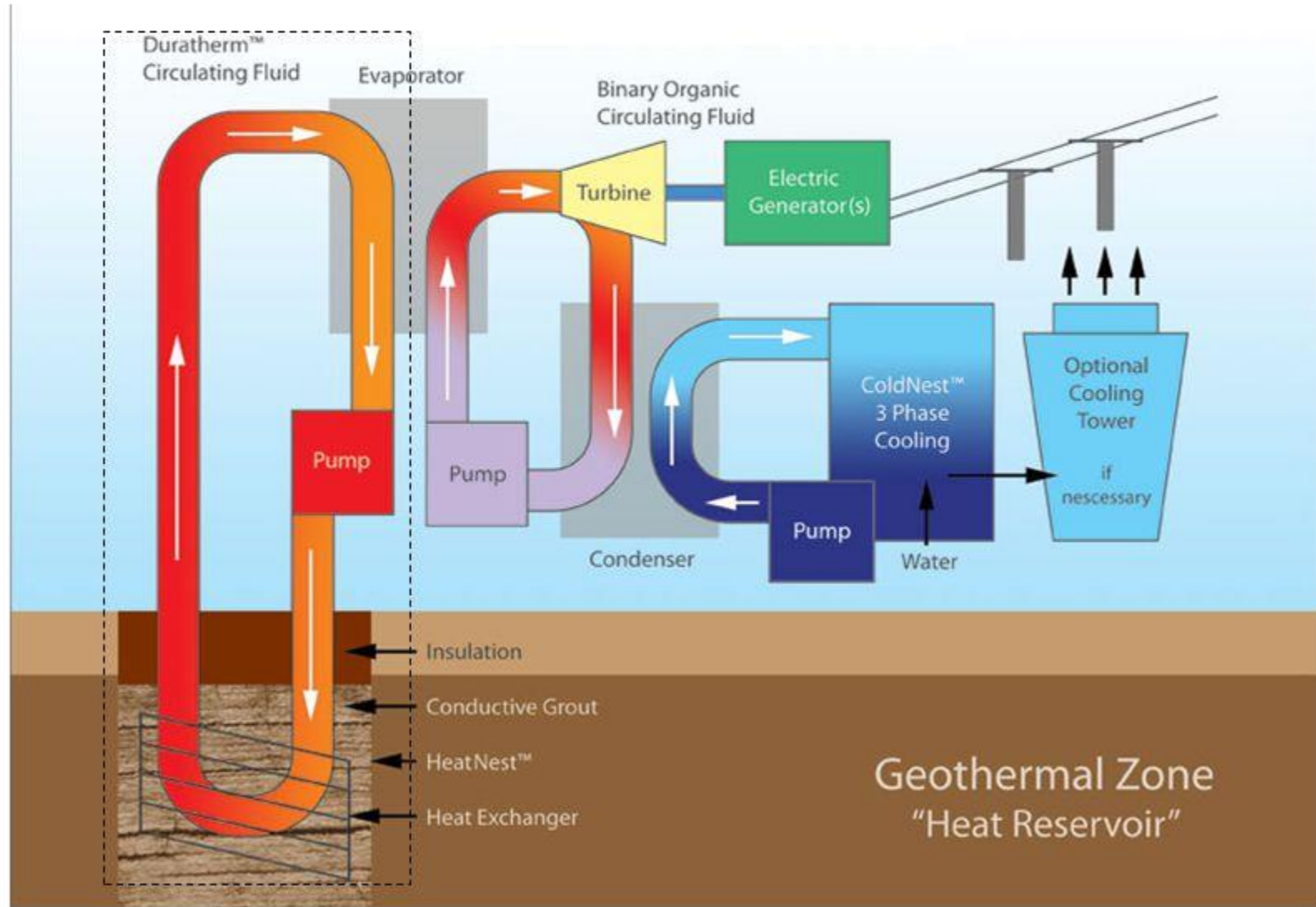
Geothermal energy uses



water temperature

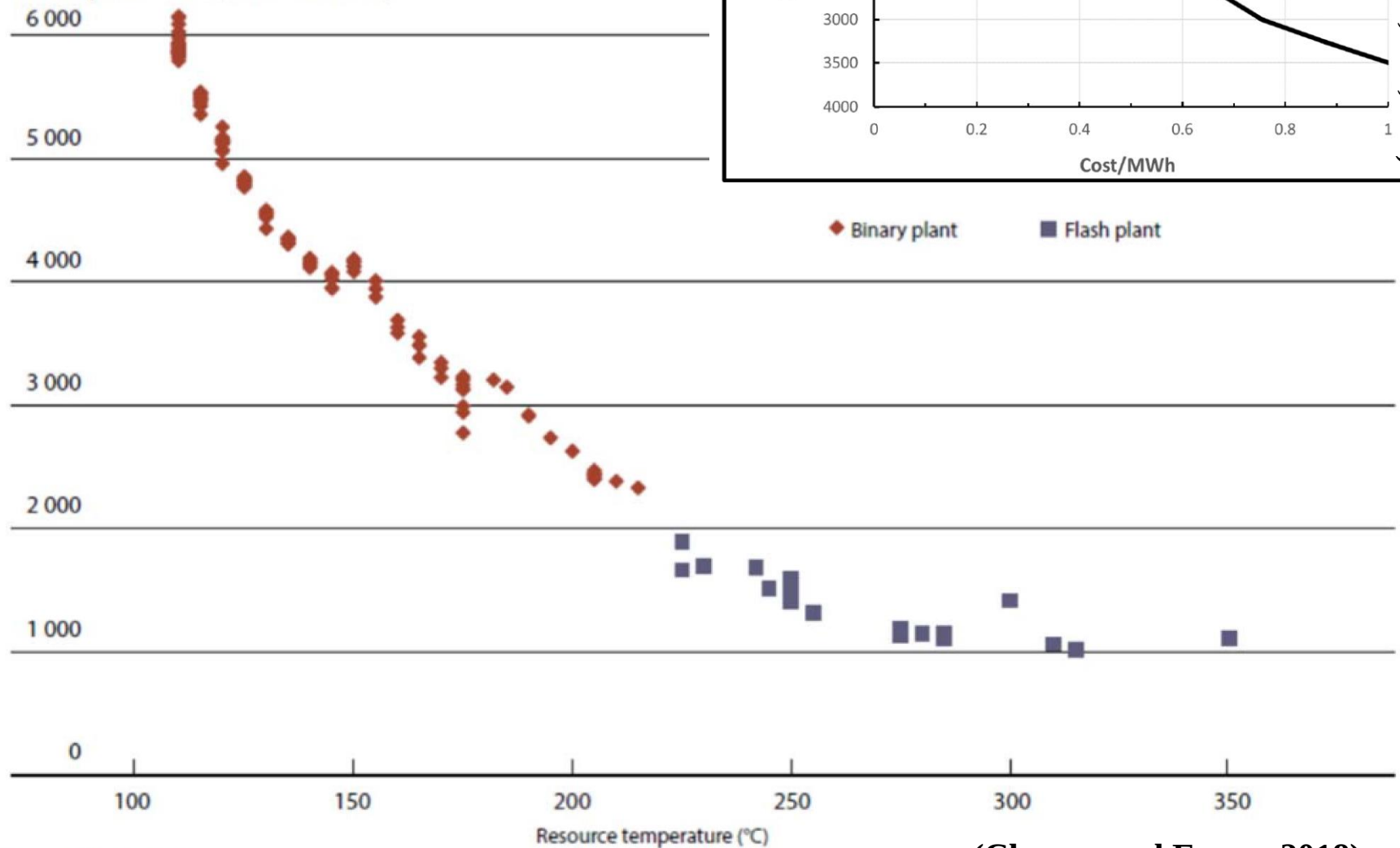
Source: Geothermal Education Office, Tiburon, California

Rankine Cycle for Geothermal Power Plant

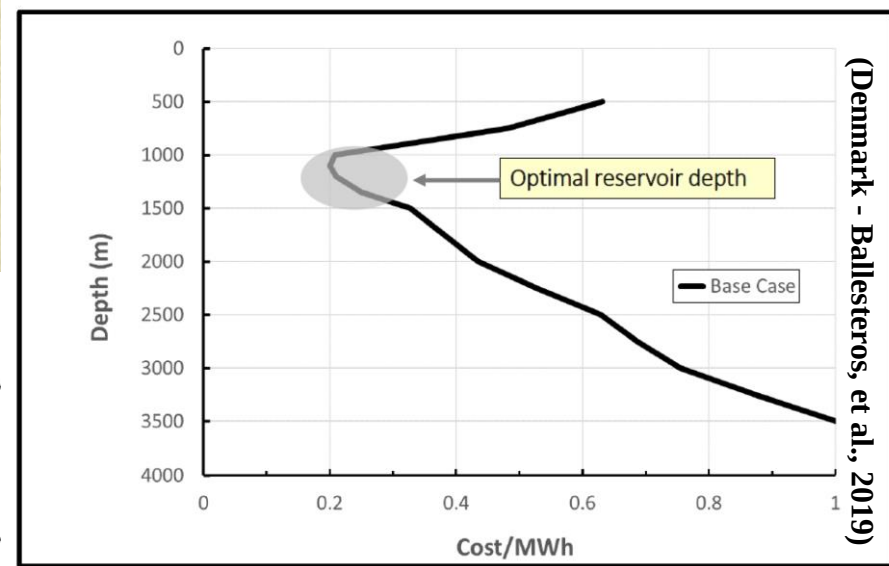


Optimizing the Economics

Power plant costs (2009 USD/kW)



Source: NREL, 2012

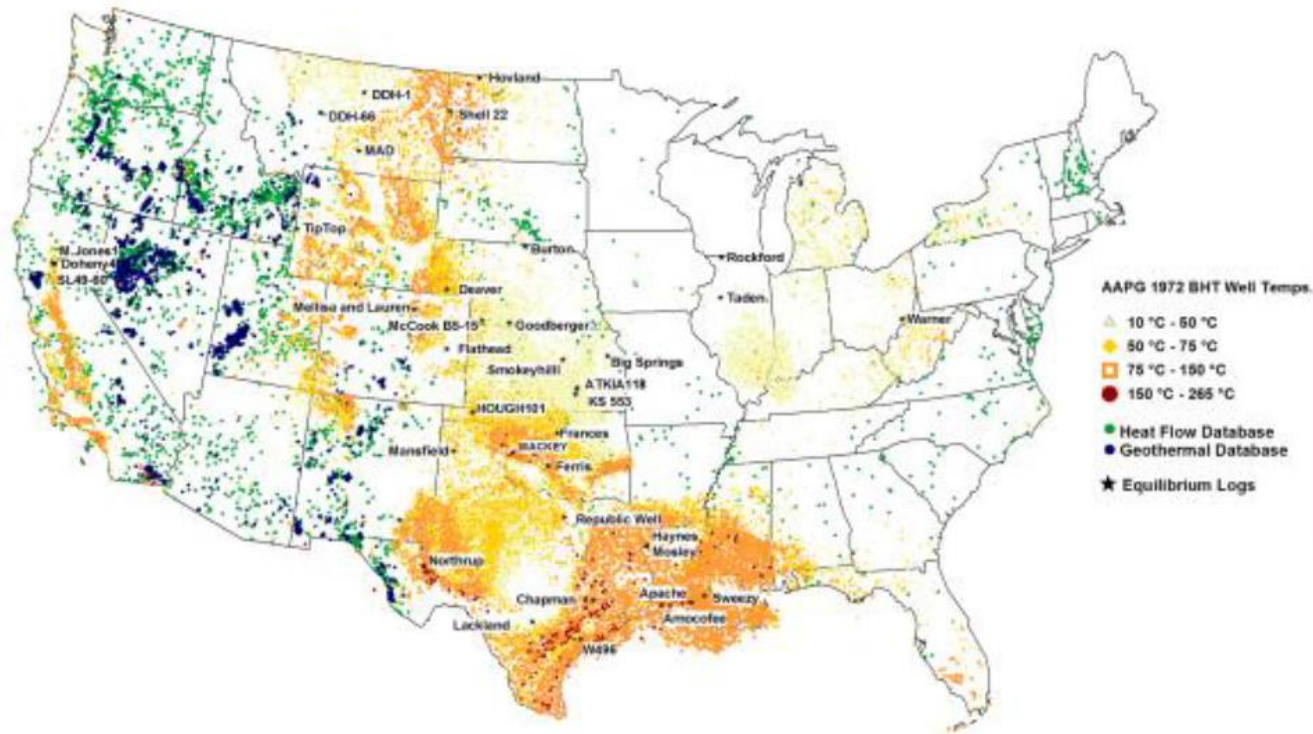


(Denmark - Ballesteros, et al., 2019)

(Clauser and Ewert, 2018)

The Opportunity

Co-Produced Water from Existing Wells



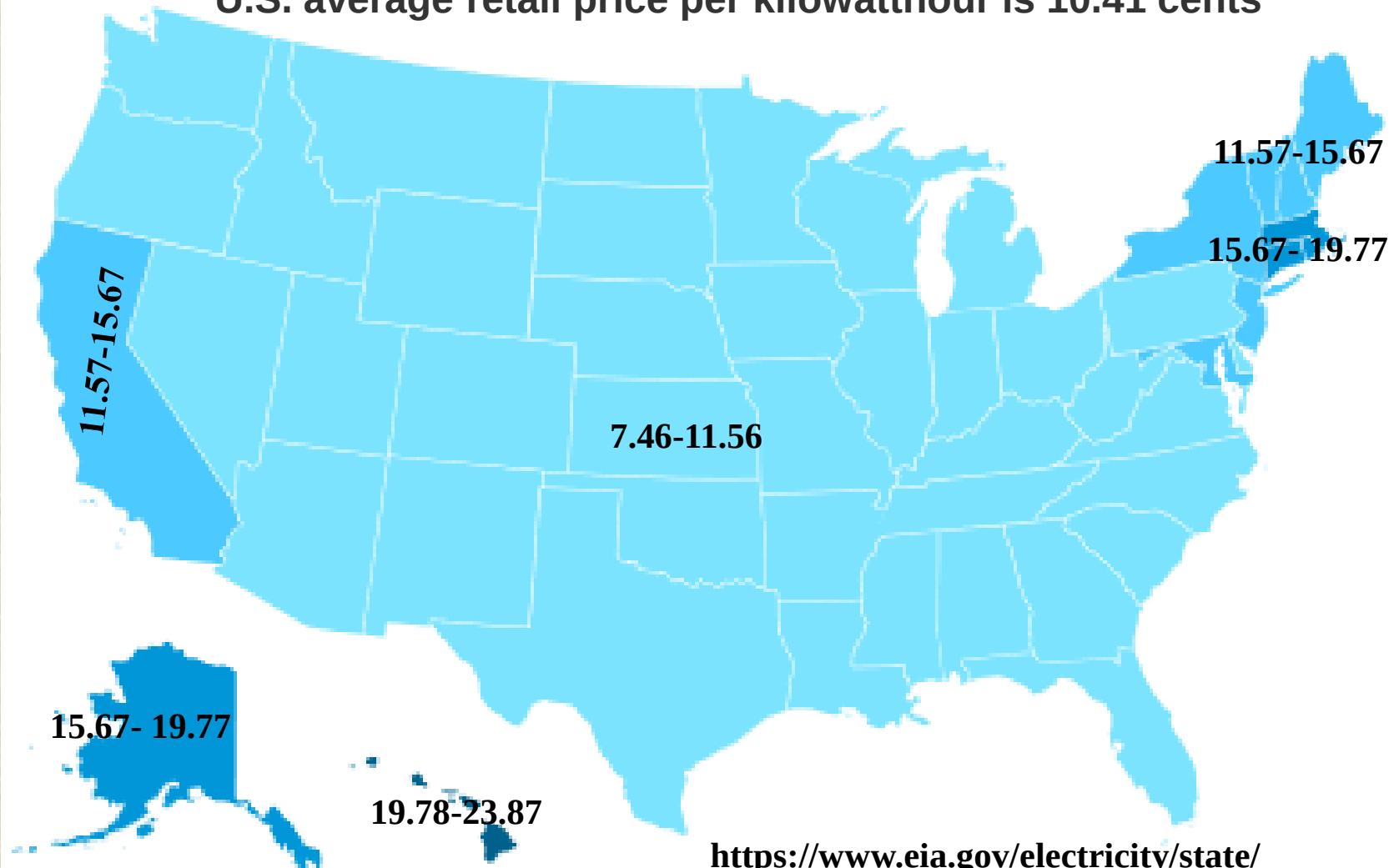
1.2M-1.5M active & inactive wells in Texas alone – USGS has characterized 17,000 wells above 200°F and on the way to 25,000 before year's end.

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*

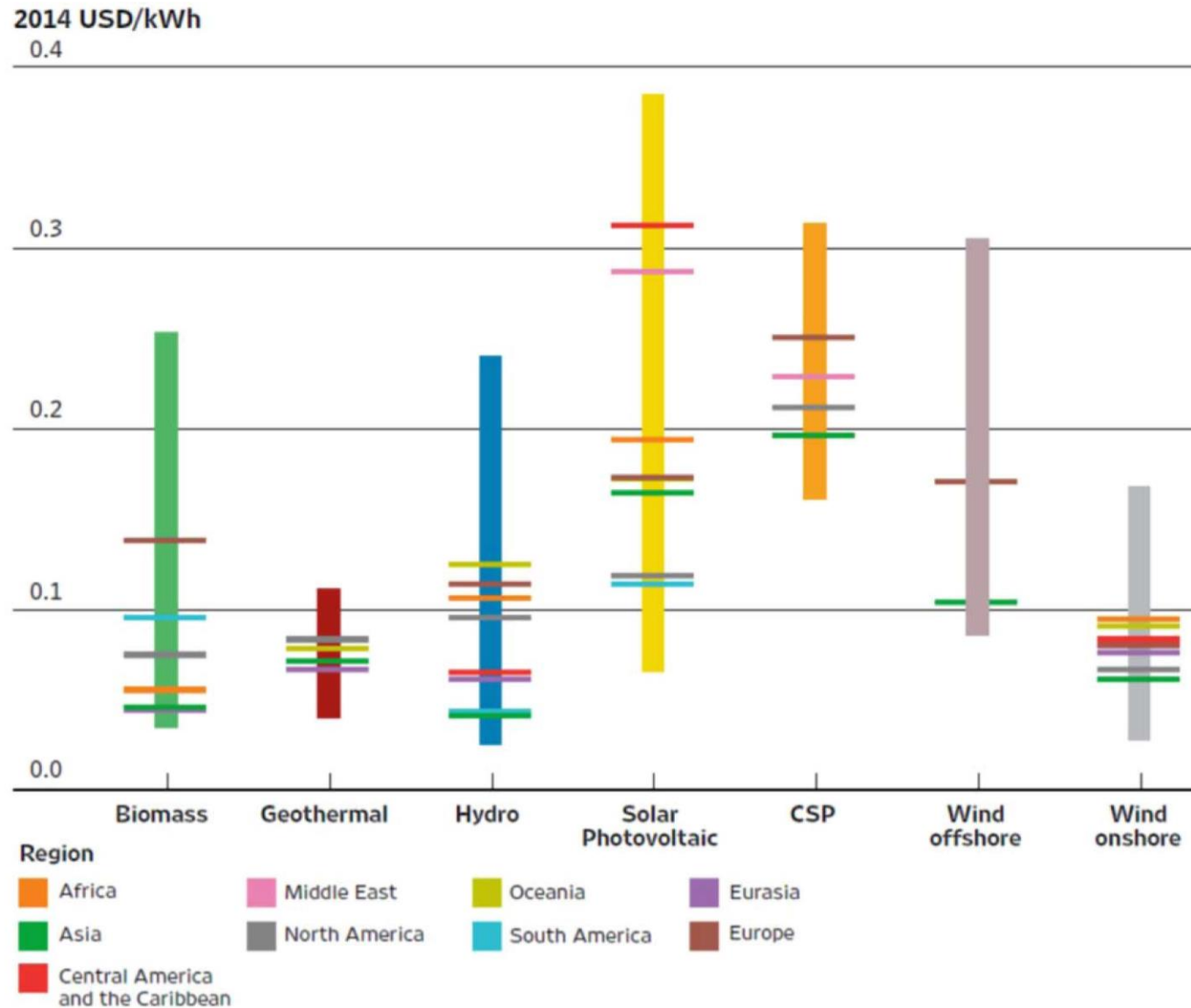
What do We Pay for Power?

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



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

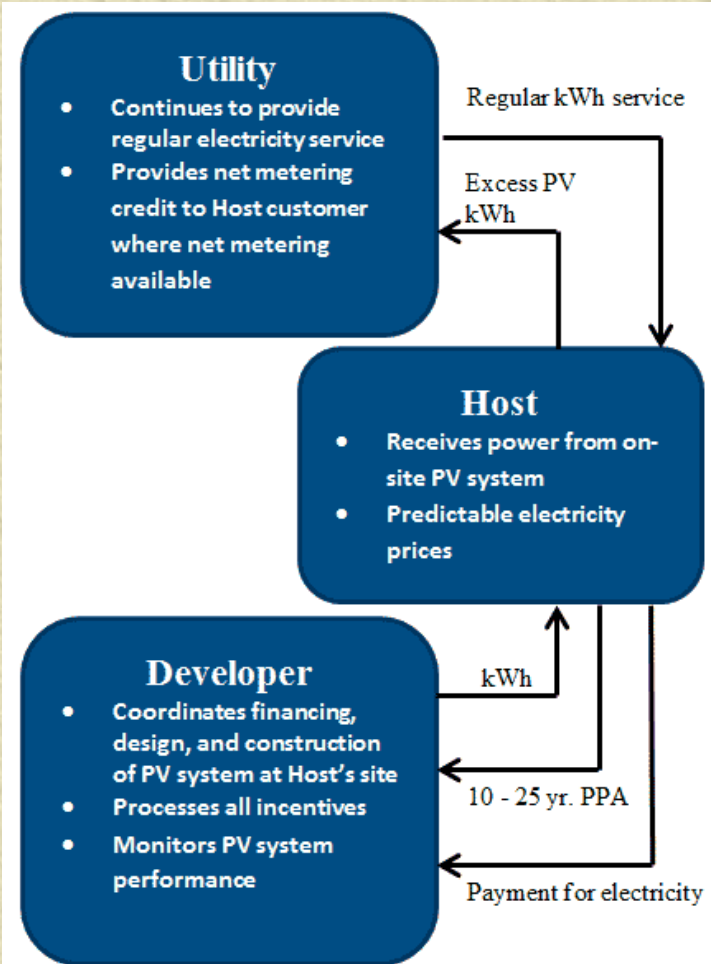
SedHeat: Gone from Maybe for Dollars to Surely for Pennies



Source: IRENA Renewable Cost Database.

(Clauser and Ewert, 2018)

The Power of the Power-Purchase Agreement

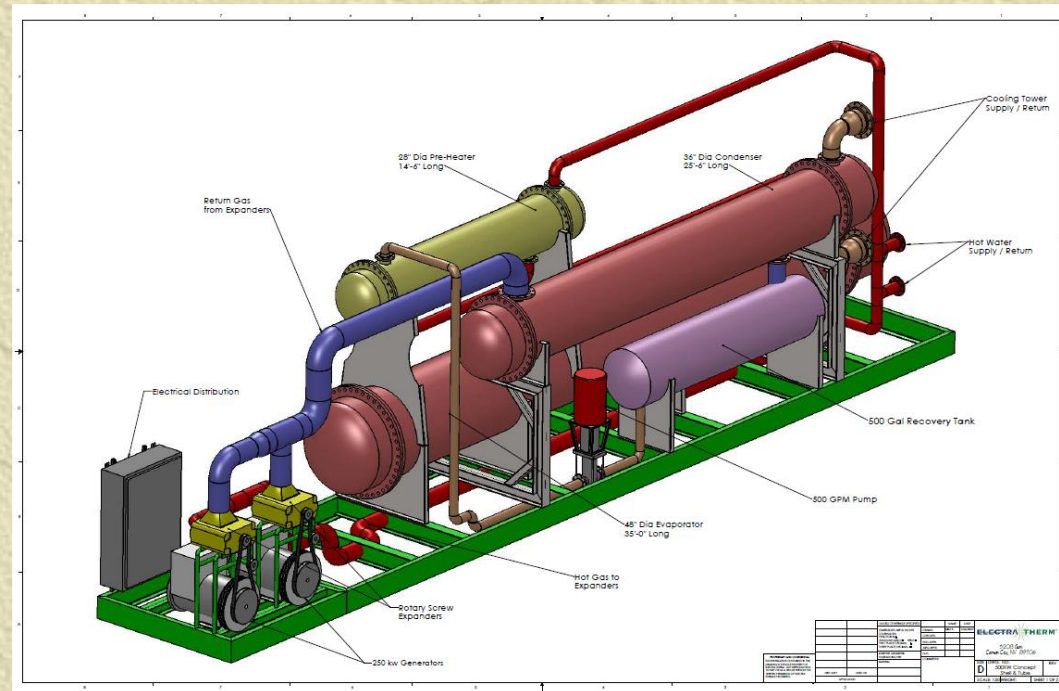


https://www.seia.org/sites/default/files/ppa-graph_0.gif



The Green Machine Example

$\leq \$0.10/\text{kwh}$ From $<100^\circ\text{C}$



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

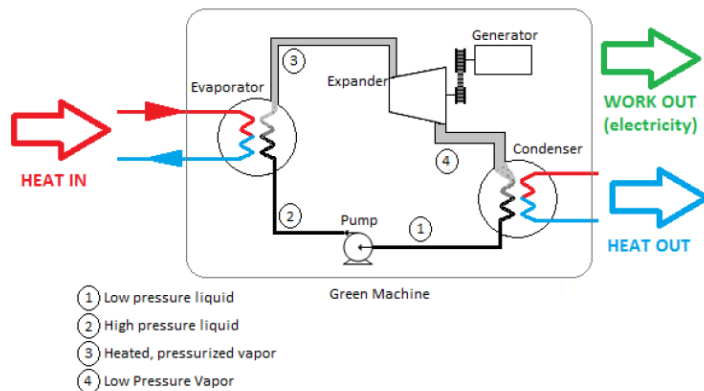
Refrigerant - Honeywell R245FA - Charge (lbs): 700 lbs.

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



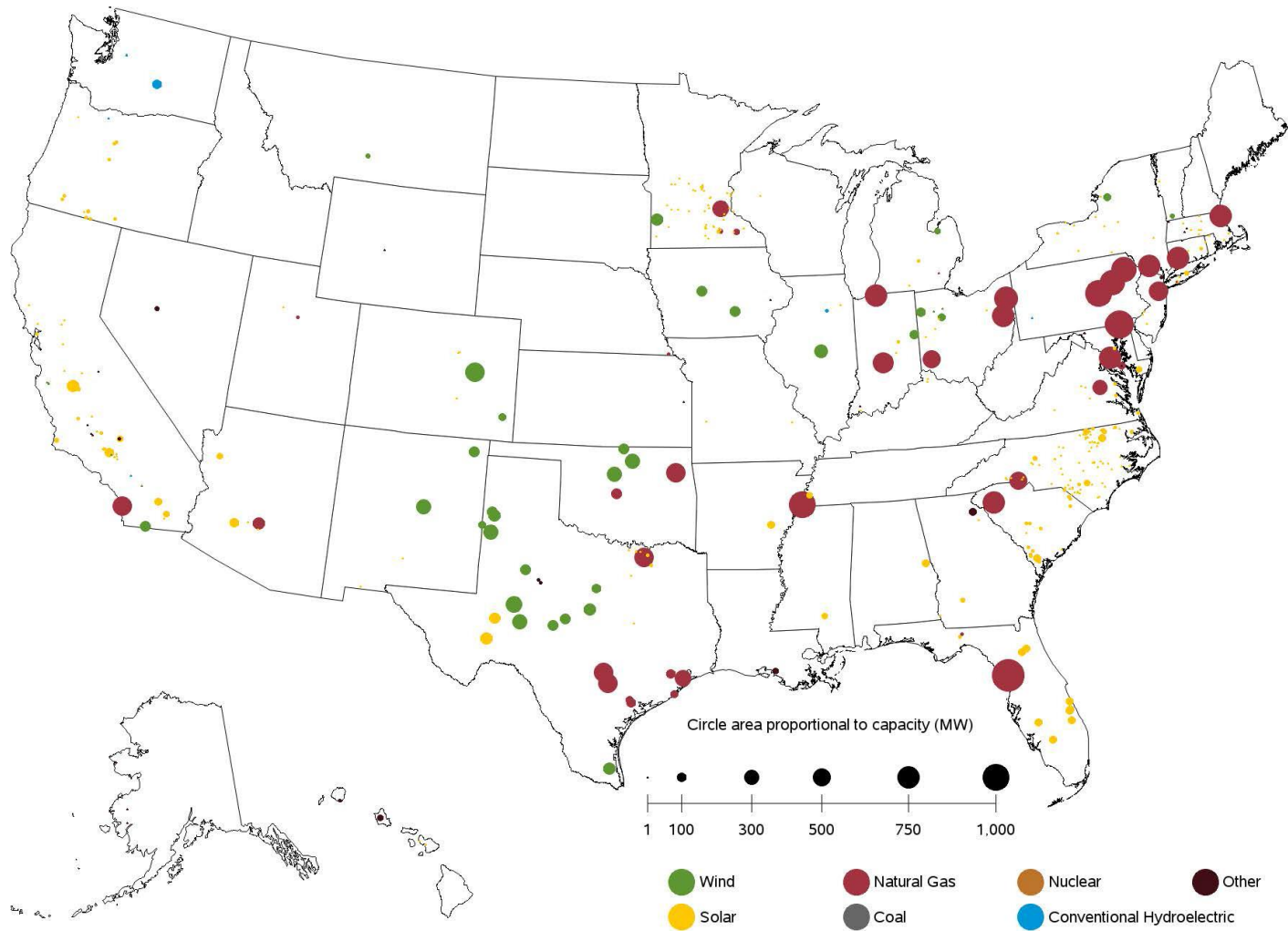
<https://www.businesswire.com/news/home/20090604005254/en/ElectraTherm-Green-Machine-Turns-Geothermal-Heat-Electricity>



We Can Do This!!!!

Need a little activation energy

Figure 6.1.C. Utility-Scale Generating Units Planned to Come Online from December 2017 to November 2018



Sources: U.S. Energy Information Administration, Form EIA-860, 'Annual Electric Generator Report' and Form EIA-860M, 'Monthly Update to the Annual Electric Generator Report.'

Opportunities for O & G Industry

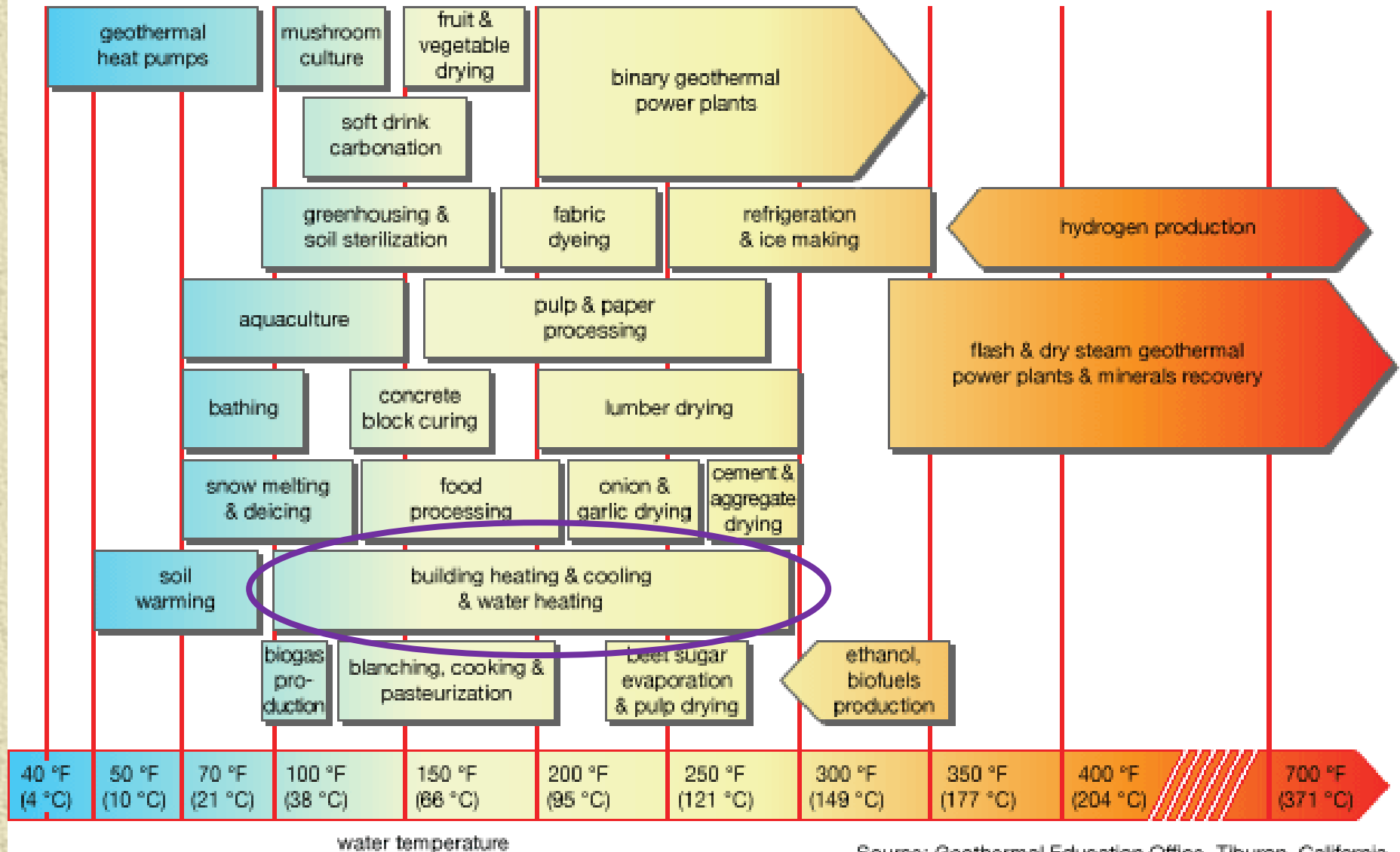
✧ The Grid

✧ **Direct Heat**

✧ Energy storage/Earth battery

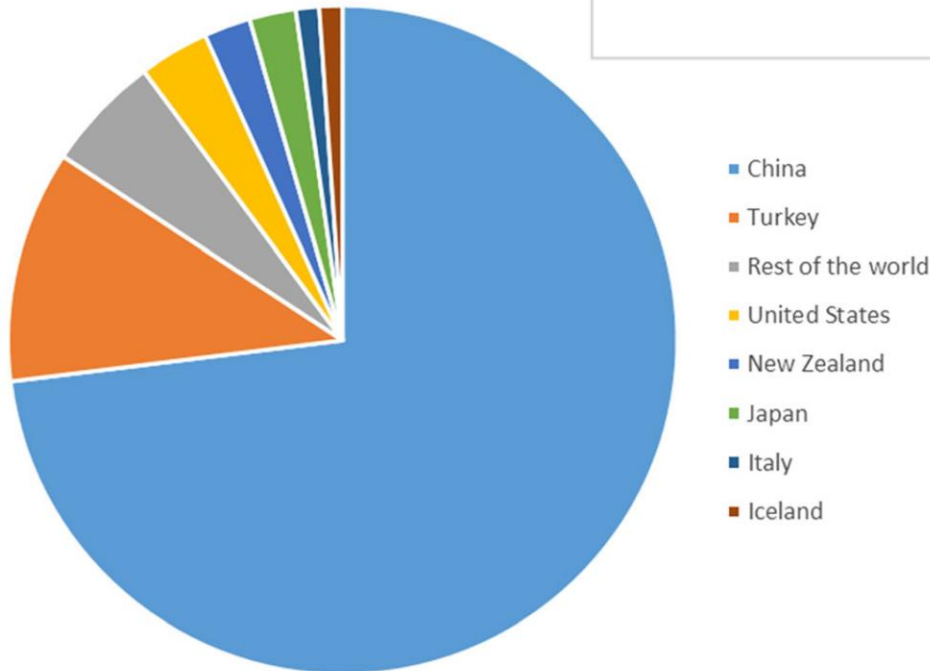
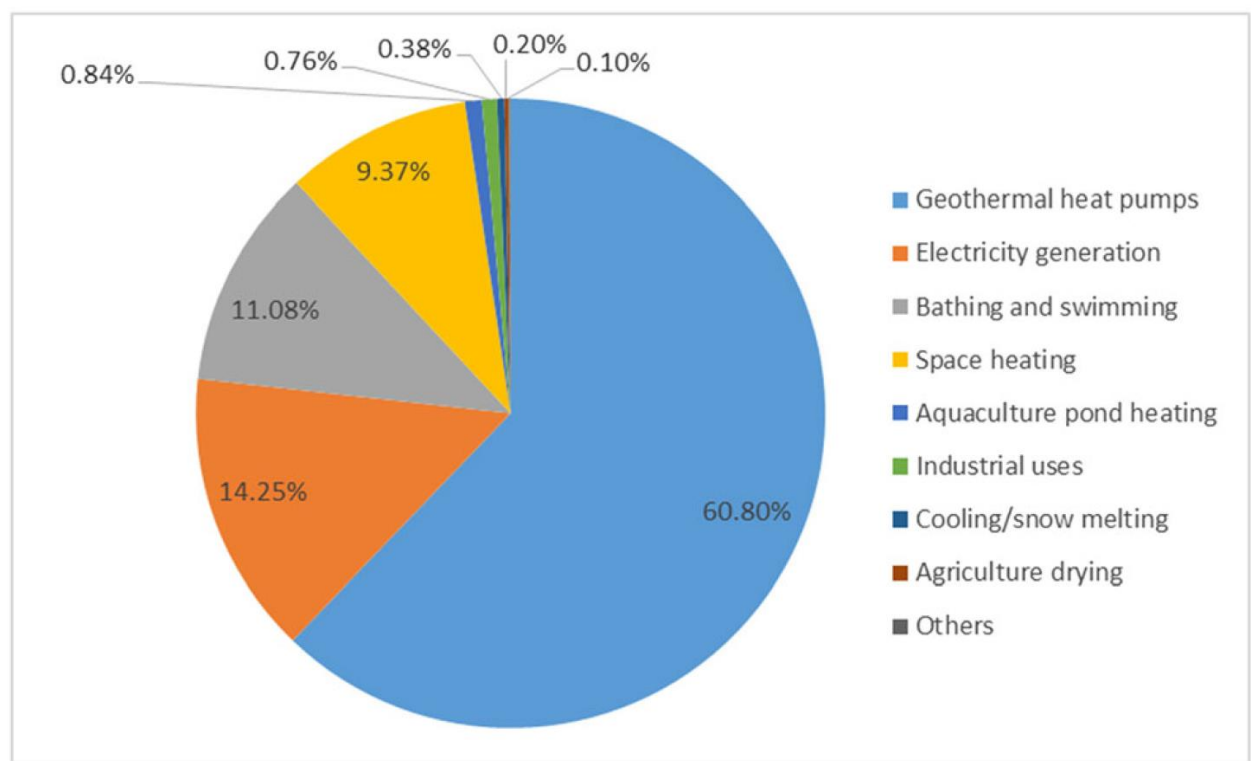
The Other Moving Parts

Geothermal energy uses



Source: Geothermal Education Office, Tiburon, California

Who's Using Direct Heat and for What?



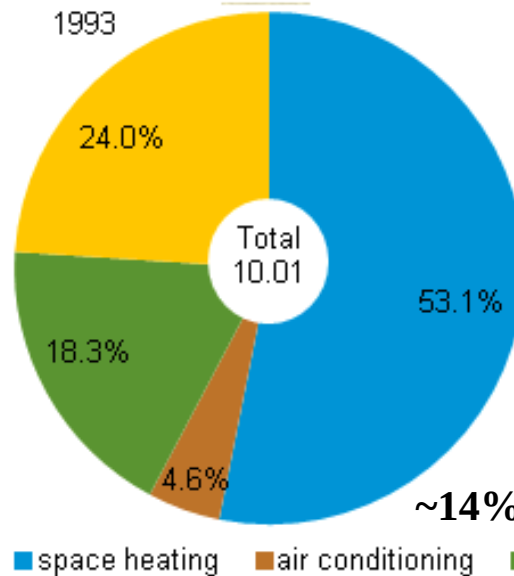
Global Use of Direct Heat

(Ghazvini, et al., 2019)

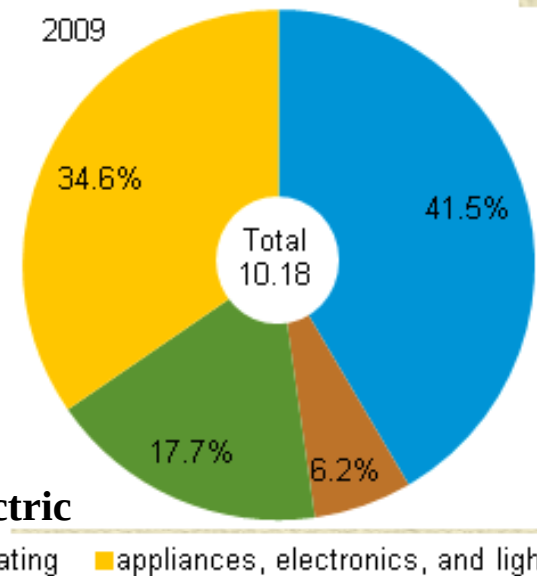
Space Heating

An Electron Saved is and Electron Earned

Energy consumption in homes by end uses
quadrillion Btu and percent

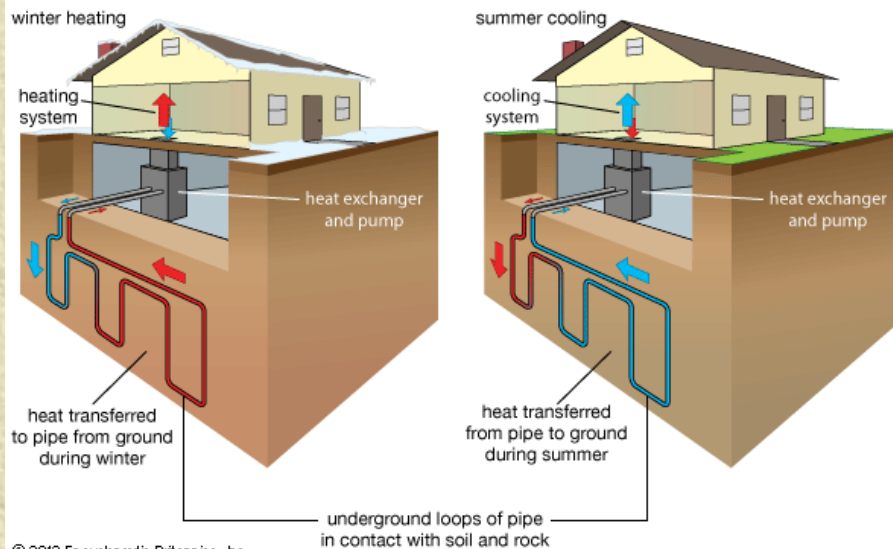


2009



~14% of Electric

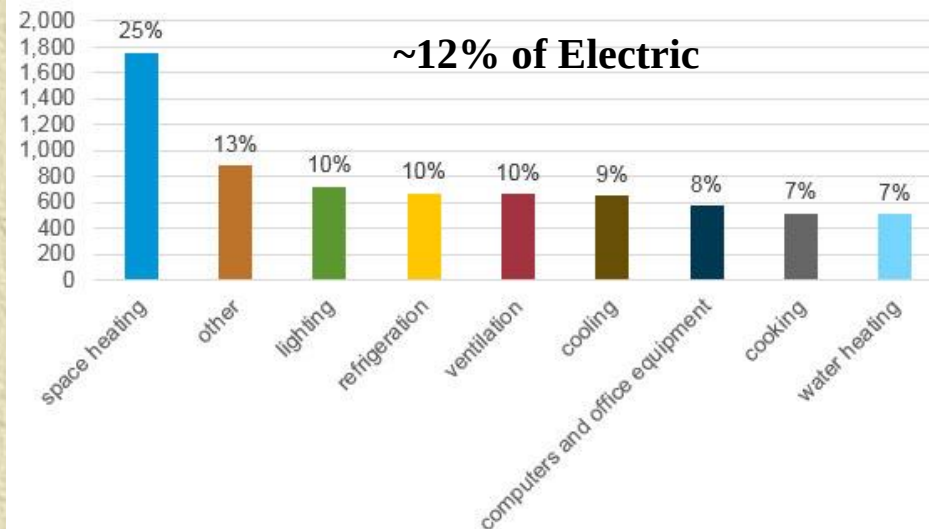
Residential heat pump



© 2012 Encyclopædia Britannica, Inc.

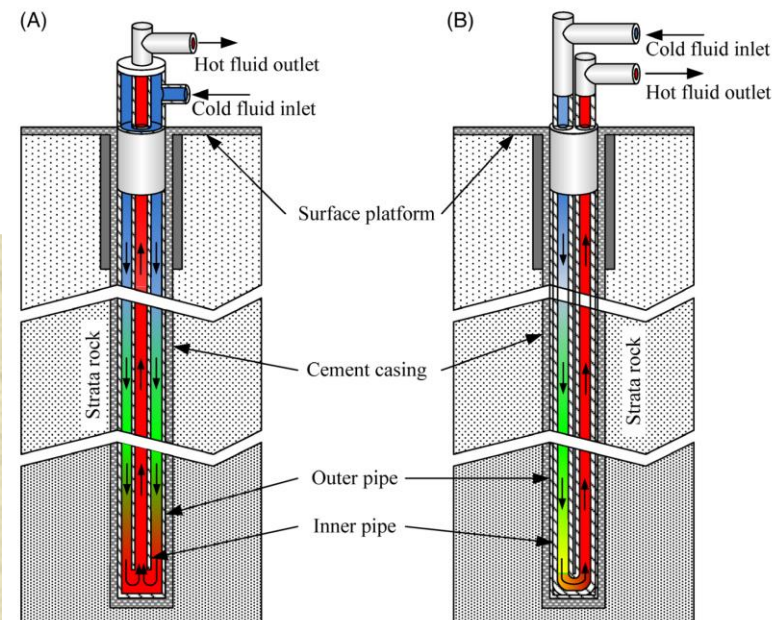
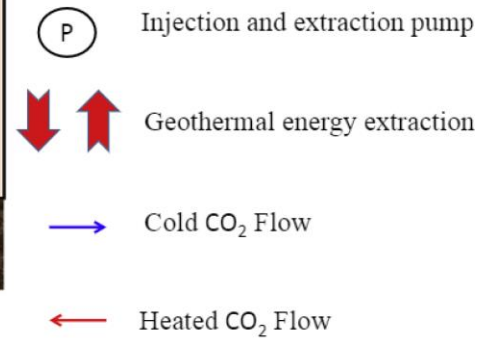
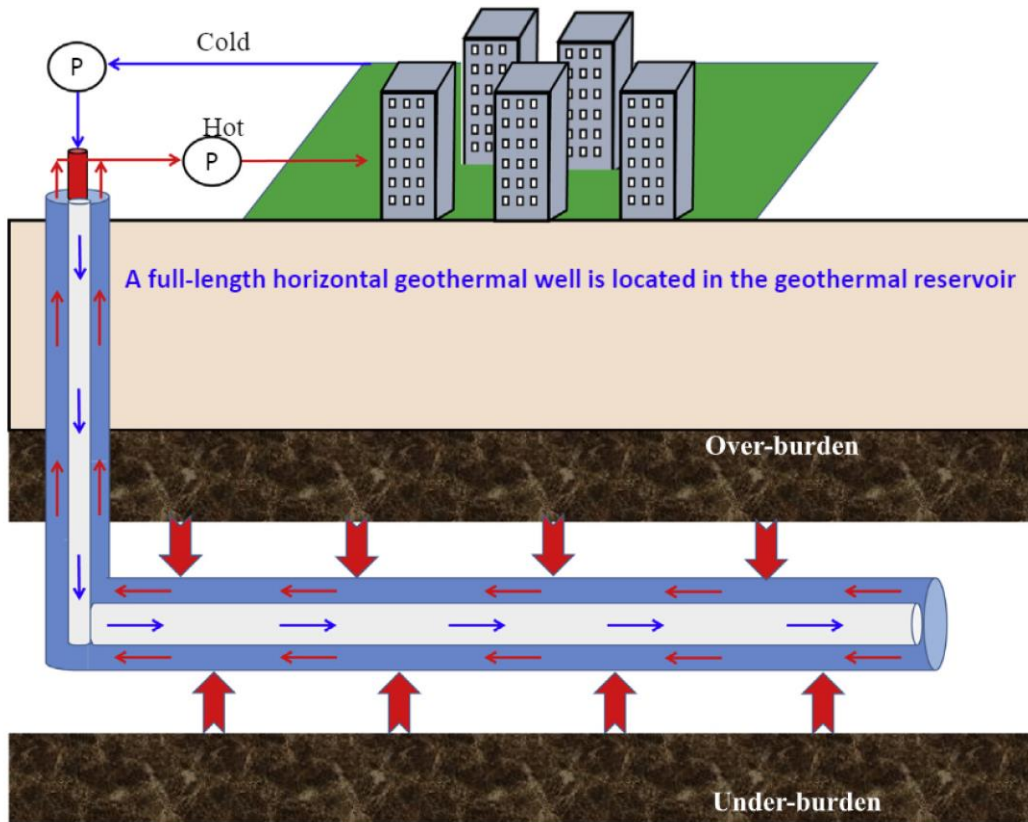
Energy use in U.S. commercial buildings by major end uses, 2012

trillion British thermal units



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

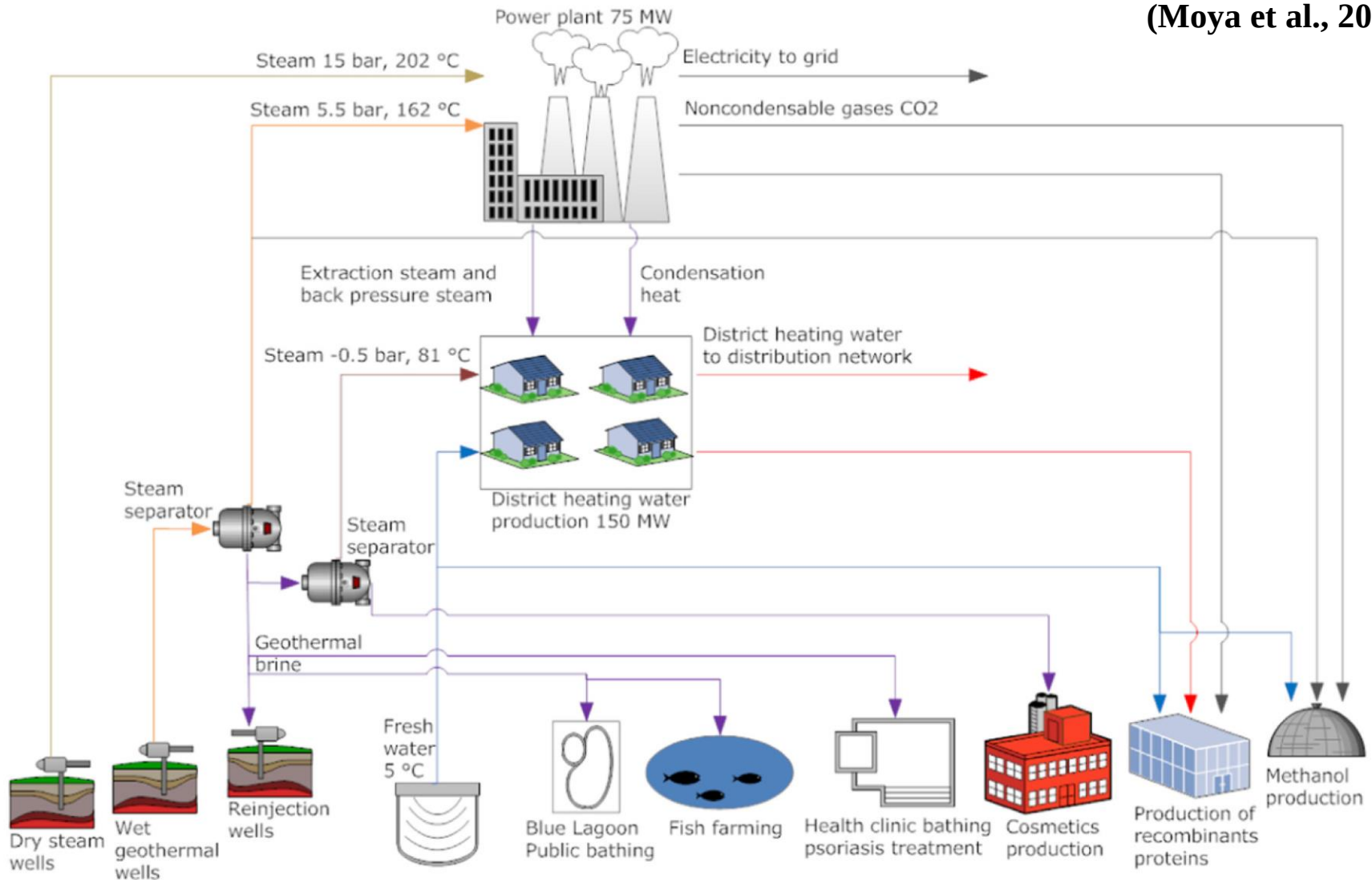
Can Be upscaled



Can Be Coupled

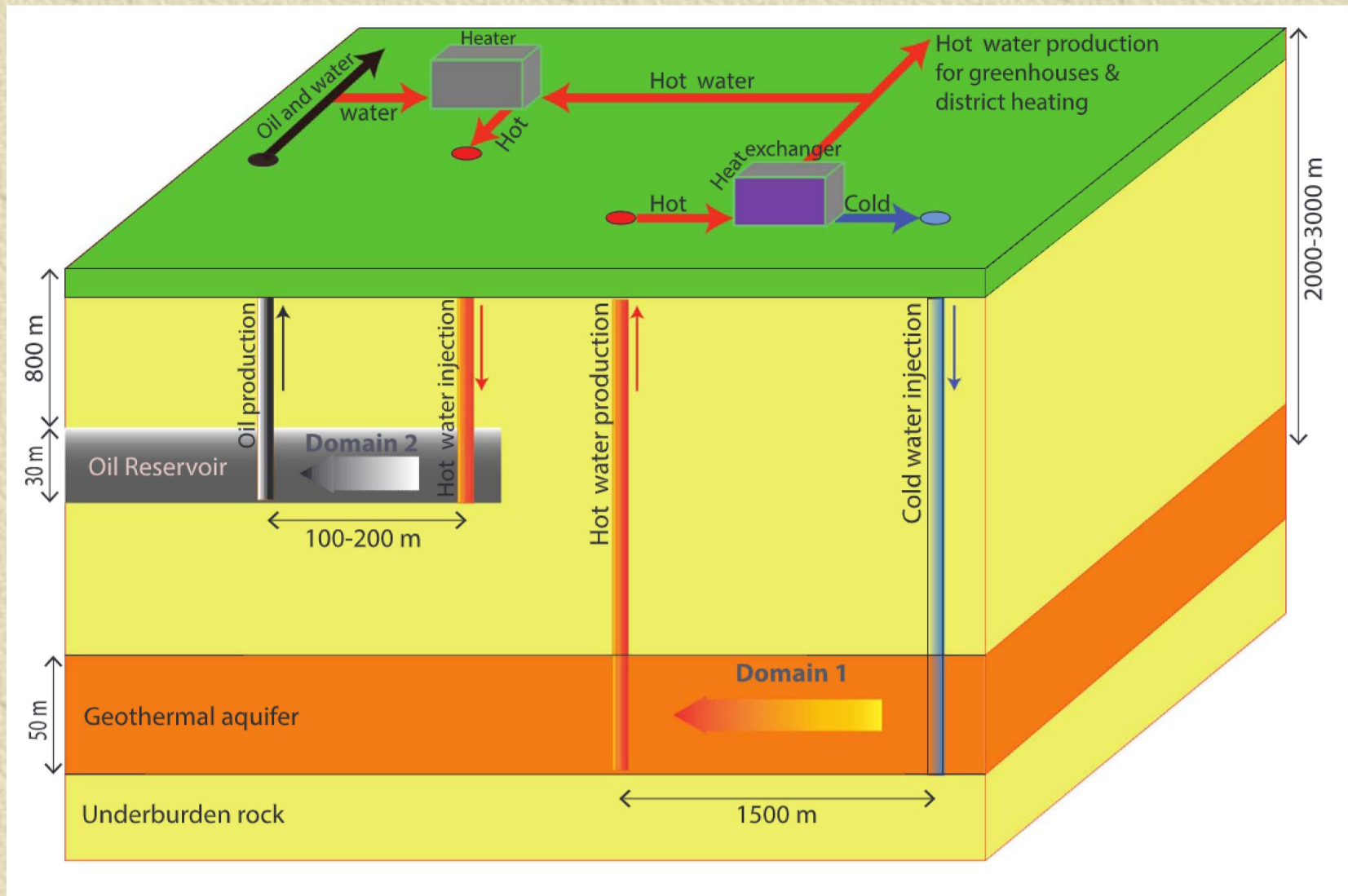
Iceland's Blue Lagoon Cascading System

(Moya et al., 2018)



Can Be Coupled

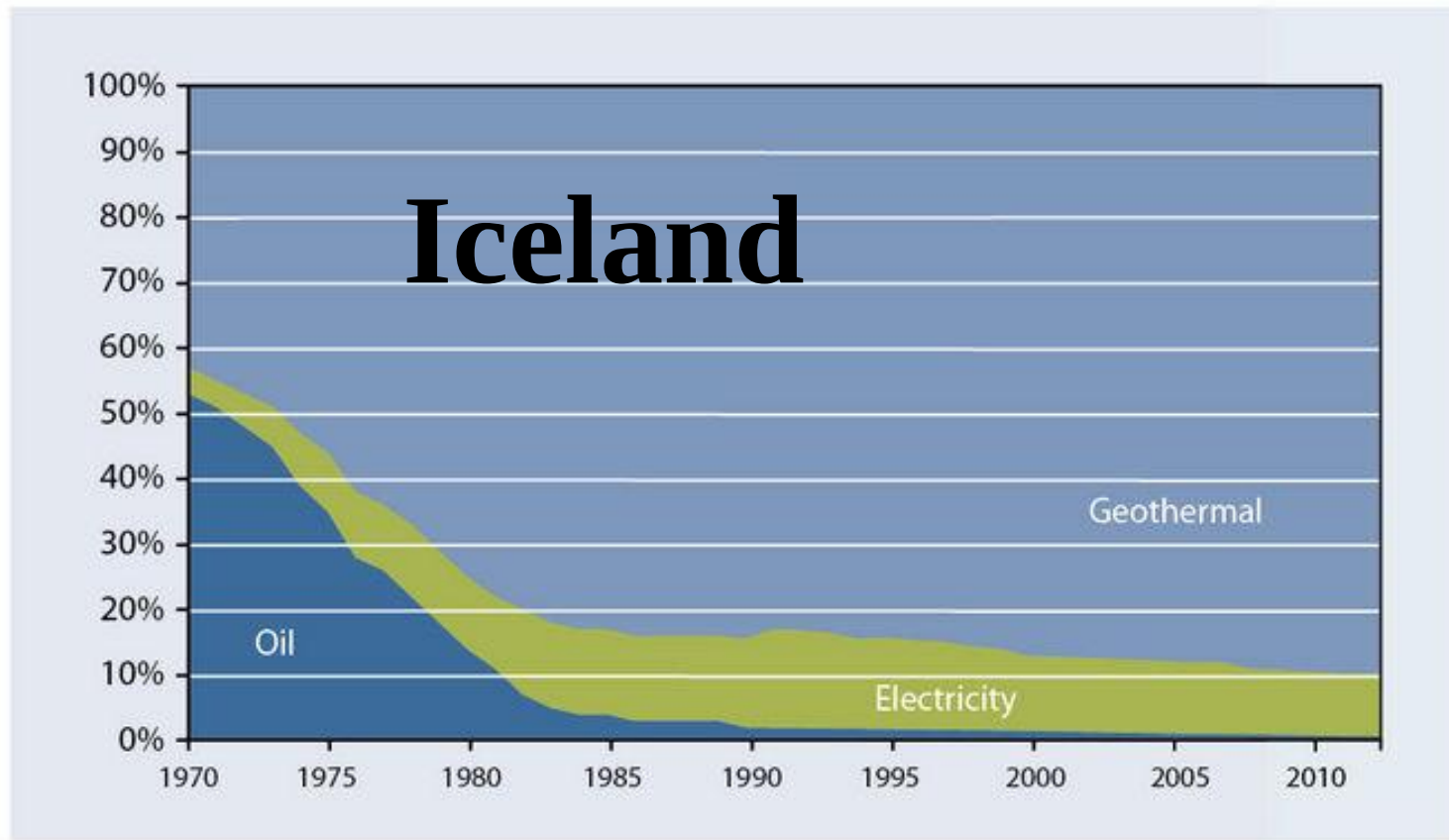
Secondary Recovery



(Ziabakhsh-Ganji, et al., 2018)

And Still World Champion

Space heating 1970–2013



<https://nea.is/geothermal/direct-utilization/space-heating/>



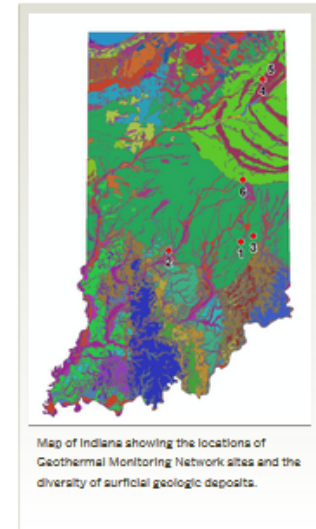
The Indiana Shallow Geothermal Monitoring Network: A test bed for facilitating the optimization of geothermal heat pumps in the glaciated Midwest



Shallow geothermal energy represents a renewable resource that can be further developed via ground-source heat pumps (GSHPs). The costs of these systems can be minimized by allowing designers and installers to make decisions about construction technologies that take into account the appropriate thermal properties and predominant moisture regime of the geologic material being utilized.

Researchers at the Center for Geospatial Data Analysis and Indiana Geological Survey developed a comprehensive monitoring network that provides in-situ measurements of shallow subsurface thermal conductivity, temperature gradients, and soil moisture. Continuous measurements of 1) thermal gradients in the upper 6 feet of the ground, 2) thermal conductivity, and 3) volumetric moisture content are collected at six monitoring sites near Indianapolis and Fort Wayne, the two largest population centers in Indiana

Although software allows GSHP installers to calculate optimal lengths and configurations of ground-coupling geothermal systems, there are input parameters that must first be determined for these applications, including soil thermal properties and earth temperatures. The fundamental control on heat transfer for a ground-coupled heat pump system is the thermal conductivity of the earth materials in which the system is installed. The determination of thermal properties for typical unconsolidated sediments in the upper 6 feet of the ground will support the design of more efficient systems by allowing GSHP installers to efficiently tailor the configurations of their systems to specific geological conditions and also to account for seasonal changes.



✦ Contact information:

✦ Shawn Naylor
✦ snaylor@indiana.edu
✦ 812-855-2504

✦ Bob Autio
✦ rjautio@indiana.edu
✦ 812-856-9104

Site locations and data

Site name (click name for data)	Site #	Geologic setting	Texture at 4-foot depth	Bulk density (g/cm ³)
Flat Rock River	1	alluvial terrace	sandy clay loam	1.11-1.32
Bradford Woods	2	alluvial terrace	silt loam	1.32-1.58
Shelbyville Moraine	3	moraine crest	silty clay loam	1.41-1.79
Eel River Valley	4	outwash terrace	sandy loam	1.46-1.71
Wabash Moraine	5	moraine crest	clay loam	1.64-1.80
Ball State Univ.	6	till plain	silt loam	NA

<https://igws.indiana.edu/Geothermal/ShallowGeothermal.cfm>

Geothermal Play Fairway Analysis of the Appalachian Sedimentary Basin

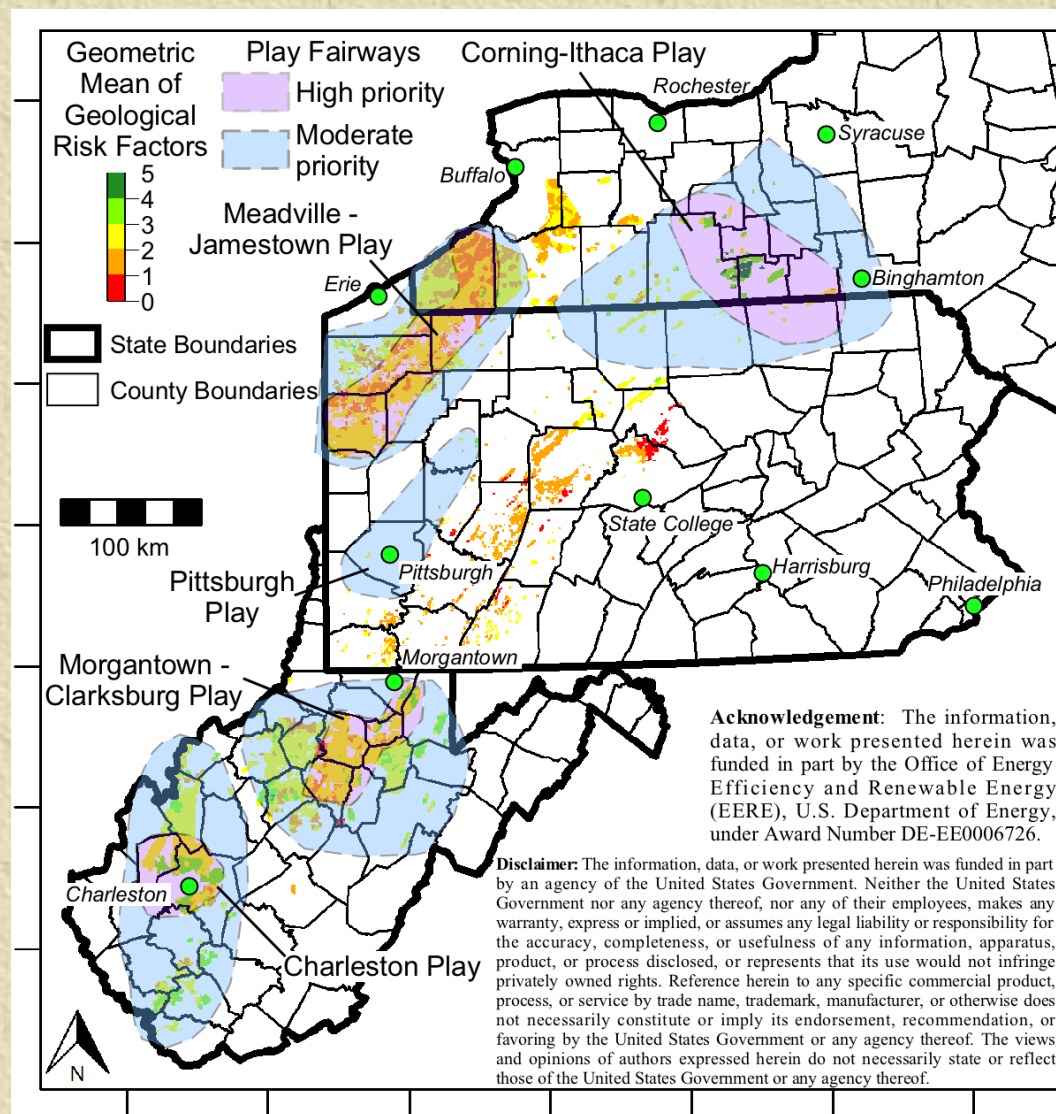
Appalachian Basin Geothermal Play Fairway Team

Terea E. Jordan¹, Maria C. Richards², Franklin G. Horowitz¹, Erin Camp¹, Jared D. Smith¹, Calvin A. Whealton¹, Jerry R. Stedinger¹, Matthew J. Hornbach², Zachary S. Frone², Jefferson W. Tester¹, Brian Anderson³, Kelydra Welcker³, Catherine Chickering Pace², Xiaoning He³, Maria Beatrice Magnani², Rahmi Bolat²

¹Cornell University

²Southern Methodist University

³West Virginia University



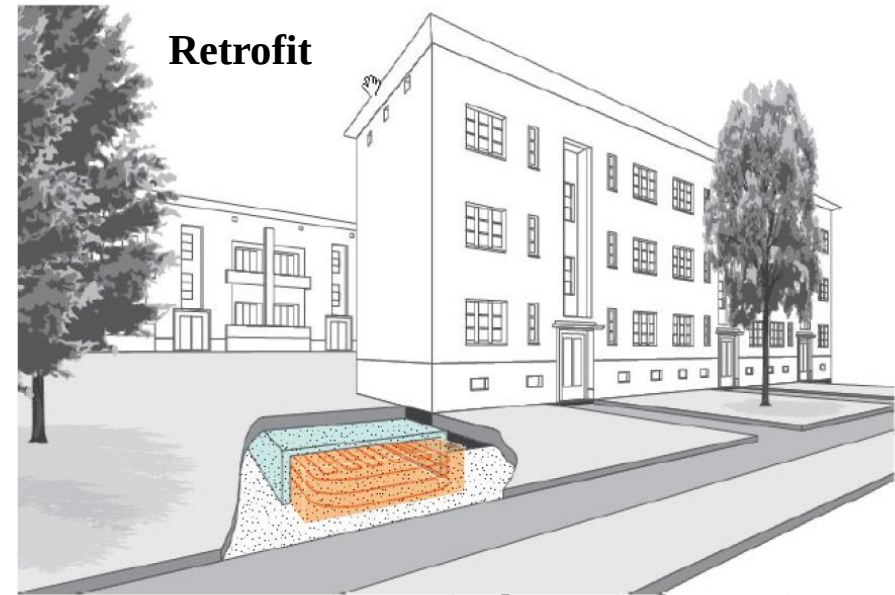
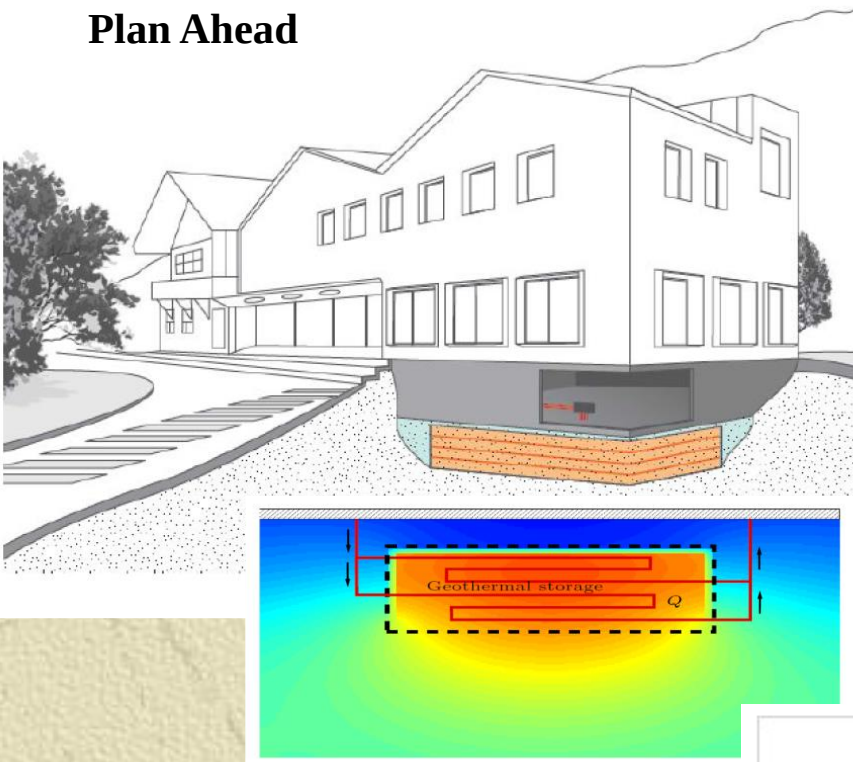
Opportunities for O & G Industry

✧ The Grid

✧ Direct Heat

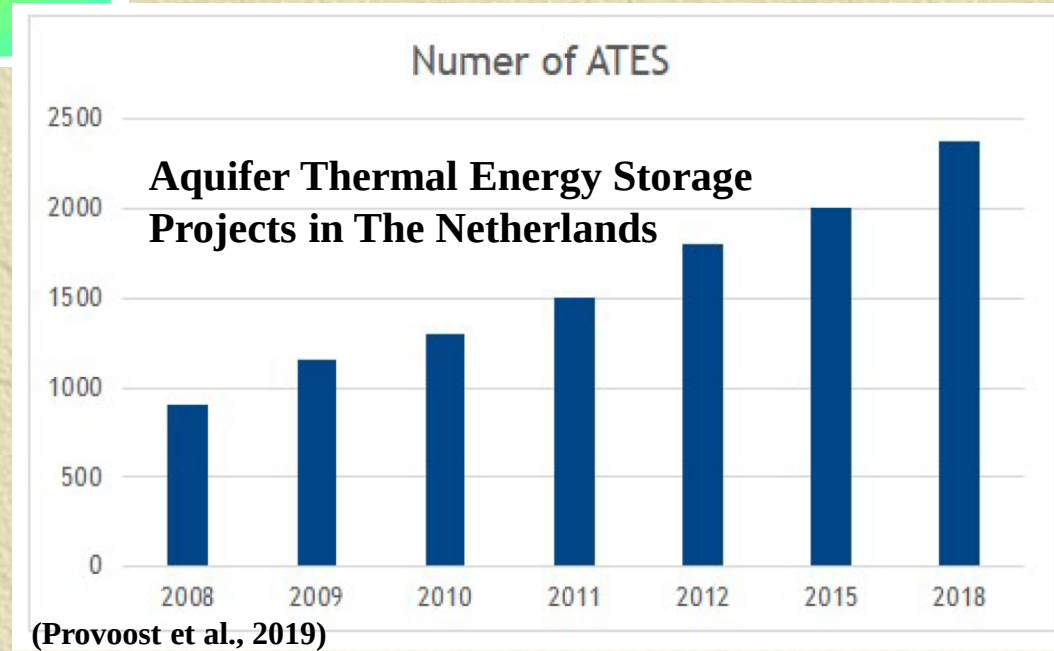
✧ **Energy storage/Earth
battery**

Plan Ahead



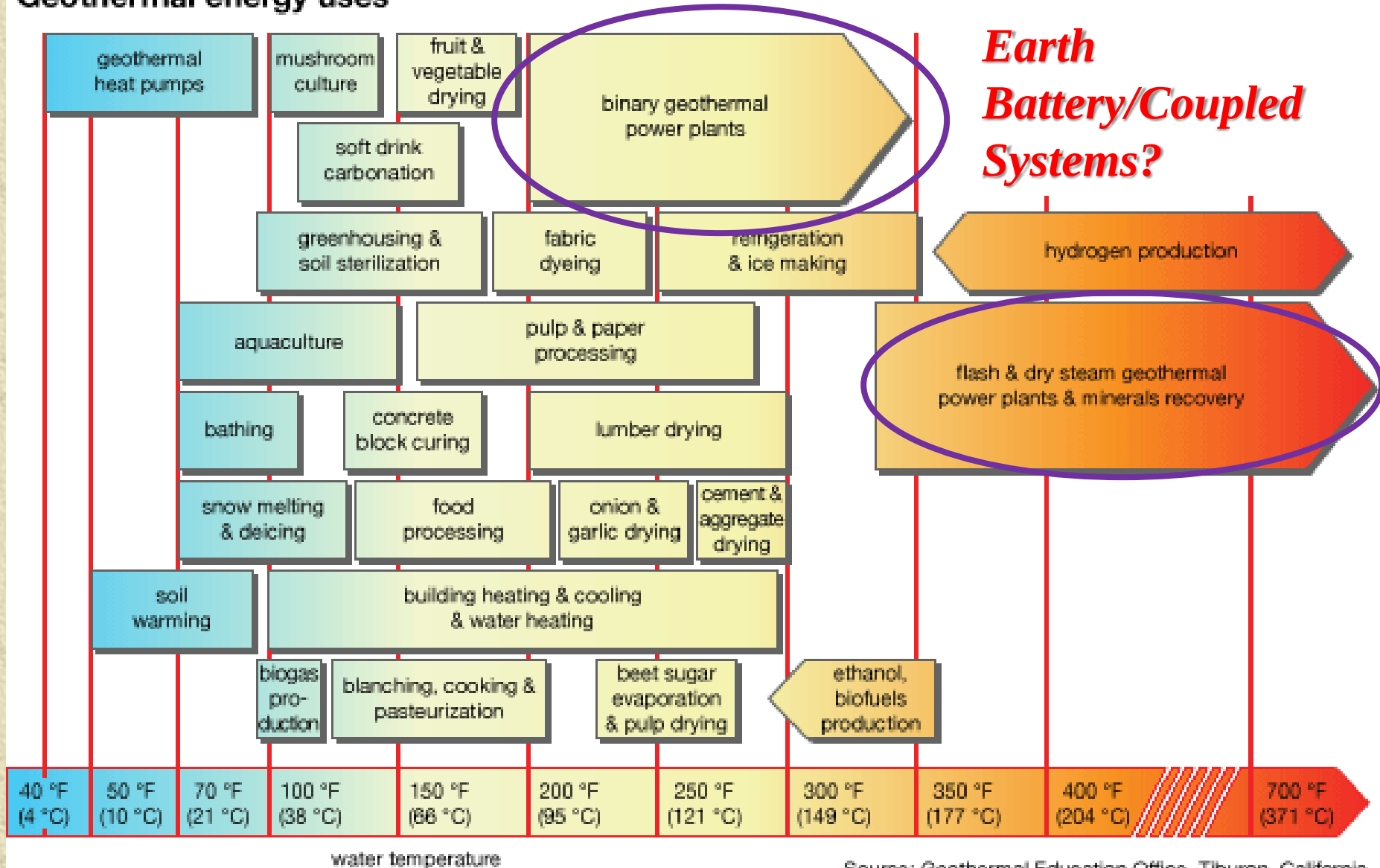
(Takam et al., 2021)

Earth Battery Comes Home



The Other Moving Parts

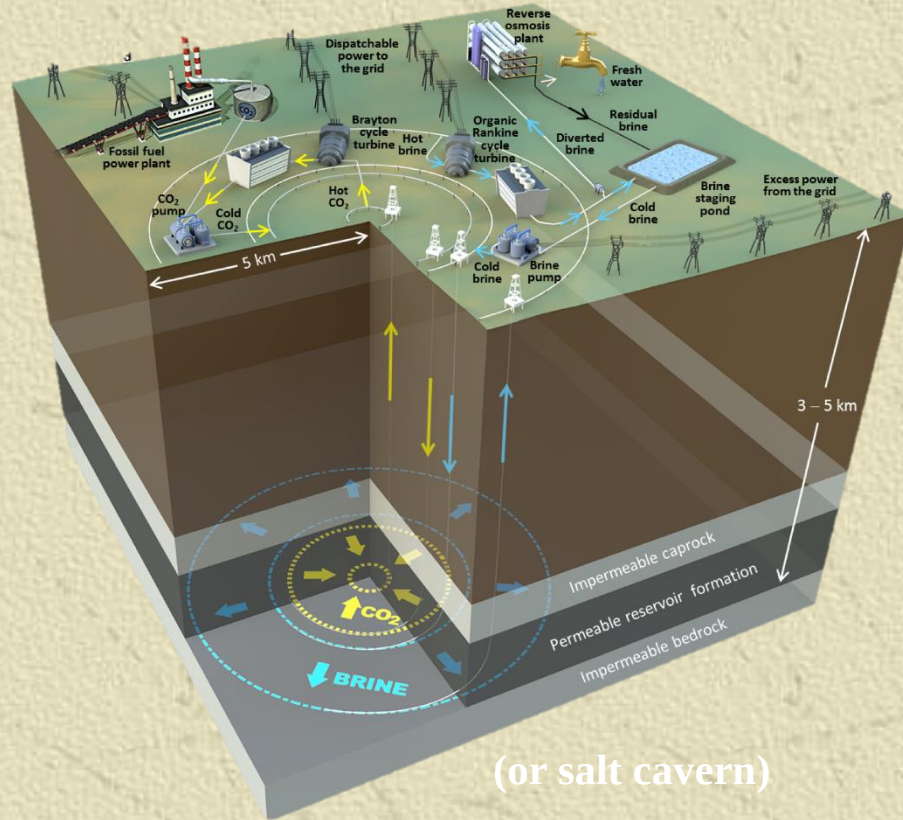
Geothermal energy uses



Source: Geothermal Education Office, Tiburon, California

Earth Battery

Incubator Workshop 2016



Energy Storage in Sedimentary Basin Geothermal Resources

August 15-16, 2016 |
Columbus, OH

*Jeff Bielicki and
Tom Buscheck*

CO₂-Geothermal Bulk Energy Storage System

Buscheck, T., Bielicki, J., et al. (2016). "Multi-Fluid Geo-Energy Systems: Using Geologic CO₂ Storage for Geothermal Energy Production and Grid-Scale Energy Storage in Sedimentary Basins." *Geosphere*, 12(3), 1-19.

Energy Sustainability Research Laboratory

Can We Get the Flow Rates?



Typical Injection well at about 100C

Earth Battery

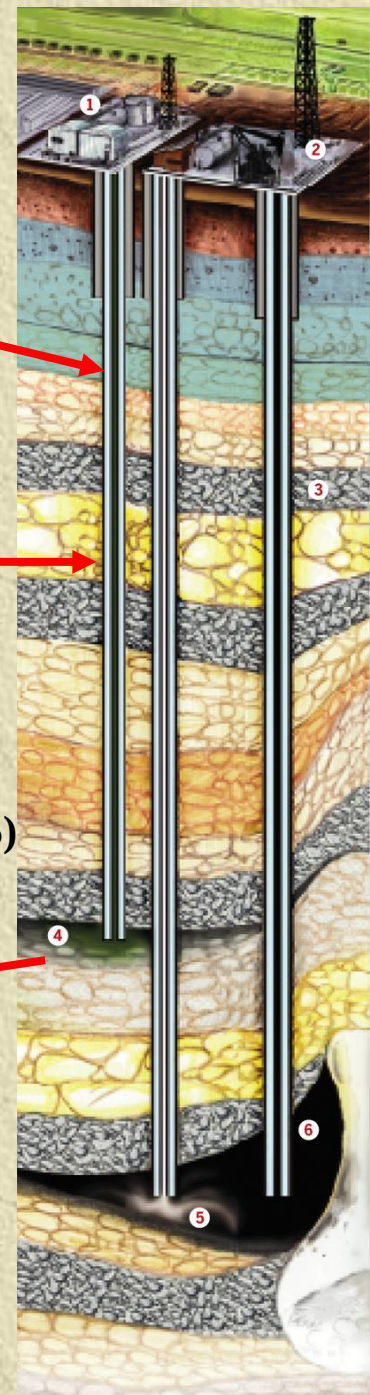
Economic Sedheat

0.5 barrels/sec at 150C

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



Power From the Battery



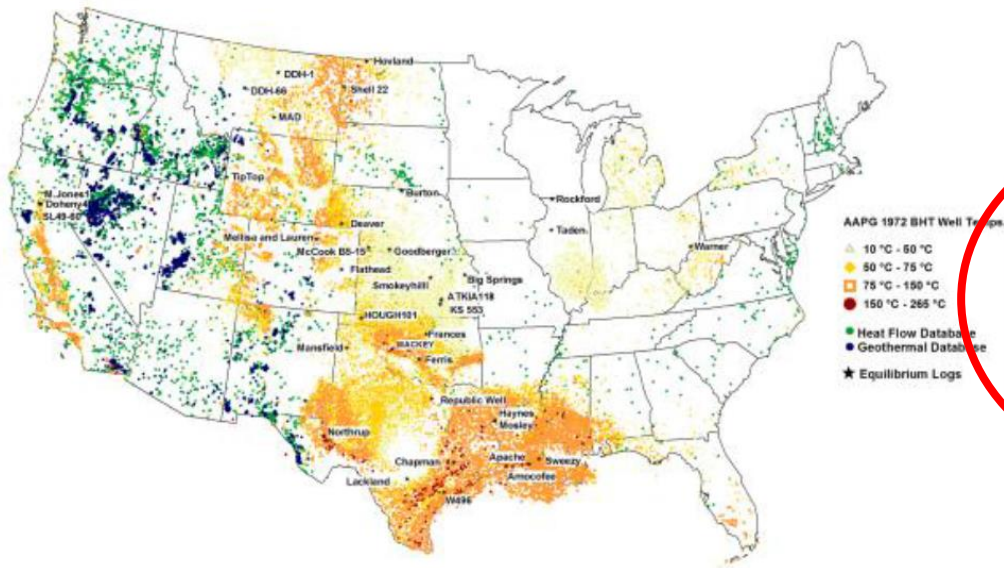
1. Disposal well 2. Enhanced oil recovery 3. Production well 4. Injected brine 5. Injected fluid 6. Oil

Solar Base Load!!



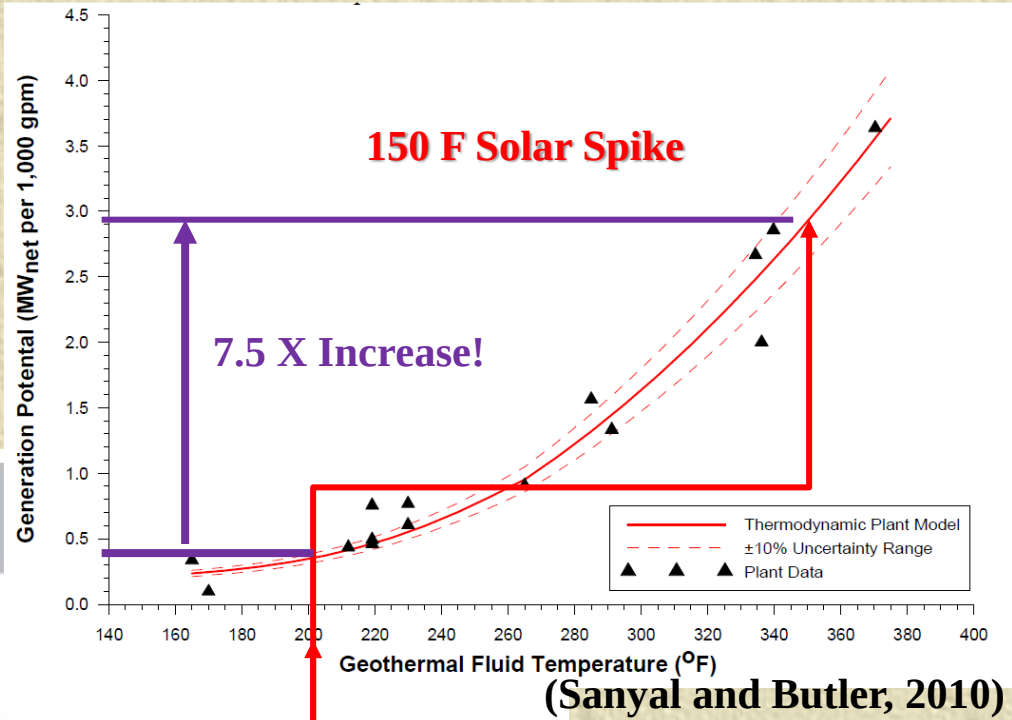
The Opportunity

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?

The Hybrid Model

Stillwater Plant, Fallon, NV



Solar Photovoltaic Plant

Geothermal Plant

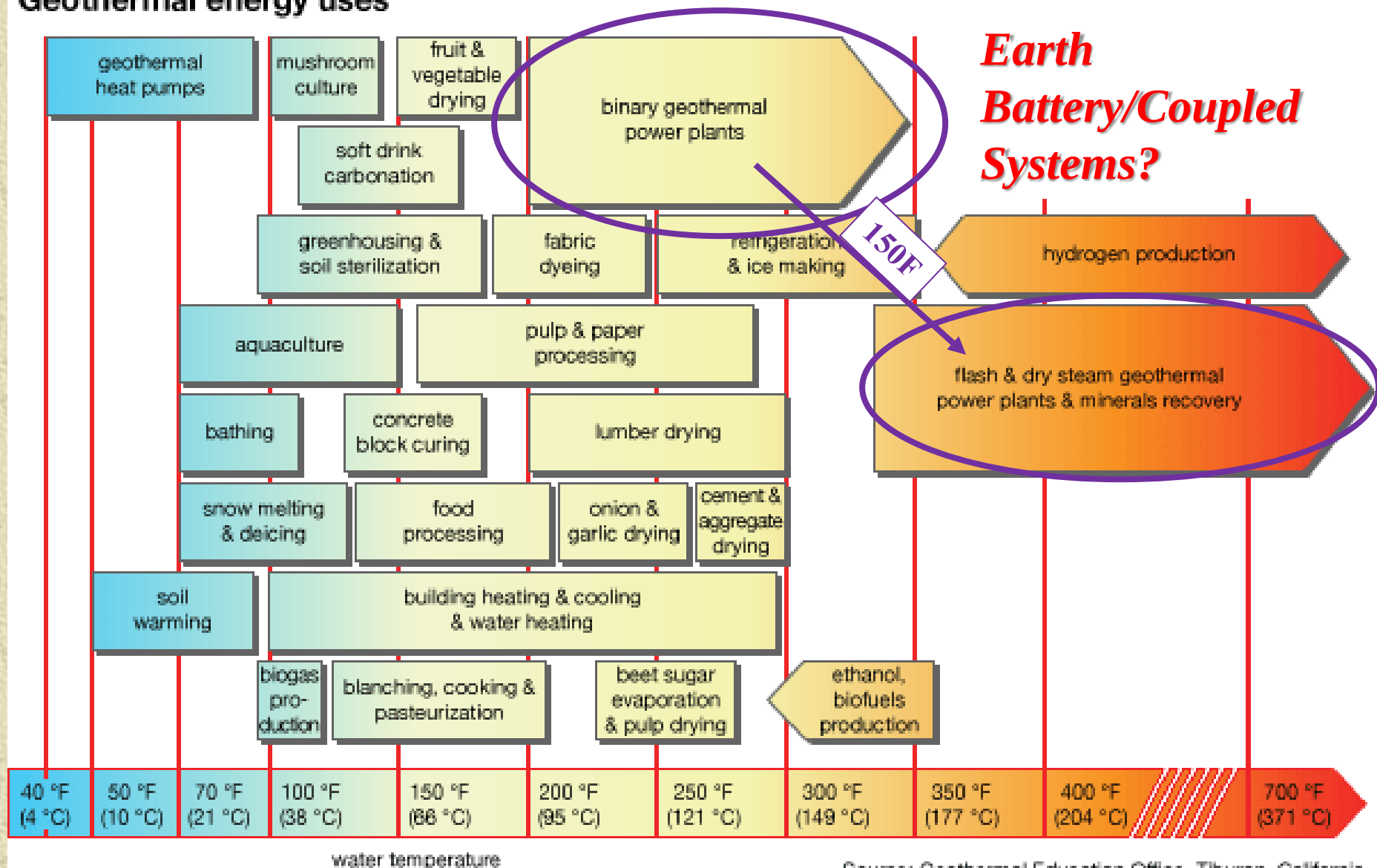
Thermal Solar Plant

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.

So Why Does Storage Matter?

Geothermal energy uses

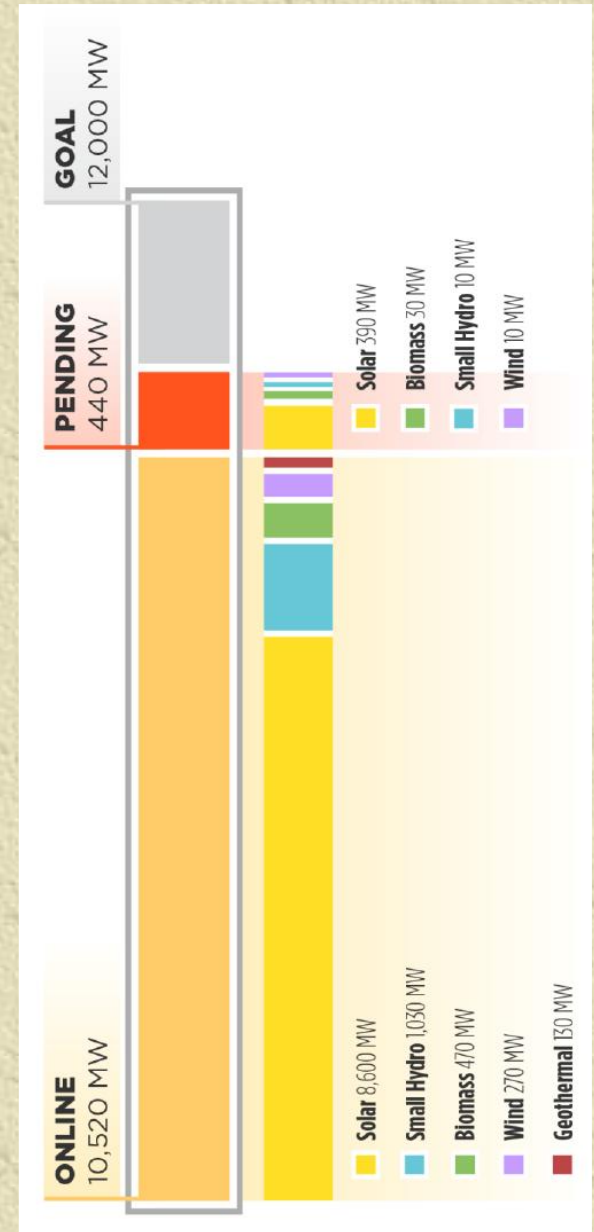
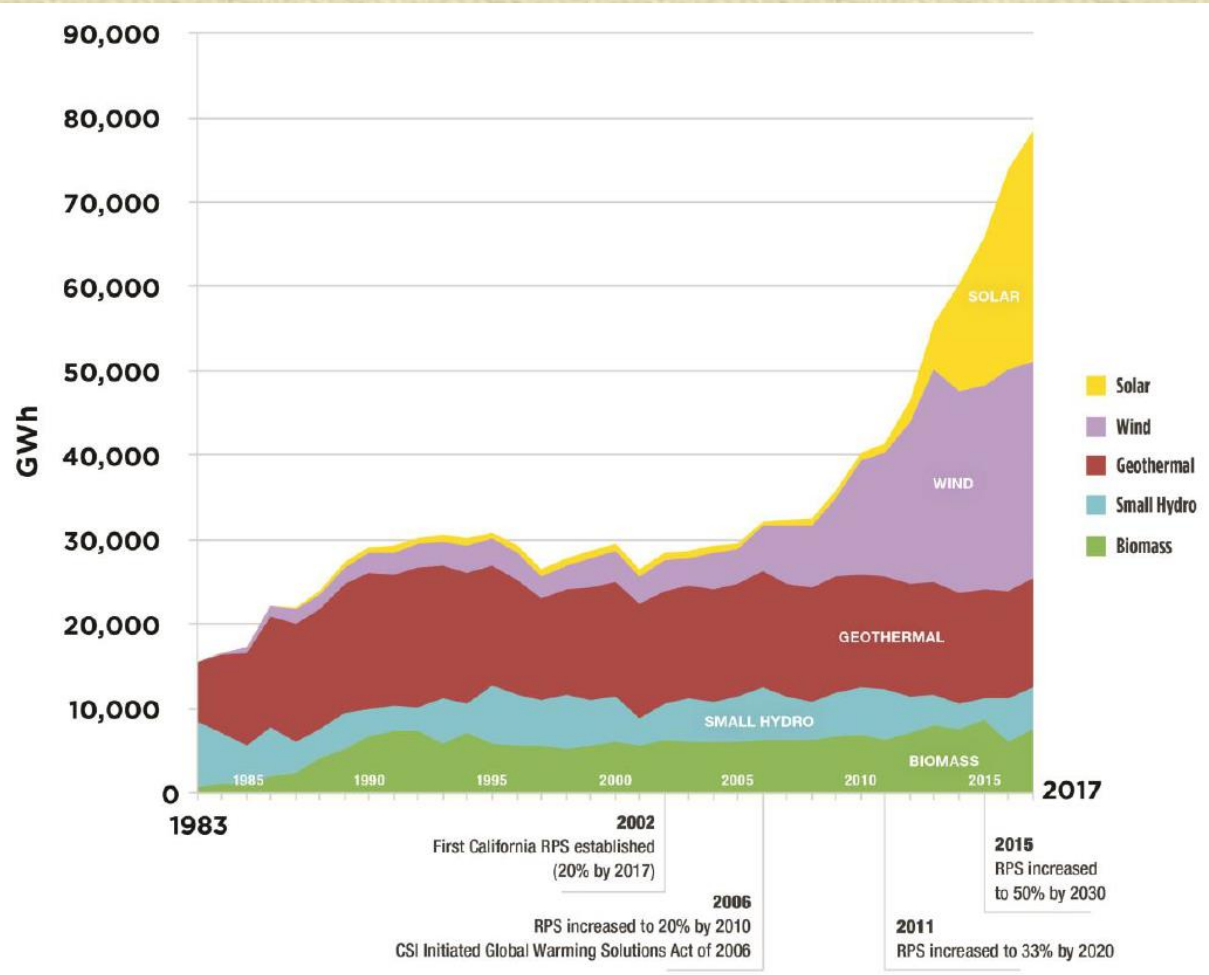


Source: Geothermal Education Office, Tiburon, California

So Why Does Storage Matter?

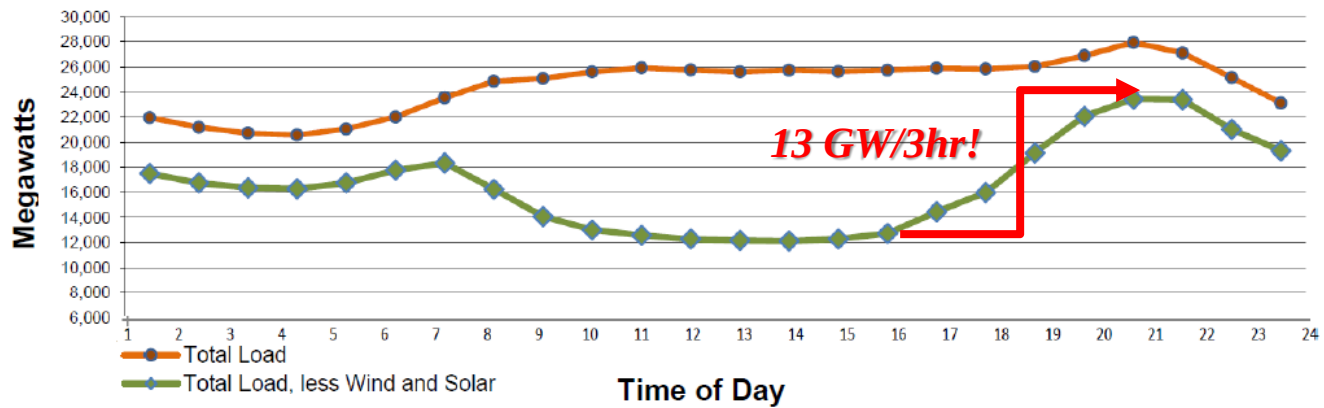
California Power

A Solar Wind With no Sign of Slowing



The “Duck” Dilemma

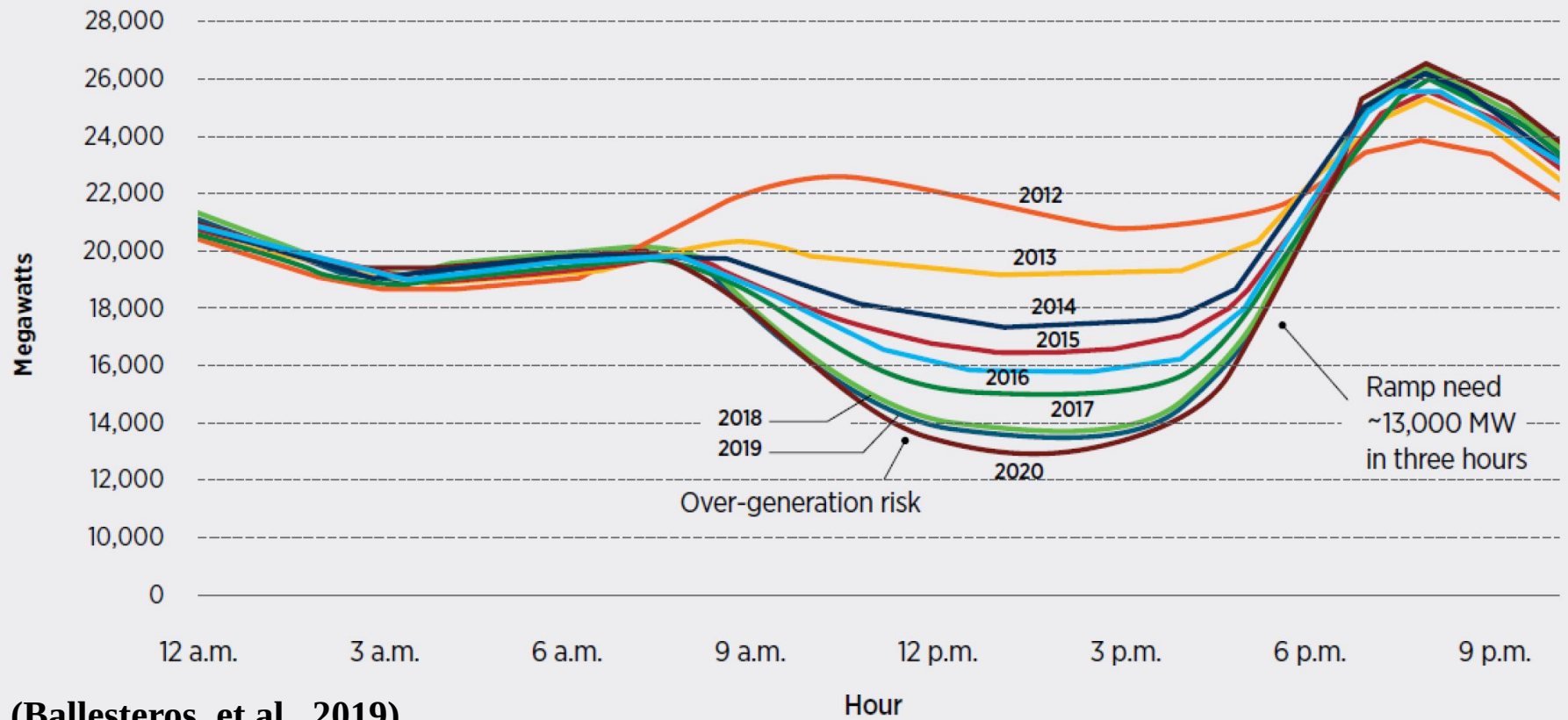
Figure 7: Average Hourly Net Load in California ISO on 5/16/17^{viii}



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



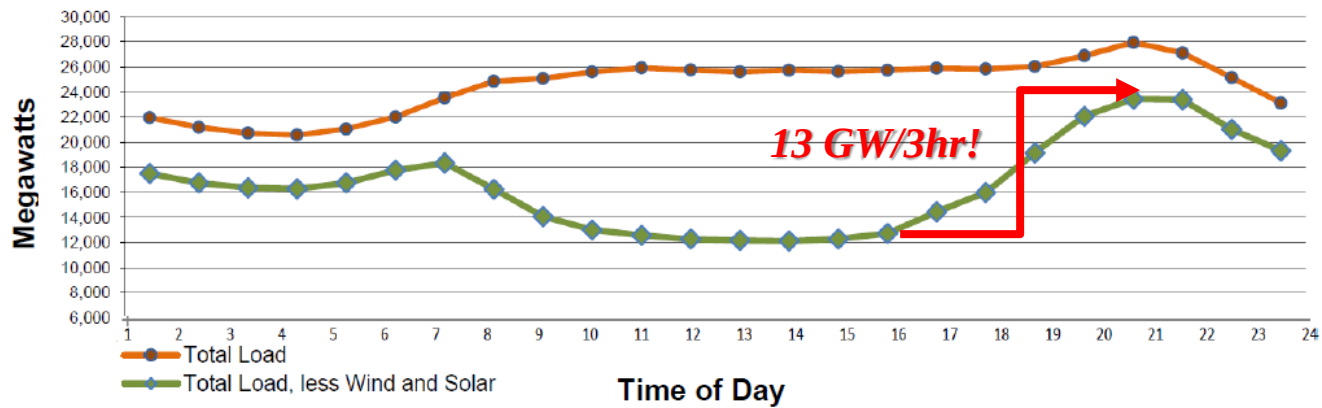
The “Duck” Dilemma



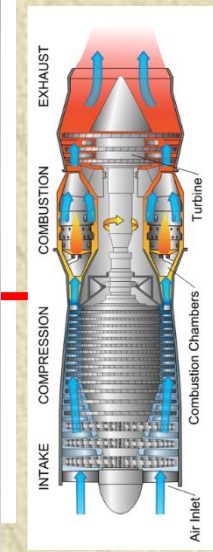
(Ballesteros, et al., 2019)

The “Duck” Dilemma

Figure 7: Average Hourly Net Load in California ISO on 5/16/17^{viii}

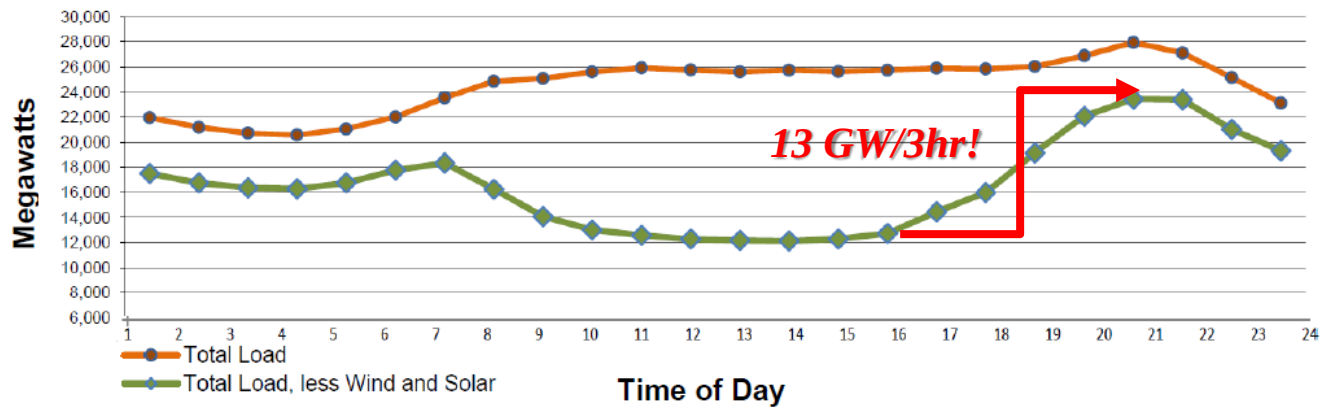


Source: http://content.caiso.com/green/renewrpt/20170516_DailyRenewablesWatch.pdf



The “Duck” Dilemma

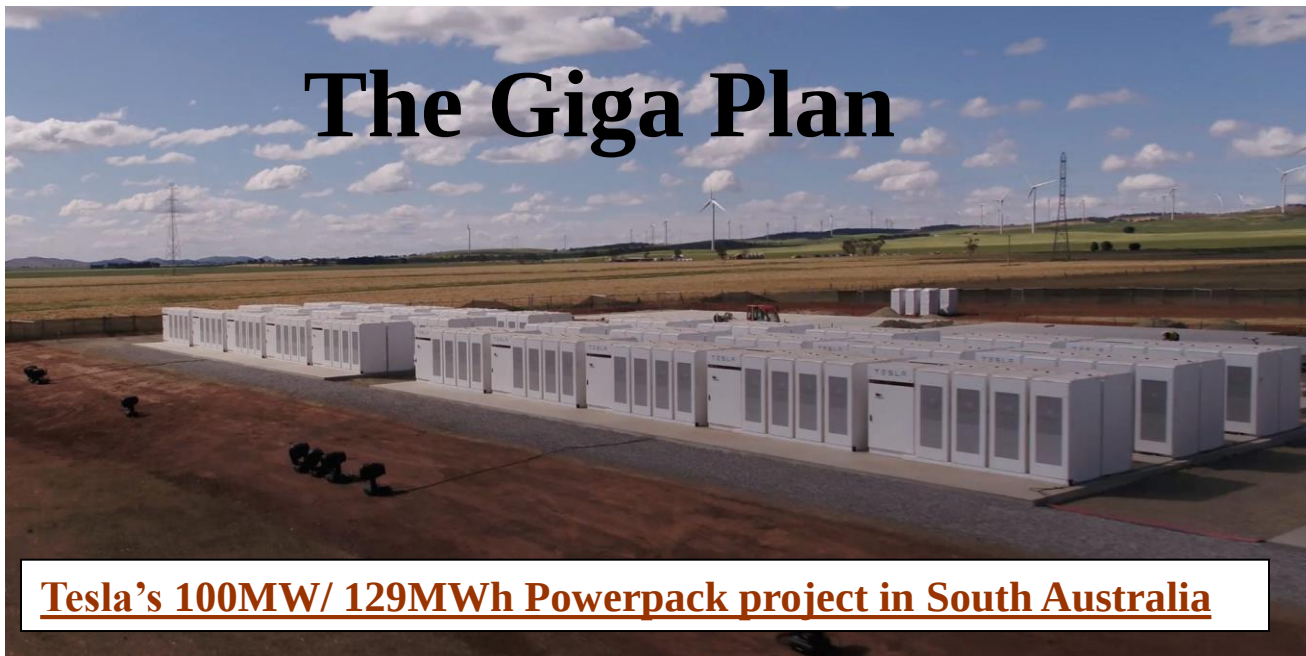
Figure 7: Average Hourly Net Load in California ISO on 5/16/17^{viii}



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

The Giga Plan

Megawatts



Tesla's 100MW/ 129MWh Powerpack project in South Australia

Can We Get the Flow Rates?



Typical Injection well at about 100C

Earth Battery

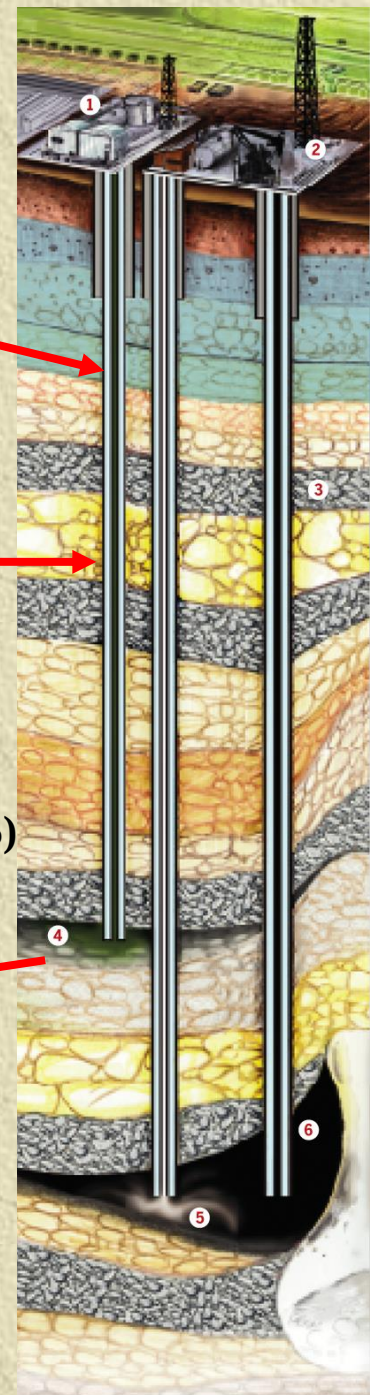
Economic Sedheat

0.5 barrels/sec at 150C

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Power From the Battery



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

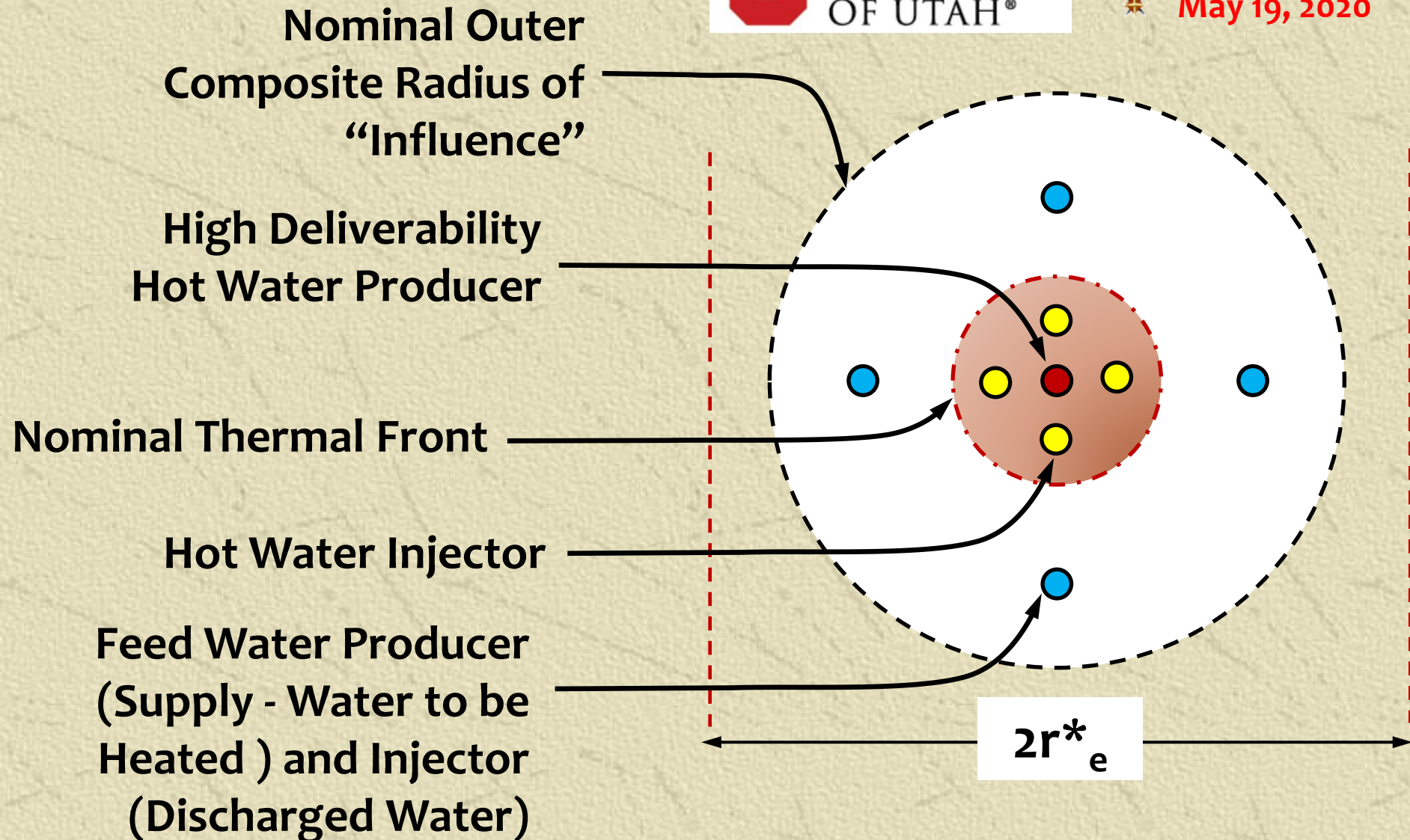
Solar Base Load!!

Schematic Storage-Production Unit



✧ John McLennan

✧ May 19, 2020



Operating Schedule and Boundary Condition

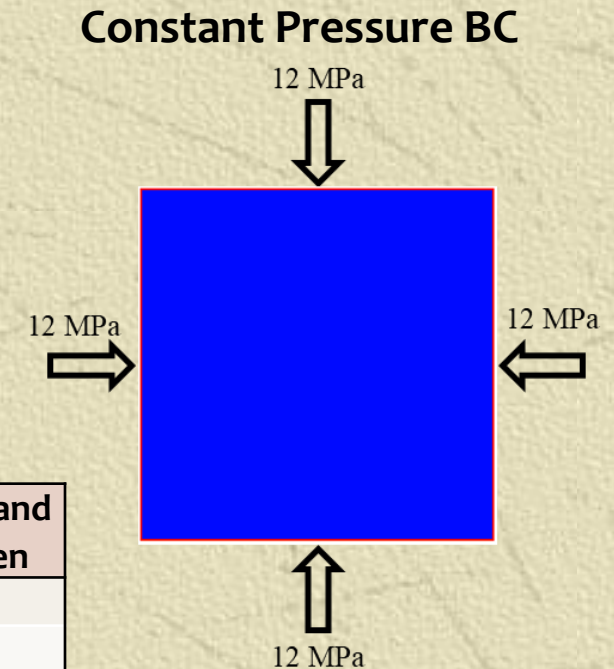
- Daily cycle (24 hrs.)

Injection 8 hr	Production 10 hr	Shut-In 6 hr
-------------------	---------------------	-----------------

Injection Rate = 40 kg/sec,
Total Injection in 8 hrs. = 1152 tonne

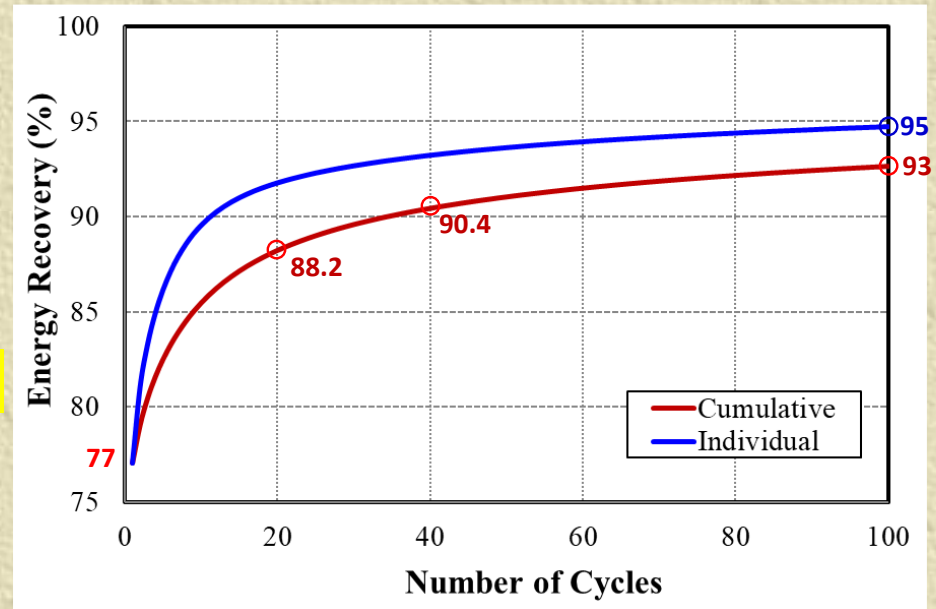
Production Rate = 32 kg/sec,
Total Production in 10 hrs. = 1152 tonne

Parameters	Formation	Overburden and Underburden
Specific Heat of Rock (J/(kg-K))	930	770
Thermal Conductivity (W/(m-K))	2.5	1.05
Density (kg/m ³)	2000	2500
Horizontal Permeability, k_x and k_y (mD)	100	0.0001
Porosity (%)	15	2.5
Initial Temperature (°C)	120	120
Initial Pressure (MPa)	12	12
Formation Thickness (m)	110	70



Effect of Number of Cycles

- Initially, energy recovery increases drastically and then increases slowly
- After 40 cycles, overall energy recovery increases asymptotically
- Energy recovery in an individual cycle reaches about 95% after ~ 100 cycles
- Mirrors Tsang et al., 1977 predictions
- Attractive Storage Medium



Can We Get the Flow Rates?

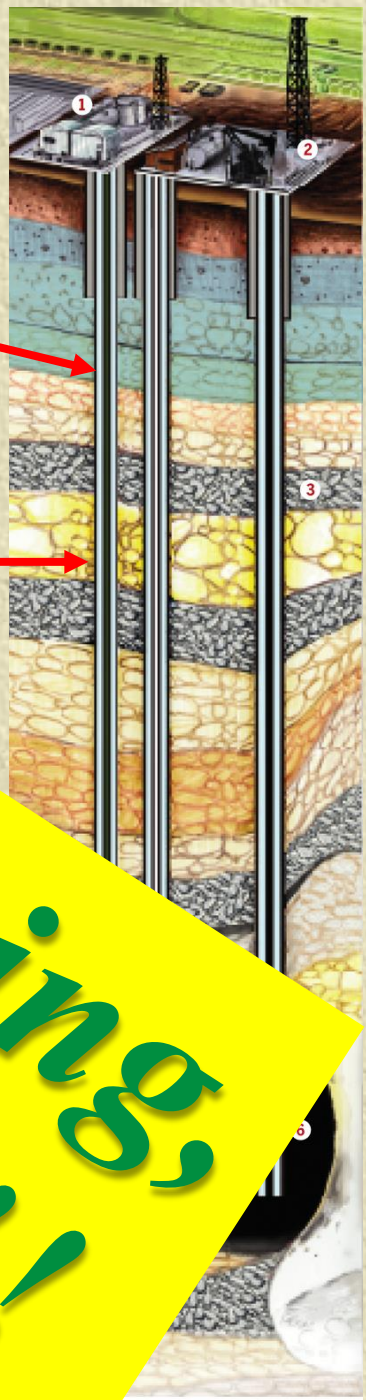
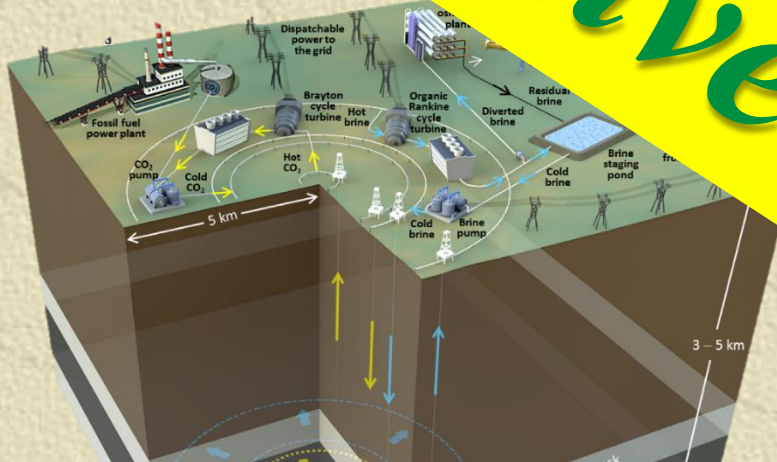
Our Green Opening,
Let's Give it a try!!!

Types

Earth Bats

100C

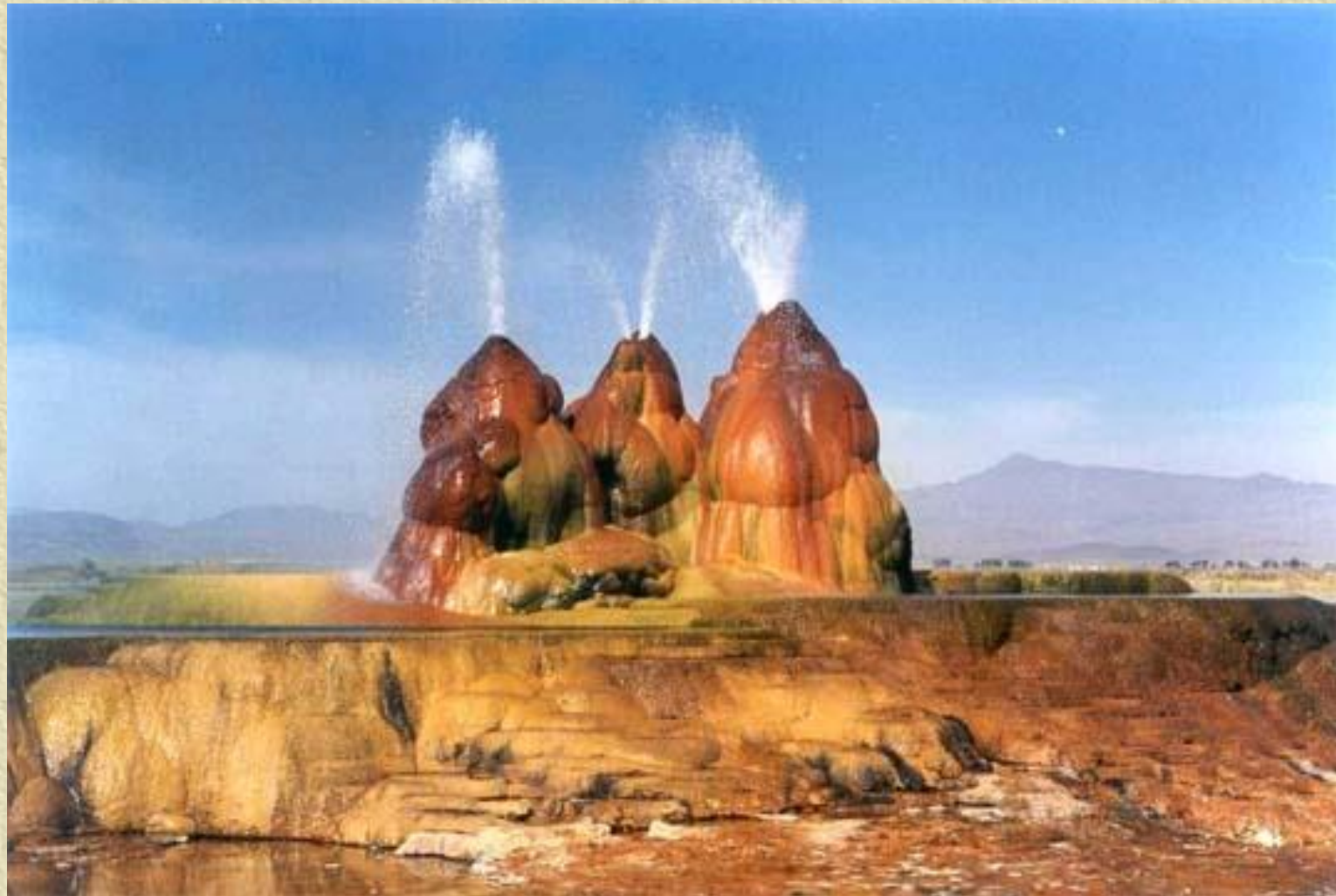
Spike It



Solar Base Load!!

2. Enhanced oil recovery 3. Production
4. Produced brine 5. Injected fluid 6. Oil

Thank you for your attention



C.O. Joe Moore

Texas H.B. 3576.

[https://urldefense.com/v3/https://legiscan.com/TX/bill/HB3576/2021;!!O2IDA!grA6c9cww5T0bbqLQhZuHVUXBoCJUohCb93Mx8Qnov72dxUIN9XFvM9uFI6JnURKVGxd\\$](https://urldefense.com/v3/https://legiscan.com/TX/bill/HB3576/2021;!!O2IDA!grA6c9cww5T0bbqLQhZuHVUXBoCJUohCb93Mx8Qnov72dxUIN9XFvM9uFI6JnURKVGxd$) .

2021-04-27

“...relating to the authority of the Railroad Commission of Texas to invest in private entities that explore for, develop, and produce geothermal energy and associated resources.”



Bill Text: TX HB3576 | 2021-2022 | 87th Legislature | Introduced Texas House Bill 3576

Bill Title: Relating to the authority of the Railroad Commission of Texas to invest in private entities that explore for, develop, and produce geothermal energy and associated resources.

Spectrum: Partisan Bill (Democrat 1-0)

Status: (Introduced) 2021-04-27 - Reported favorably as substituted [HB3576 Detail]

Download: Texas-2021-HB3576-Introduced.html

87R9416 JXC-D

By: Guerra

H.B. No. 3576

A BILL TO BE ENTITLED

AN ACT

relating to the authority of the Railroad Commission of Texas to invest in private entities that explore for, develop, and produce geothermal energy and associated resources.

BE IT ENACTED BY THE LEGISLATURE OF THE STATE OF TEXAS:

SECTION 1. Chapter 141, Natural Resources Code, is amended by adding Subchapter E to read as follows:

SUBCHAPTER E. GEOTHERMAL PUBLIC-PRIVATE PARTNERSHIPS

Sec. 141.151. DUTY OF THE RAILROAD COMMISSION. The commission shall establish a program to enter into partnerships with producers of geothermal energy and associated resources in this state to:

(1) encourage the production of geothermal energy and associated resources in this state; and

(2) earn a return on investment for the state.

Sec. 141.152. PROGRAM CRITERIA AND OPERATION. (a) The commission may enter into a partnership under this subchapter only with a producer of geothermal energy and associated resources that:

(1) has at least \$10 million in capital investment; and

(2) has its headquarters in this state.

(b) When the commission enters into a partnership with a producer under this subchapter, the commission may make a capital investment in the producer. The amount of the investment may not exceed the aggregate amount of the private capital investments made in the producer.

(c) The commission may make capital investments in