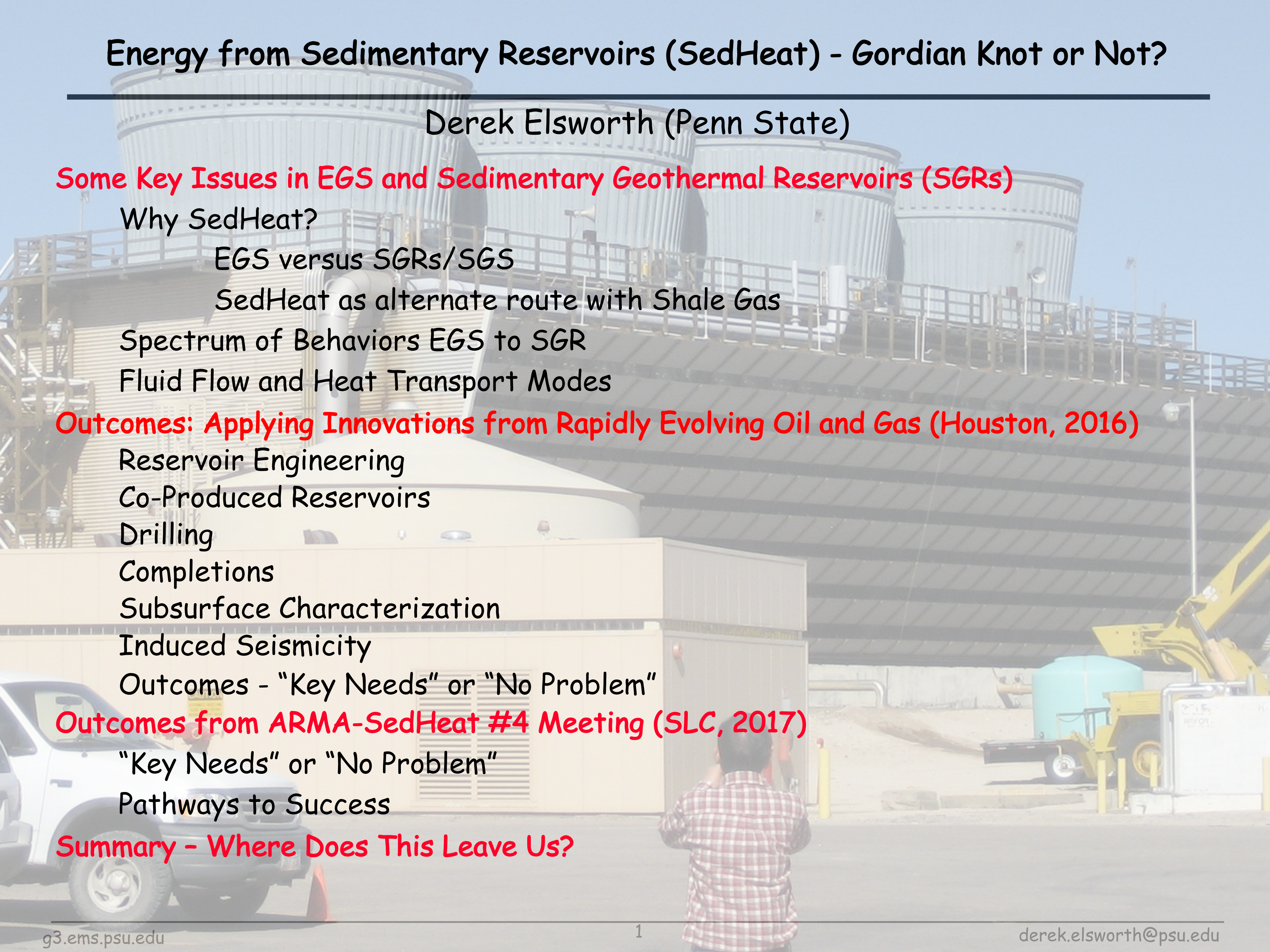


Energy from Sedimentary Reservoirs (SedHeat) - Gordian Knot or Not?

Derek Elsworth (Penn State)

Some Key Issues in EGS and Sedimentary Geothermal Reservoirs (SGRs)

- Why SedHeat?
  - EGS versus SGRs/SGS
  - SedHeat as alternate route with Shale Gas
- Spectrum of Behaviors EGS to SGR
- Fluid Flow and Heat Transport Modes

Outcomes: Applying Innovations from Rapidly Evolving Oil and Gas (Houston, 2016)

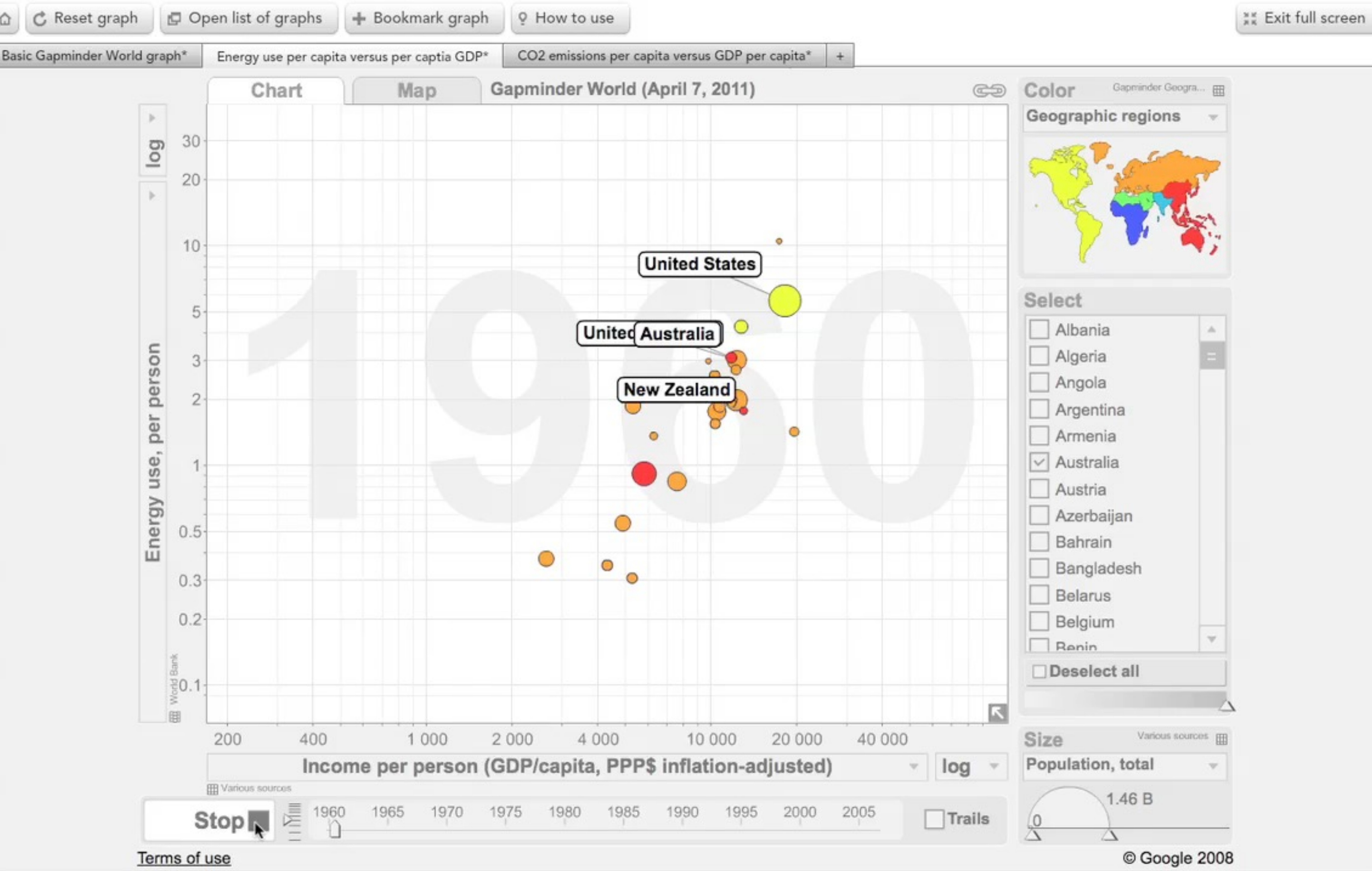
- Reservoir Engineering
- Co-Produced Reservoirs
- Drilling
- Completions
- Subsurface Characterization
- Induced Seismicity
- Outcomes - “Key Needs” or “No Problem”

Outcomes from ARMA-SedHeat #4 Meeting (SLC, 2017)

- “Key Needs” or “No Problem”
- Pathways to Success

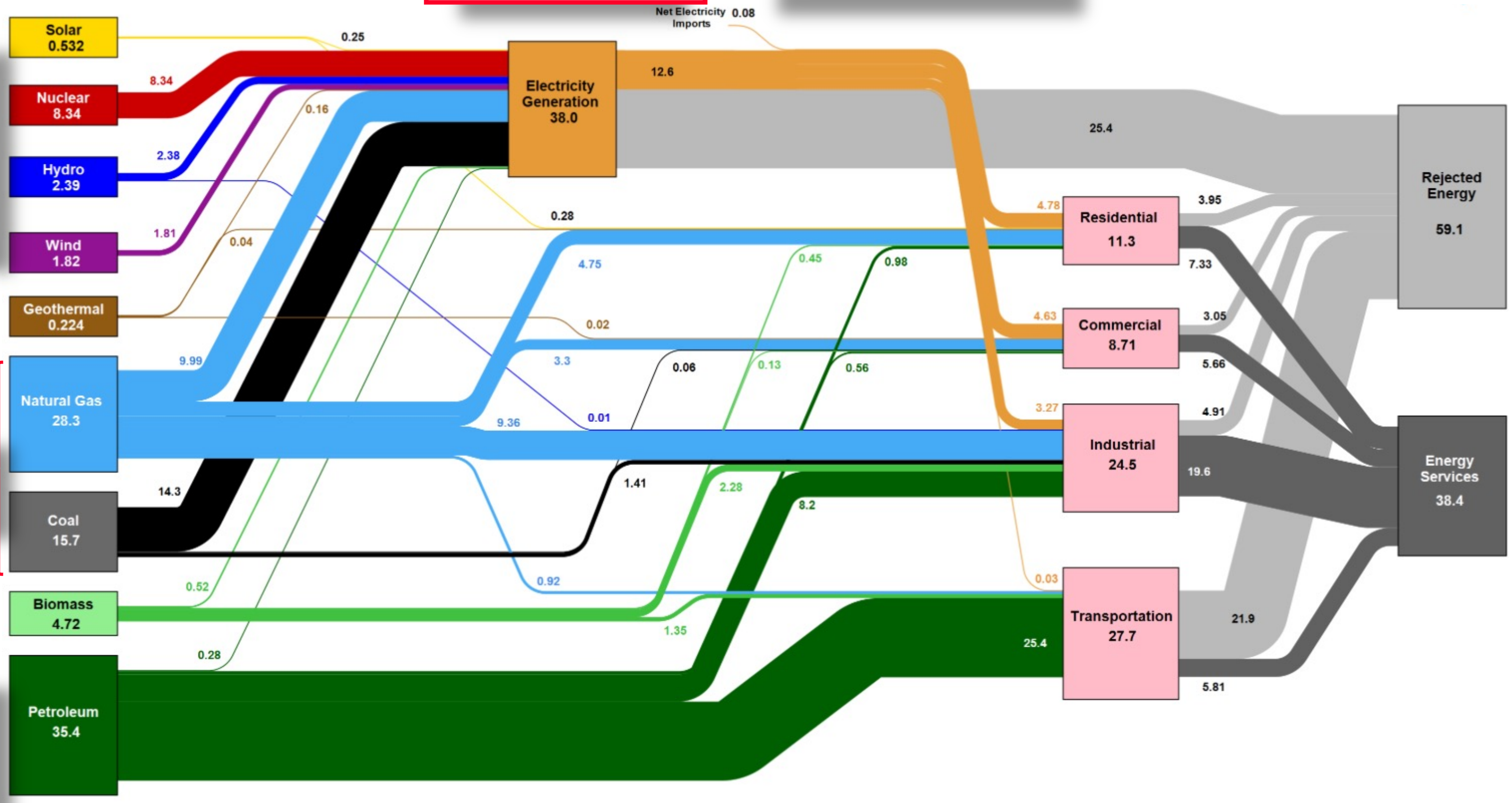
Summary – Where Does This Leave Us?

Energy & Environment: Complementary Drivers?



[Hans Rosling http://www.gapminder.org/]

US Energy Consumption 2015 – Key R&D Strategies
~100 Quads = 100 EJ = 100 tcf CH_4 (~20% of World)



Electric Energy Storage

Electricity Distribution

Zero-Emissions Net Energy Production

Fuel Switching

CCS

Fuel Switching

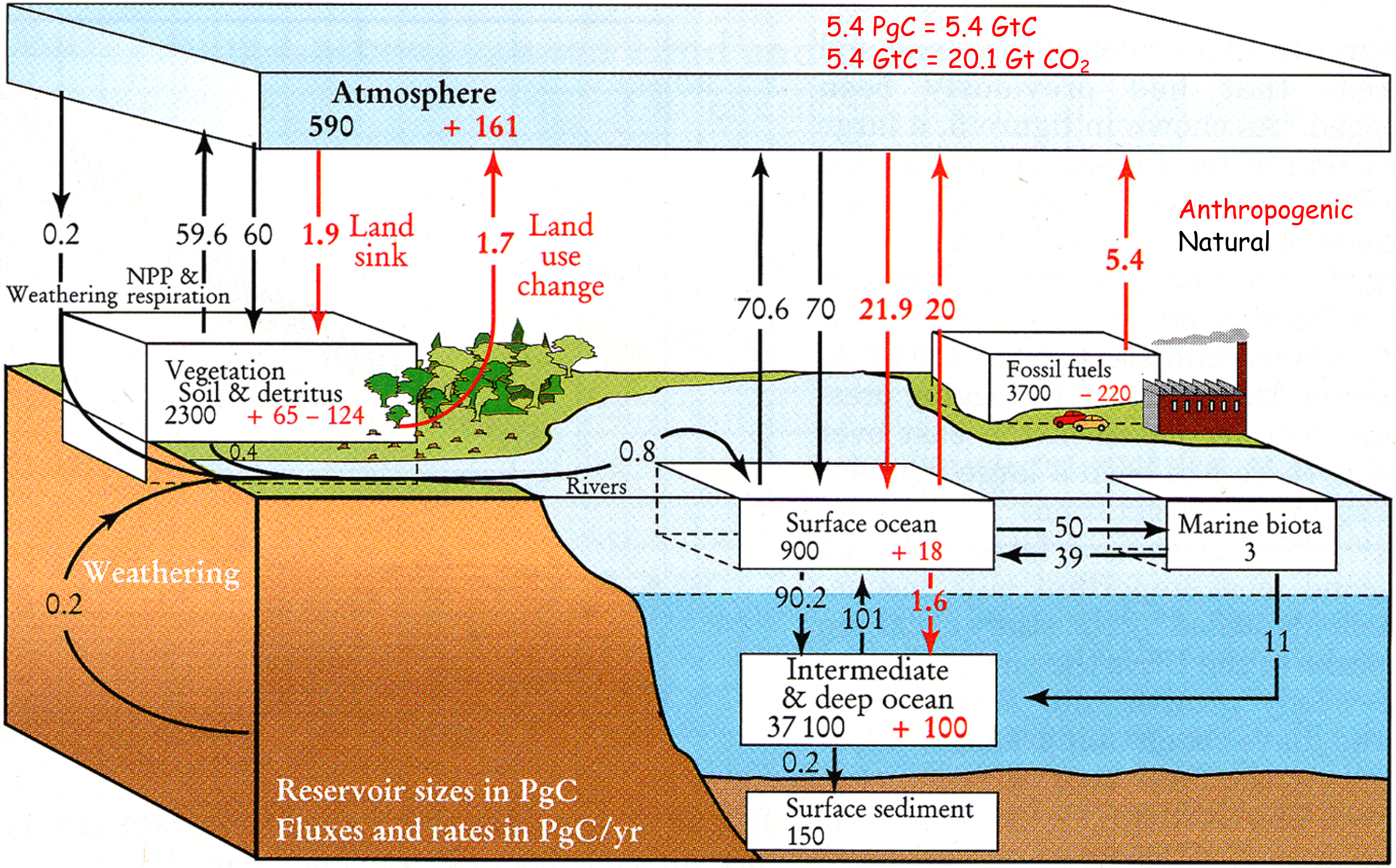
End-Use Efficiency

Conservation

Climate/Environmental Impacts

[After Pat Dehmer, US DOE, Office of Science, 2009; Sankey Diagram from LLNL]

Global Carbon Cycle



5.4 PgC = 5.4 GtC

5.4 GtC = 20.1 Gt CO_2

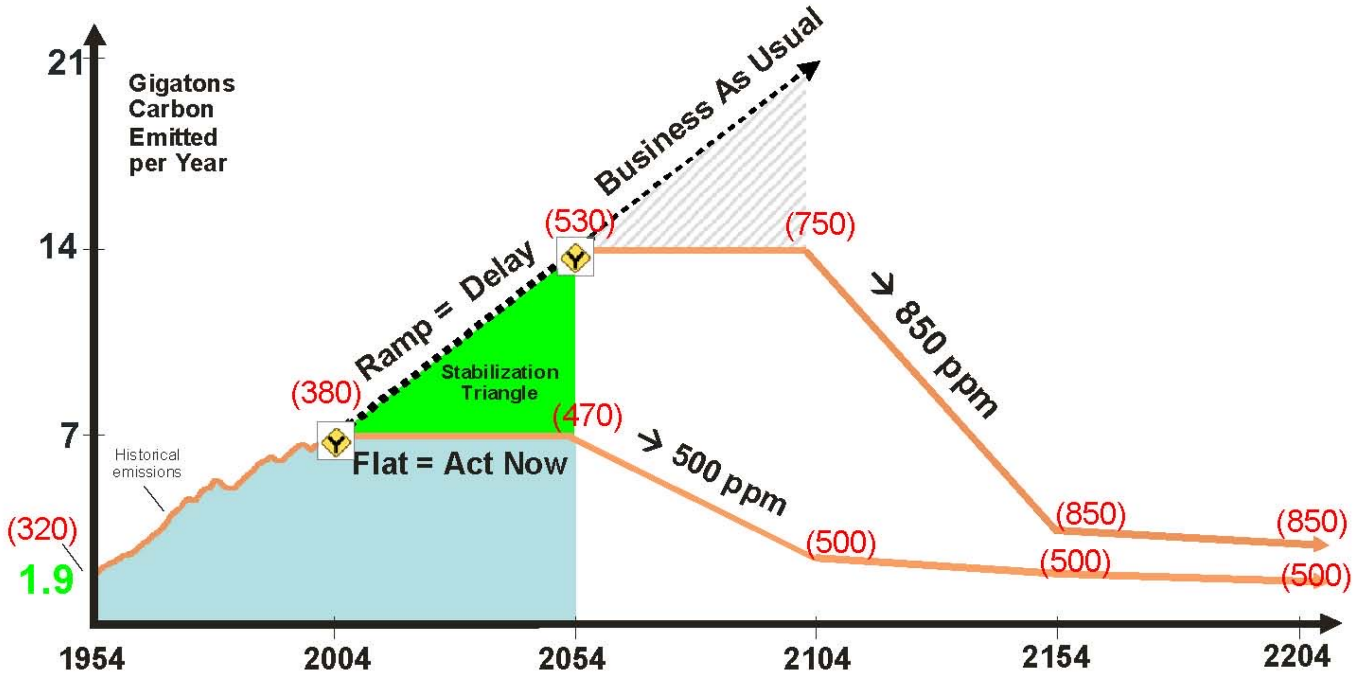
Anthropogenic

Natural

[Sarmiento and Gruber, *Physics Today*, 2002.]

Capacity Needs – Socolow Wedges

The Stabilization Triangle:
Beat doubling or accept tripling

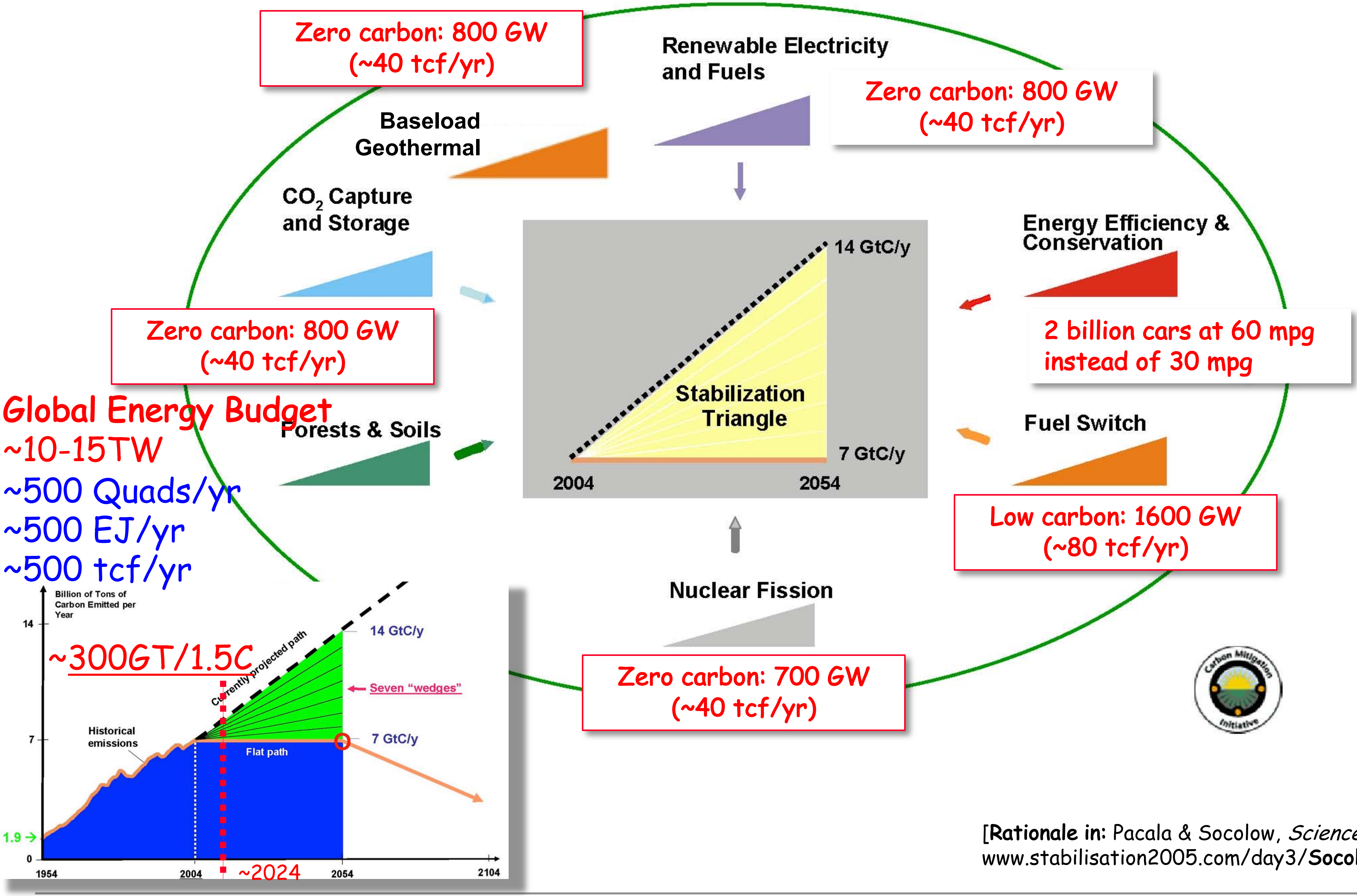


Values in parentheses are ppm. Note the identity (a fact about the size of the Earth's atmosphere): 1 ppm = 2.1 GtC.

[**Rationale in:** Pacala & Socolow, *Science*, 2004, www.stabilisation2005.com/day3/**Socolow**.pdf]

Capacity Needs – Stabilization Wedges

Fill the Stabilization Triangle with Seven Wedges



Zero carbon: 800 GW
(~40 tcf/yr)

Zero carbon: 800 GW
(~40 tcf/yr)

Zero carbon: 800 GW
(~40 tcf/yr)

2 billion cars at 60 mpg
instead of 30 mpg

Low carbon: 1600 GW
(~80 tcf/yr)

Zero carbon: 700 GW
(~40 tcf/yr)

Global Energy Budget
~10-15TW
~500 Quads/yr
~500 EJ/yr
~500 tcf/yr

[**Rationale in:** Pacala & Socolow, *Science*, 2004,
www.stabilisation2005.com/day3/**Socolow**.pdf]

Close-Out Editorial on 2008-2016 US Administration

Observations:

GHG dropped/flat on 4 occasions:

1980s, 1992, 2009 (recessions)

2014 (growth)

Electricity from Gas:

21% 2008

33% 2015

Employment:

~2.2M Energy efficiency jobs

~1.1M Fossil fuel for electricity

GapMinder Linkage:

US Energy use 2.5% less in 2015 vs 2008 but economy 10% larger

[Obama, Science, 2017]

INSIGHTS

POLICY FORUM

CLIMATE AND ENERGY

The irreversible momentum of clean energy

Private-sector efforts help drive decoupling of emissions and economic growth

By **Barack Obama**

The release of carbon dioxide (CO_2) and other greenhouse gases (GHGs) due to human activity is increasing global average surface air temperatures, disrupting weather patterns, and acidifying the ocean (*1*). Left unchecked, the continued growth of GHG emissions could cause global average temperatures to increase by another 4°C or more by 2100 and by 1.5 to 2 times as much in many midcontinent and far northern locations (*1*). Although our understanding of the impacts of climate change is increasingly and disturbingly clear, there is still debate about the proper course for U.S. policy—a debate that is very much on display during the current presidential transition. But putting near-term politics aside, the mounting economic

President of the United States, Washington, DC 20500, USA. Email: press@who.eop.gov. After 20 January 2017: contact@obamaoffice44.org

PHOTO: JEREMY WOODHOUSE/GETTY IMAGES

The New Normal?

THE CARBON HARVEST

Vast bioenergy plantations could suck up carbon and stave off climate change. They would also radically reshape the planet

By **Julia Rosen**

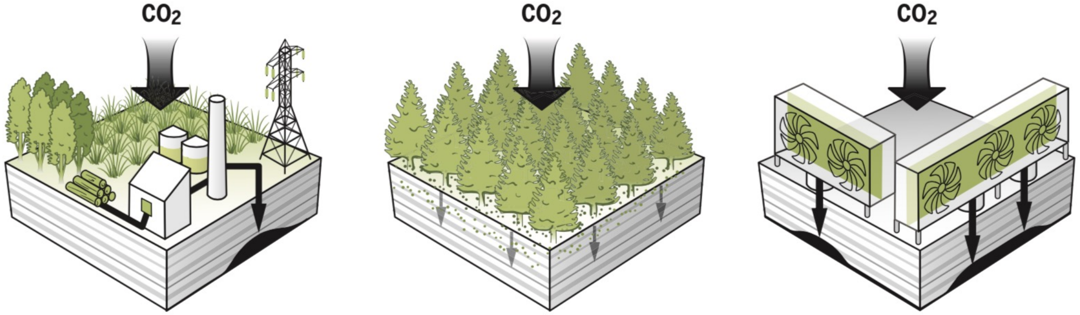
A poplar tree farm in Oregon is a fast-growing bioenergy source.

PHOTO: SEAN BAGSHAW/GETTY IMAGES

On a sunny day this past October, three dozen people file into a modest, mint-green classroom at Montana State University (MSU) in Bozeman to glimpse a vision of the future. Some are scientists, but most are people with some connection to the land: extension agents who work with farmers, and environmentalists representing organizations such as The Nature Conservancy. They all know that climate change will reshape the region in the coming decades, but that's not what they've come to discuss. They are here to talk about the equally profound impacts of trying to stop it.

Paul Stoy, an ecologist at MSU, paces in front of whiteboards in a powder blue shirt and jeans as he describes how a landscape already dominated by agriculture could be transformed yet again by a different green revolution: vast plantations of crops, sown to sop up carbon dioxide (CO_2) from the sky. "We have this new energy economy that's necessary to avoid dangerous climate

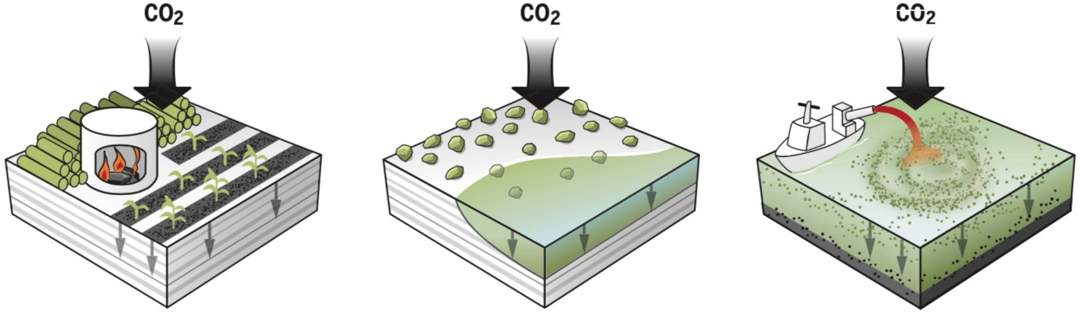
Six ways to pull CO_2 out of the air



BECCS
Fast-growing plants are harvested and burned to make energy. Exhaust carbon is captured and piped underground.

Forestation
Planted trees capture CO_2 as they grow. The carbon remains sequestered as long as forests are not cut down.

Direct air capture
CO_2 in air selectively "sticks" to chemicals in filters. Filters are reused after releasing pure CO_2, which can be stored underground.

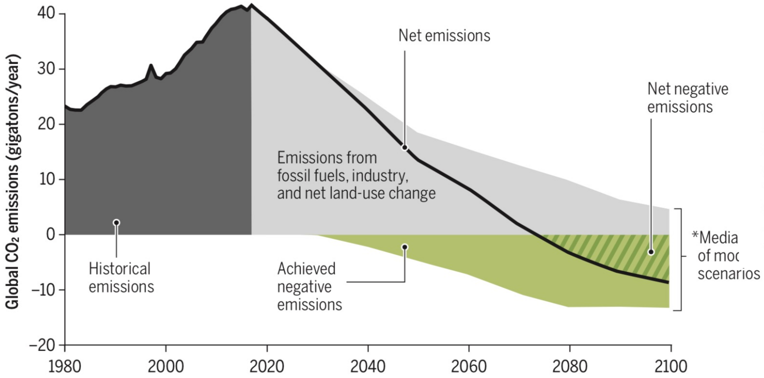


Biochar and soil sequestration
Charring biomass stores carbon in soil by making it resistant to decomposition. Altered tilling practices also enhance CO_2 storage.

Enhanced weathering
When spread across fields or beaches and wetted, crushed silicate minerals like olivine naturally absorb CO_2.

Ocean fertilization
Injections of nutrients like iron spur phytoplankton blooms, which absorb CO_2. When they die, they take the carbon to the sea floor.

A global unwinding
In order to prevent the world from warming more than 2°C, models count on the fast development of NETs. But many scientists question whether they can be scaled up in time.

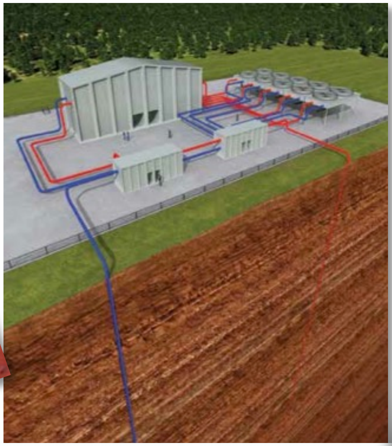


Sedimentary Geothermal Reservoirs (SGRs)

TRACKING AN ENERGY ELEPHANT

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

NSF-SEES WORKSHOP REPORT



PENROSE CONFERENCE

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

October 19 – 23, 2013, Newpark Hotel, Park City Utah

SedHeat was created to provide a central exchange of information and an opportunity to link researchers with common goals for a common purpose. It provides a place to foster training, mentor emerging scholars and a venue to present and exchange ideas. Our purpose is to build and sustain a diverse and interdisciplinary network of researchers who are focused on addressing the basic science, engineering and educational challenges for sustainable geothermal energy development from sedimentary basins.

WHAT WE DO

Our intention is to continually grow as a network, as well as attract new parties interested in the topic of sedimentary-basin geothermal energy.

- Steering Committee
- RCN Members
- Grant Programs
- Join RCN
- Workshops & Meetings
- Travel Grants

RESEARCH COORDINATION NETWORK

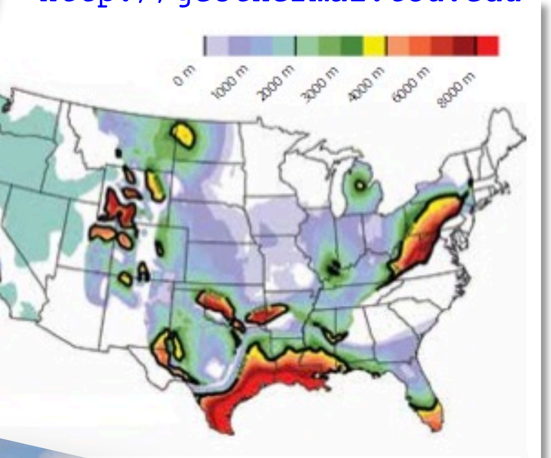
The Research Coordination Network (RCN) provides a central location for members to exchange information, the opportunity to link with researchers of common goals for common purposes, and build a research community for geothermal energy from sedimentary basins.

HOW WE DO IT

SedHeat provides information and opportunities to participate in grant programs, workshops, meetings, conferences, educational and student opportunities

SedHeat Initiative

http://geothermal.tcu.edu



…ediment thickness in the conterminous … Basin and Range basins … et al., 2006)

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

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

armasymposium.org/workshops - Information

armasymposium.org/registration - Registration

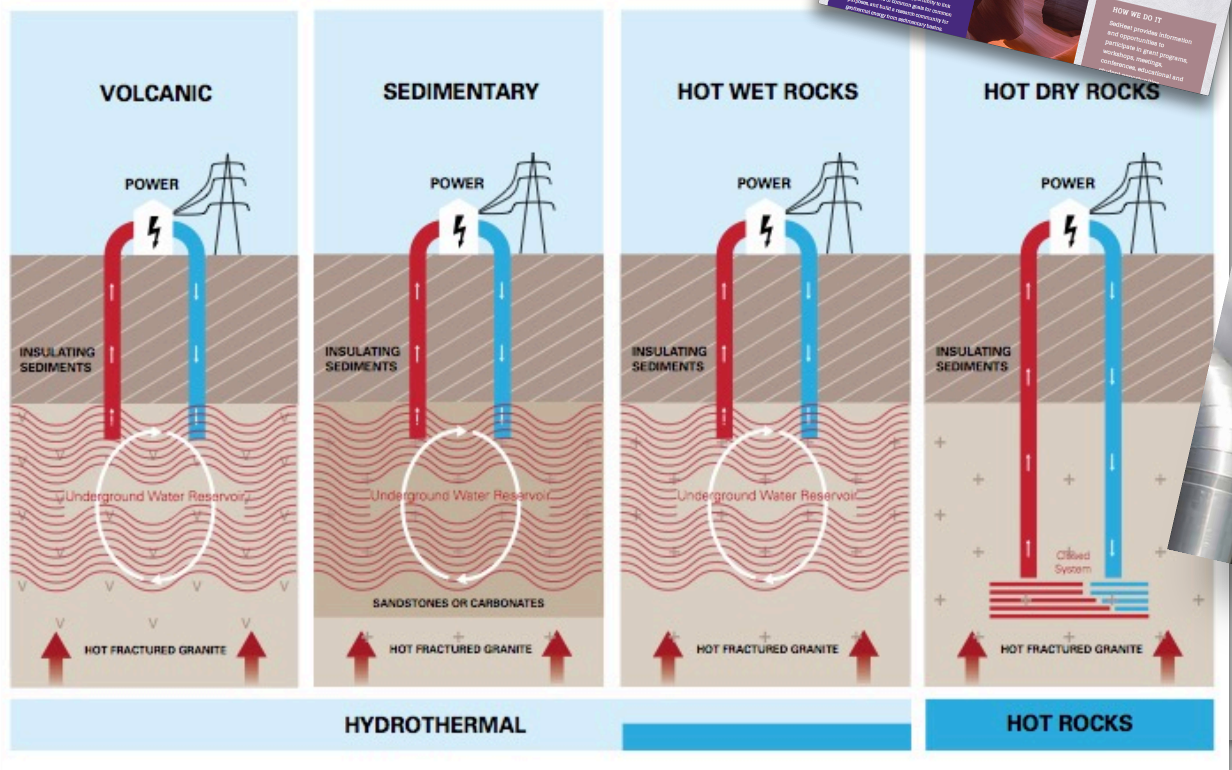
This workshop will explore the impediments to making sedimentary geothermal reservoirs a commercial reality and in particular will examine the potential to leverage new practices and techniques evolving from subsurface engineering in low permeability and environmentally challenging environments – such as for shale gas and for geothermal energy.

Topical Areas

Reservoir Engineering at Large Scale
Geopressured Resources/Co-Produced Reservoirs
Drilling
Completions
Geophysical Characterization
Induced Seismicity
Education/Cyberinfrastructure

For information on available discussion and speaking opportunities, please contact: elsworth@psu.edu

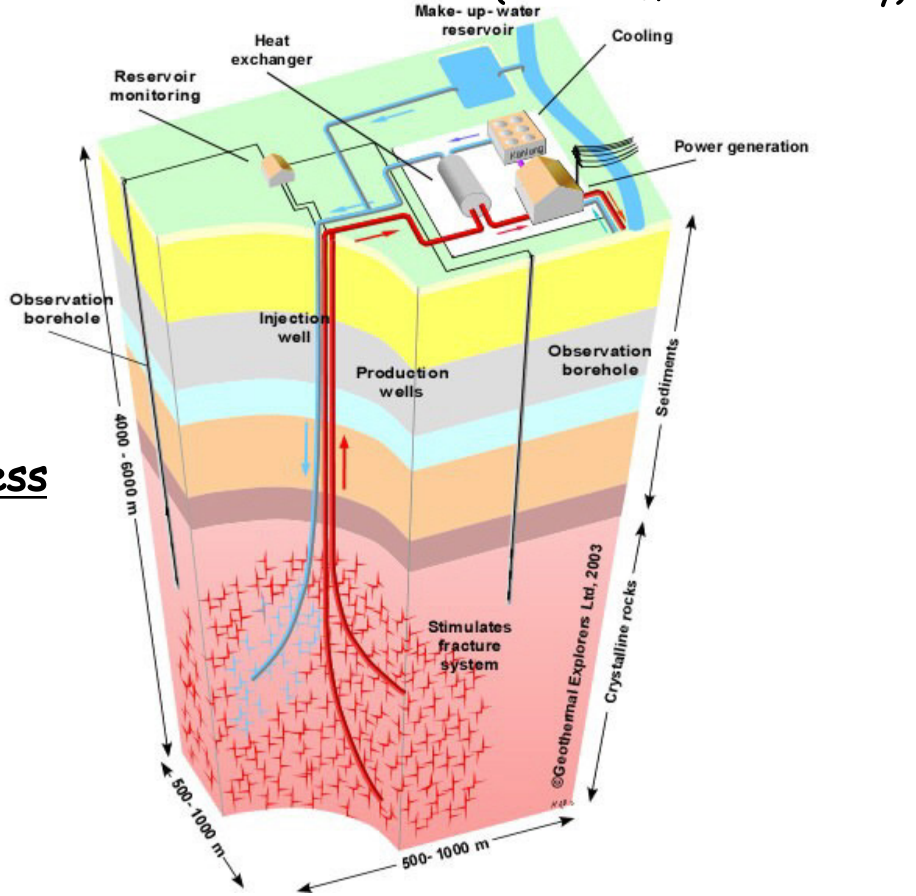
Figure 2: Average temperature at 4.5 km, contermin… …ted States. (Tester, et al., 2006, after Blackwell and Richards, 2004)



Basic Observations of Permeability Evolution and IS

Challenges
- Prospecting (characterization)
- Accessing (drilling)
- Creating reservoir
- Sustaining reservoir
- Environmental issues

Resource
- Hydrothermal (US:10^4 EJ)
- EGS (US:10^7 EJ; 100 GW in 50y)

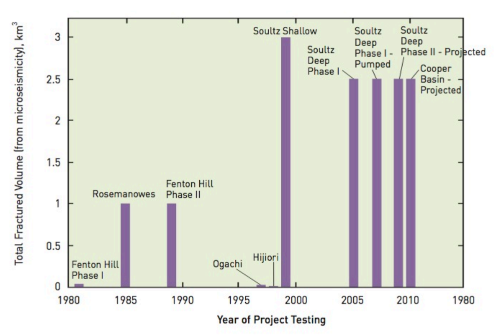


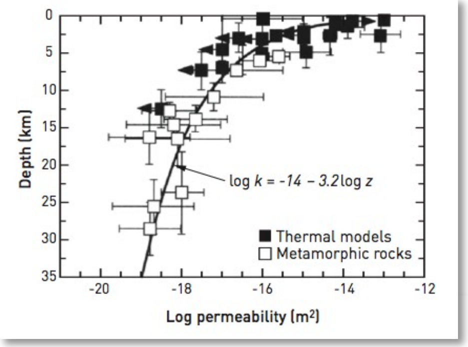
Observation
- Stress-sensitive reservoirs
- T H M C all influence via effective stress
- Effective stresses influence
  - Permeability
  - Reactive surface area
  - Induced seismicity

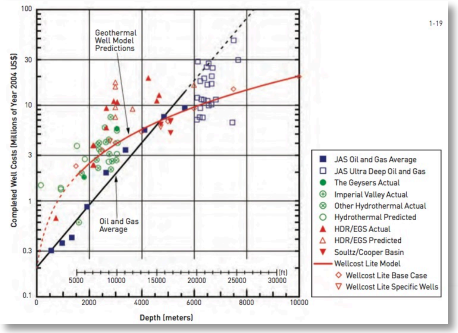
Understanding T H M C is key:
- Size of relative effects of THMC(B)
- Timing of effects
- Migration within reservoir
- Using them to engineer the reservoir

{ Permeability
Reactive surface area
Induced seismicity

Can EGS ever be Viable?

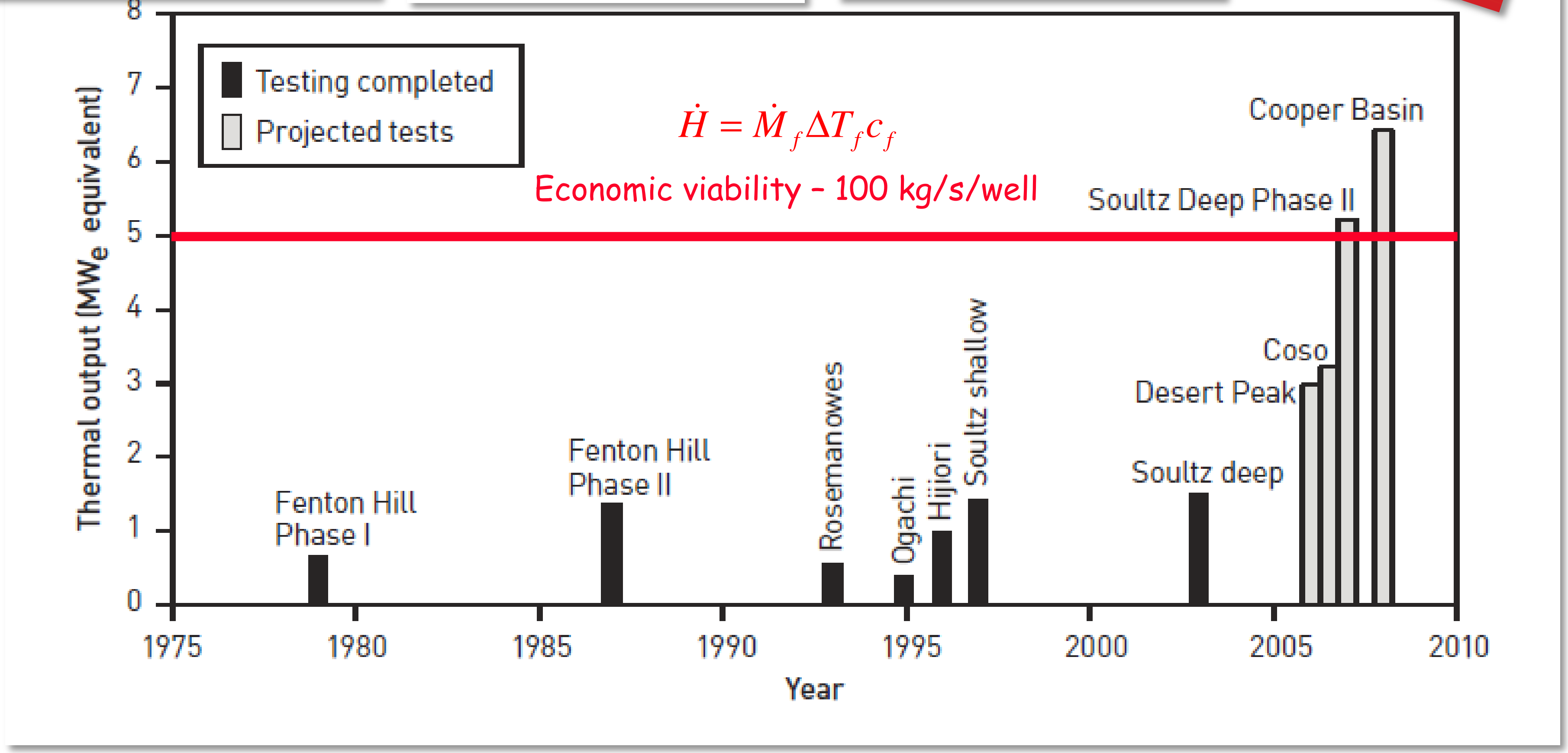







The Future of Geothermal Energy

Impact of Enhanced Geothermal Systems (EGS) on the United States in the 21st Century



$$\dot{H} = \dot{M}_f \Delta T_f c_f$$

Economic viability – 100 kg/s/well

Induced Seismicity

The New York Times

Quake Fears Stall Energy Extraction Project

By JAMES GLANZ
Published: July 13, 2009

Two federal agencies are stopping a contentious California project from fracturing bedrock miles underground and extracting its geothermal energy until a scientific review determines whether the project could produce dangerous earthquakes, spokeswomen for the Energy and Interior Departments said on Monday.

Jim Wilson/The New York Times

The project by AltaRock Energy, a start-up company with offices in Seattle and Sausalito, Calif., had won a grant of $6.25 million from the Energy Department, and officials at the Interior Department had indicated that it was likely to issue permits allowing the company to fracture bedrock on federal land in one of the most seismically active areas of the world, Northern California.

But when contacted last month by The New York Times for an article on the project, several federal officials said that AltaRock had not disclosed that a similar project in Basel, Switzerland, was shut down when it generated earthquakes that shook the city in 2006 and 2007.

Key Questions in SGRs and EGS

Needs $\dot{H} = \dot{M}_f \Delta T_f c_f$

- Fluid availability
    - Native or introduced
    - H_2O/CO_2 working fluids?
    - Combined with sequestration?
- Fluid transmission
    - Permeability microD to mD?
    - <u>Distributed permeability</u>
- Thermal efficiency
    - Large heat transfer area
    - Small conduction length
- Long-lived
    - Maintain mD and HT-area
    - Chemistry
- Environment
    - Induced seismicity
    - Fugitive fluids
- Ubiquitous

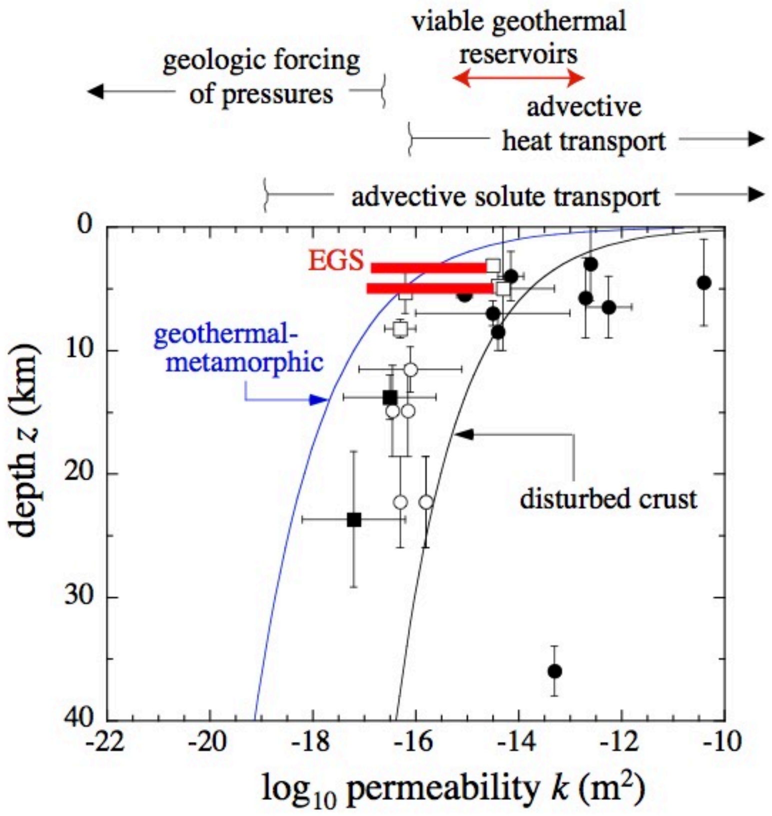


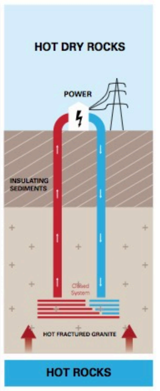
Figure 12: Evidence for relatively high crustal-scale permeabilities showing showing power-law fit to data. Geothermal-metamorphic curve is the best-fit to geothermal-metamorphic data [*Manga and Ingebritsen*, 1999, 2002]. "Disturbed-crust" curve interpolates midpoints in reported ranges in *k* and *z* for a given locality [*Manning and Ingebritsen*, 2010, their Table 1]; error bars depict the full permissible range for a plotted locality and are not Gaussian errors, and the Dobi (Afar) earthquake swarm is not shown on this plot (it is off-scale). Red lines indicate permeabilities before and after EGS reservoir stimulation at Soultz (upper line) and Basel (lower line) from *Evans et al.* [2005] and *Häring et al.* [2008], respectively. Arrows above the graph show the range of permeability in which different processes dominate.

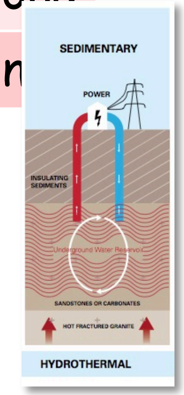
Steve.ai [Ingebritsen and Manning, various, in Manga et al., 2012]

Contrasts Between EGSs & SGRs

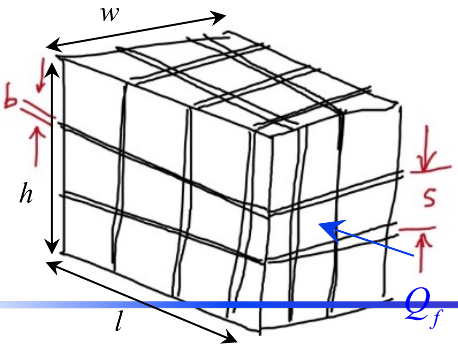
EGS (Order of Mag.)	Property	SGRs (Order of Mag)
Fractured-non-porous	General	Porous-fractured
<<1%,<1%	Porosity, n_0 -> n_{stim}	~10-30%, ~same
microD -> mD	Permeability, k_0 -> k_{stim}	>mD -> >>mD
10^6	K_f/k_{matrix}	10^6 ->1
10-100m	Heat transfer length, s	1m -> 1cm
>>100/1. >100/1	*$\text{Heat}_{solid}/\text{Heat}_{fluid}$	~10/1-2/1, same
?	Chemistry	?
V Strong	TM Perm. Feedbacks	Less strong
oderate, late time	TC Perm. Feedbacks	Stron

$$* \frac{\text{Heat in solid}}{\text{Heat in fluid}} = \frac{\cancel{V}(1-n)\rho_R c_R \Delta T}{\cancel{V}(n)\rho_W c_W \Delta T} = \frac{(1-n)}{n}\frac{\rho_R c_R}{\rho_W c_W}$$





Thermal Drawdown EGS -vs- SGRs



$$\dot{H}_{solid} \sim A\lambda_R \frac{dT}{dx} \sim \frac{V\lambda_R \Delta T}{s^2}$$

$$\dot{H}_{fluid} \sim Q_f \rho_W c_W \Delta T$$

$$\frac{\dot{H}_f}{\dot{H}_s} \sim \frac{\rho_W c_W}{\lambda_R}\frac{Q_f s^2}{V} = Q_D$$

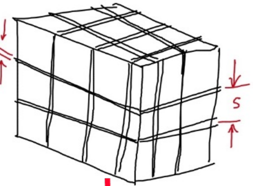
$EGS:$

$\dot{H}_f \to \infty$

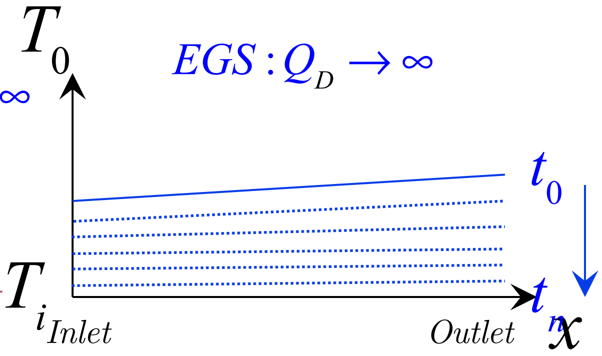
$\dot{H}_f / \dot{H}_s \to \infty$

$Q_D \to \infty$

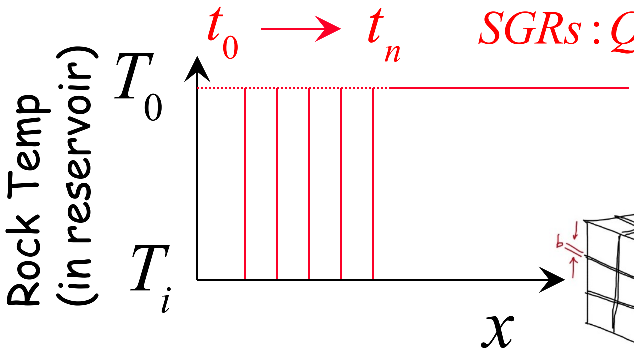
In-Reservoir Water Temperature Distributions:



$EGS: Q_D \to \infty$



$SGRs: Q_D \to 0$

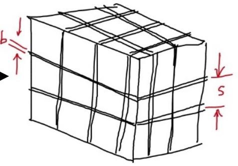


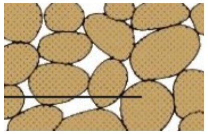
$SGRs:$

$\dot{H}_s \to 0$

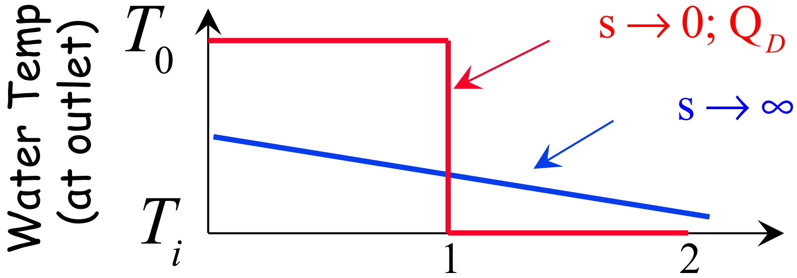
$\dot{H}_f / \dot{H}_s \to 0$

$Q_D \to 0$





Thermal Output:



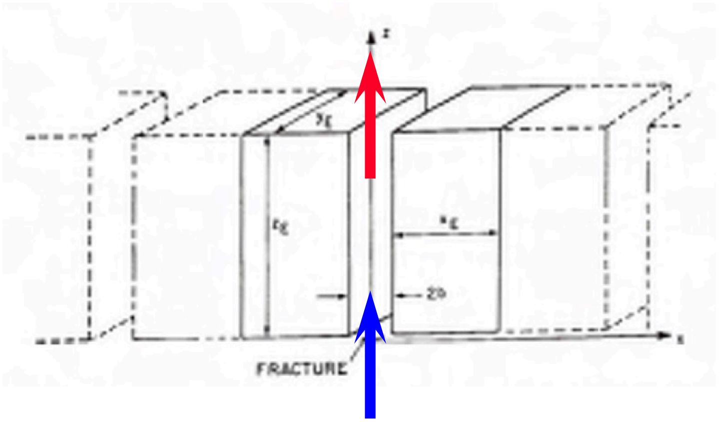
s → 0; $Q_D \to 0$; Thermal-front present

s → ∞; $Q_D \to \infty$; Thermal front absent

$$t_D = \frac{\rho_W c_W}{\rho_R c_R}\frac{Q_f t}{V}$$

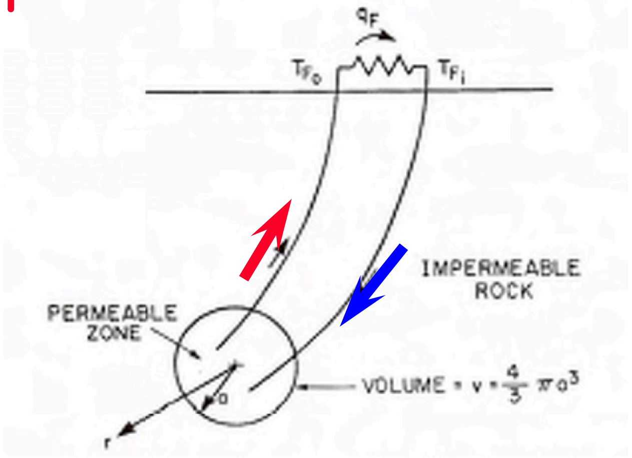
Thermal Recovery at Field Scale

Parallel Flow Model



[Gringarten and Witherspoon, Geothermics,1974]

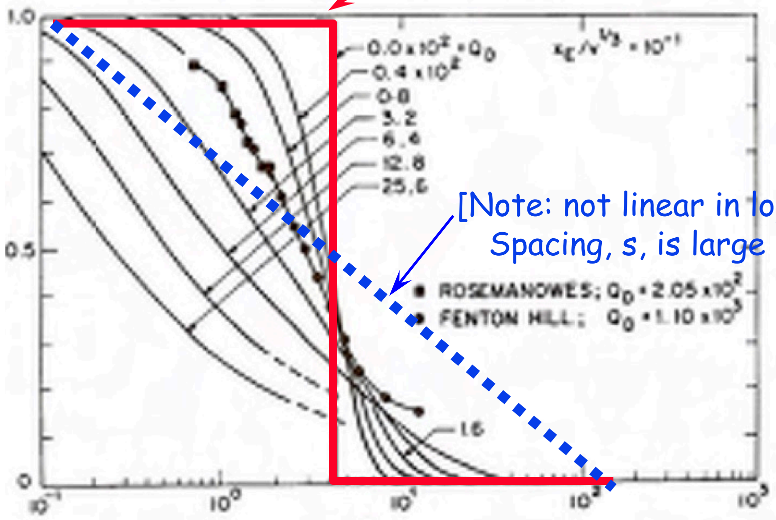
Spherical Reservoir Model



[Elsworth, JGR, 1989]

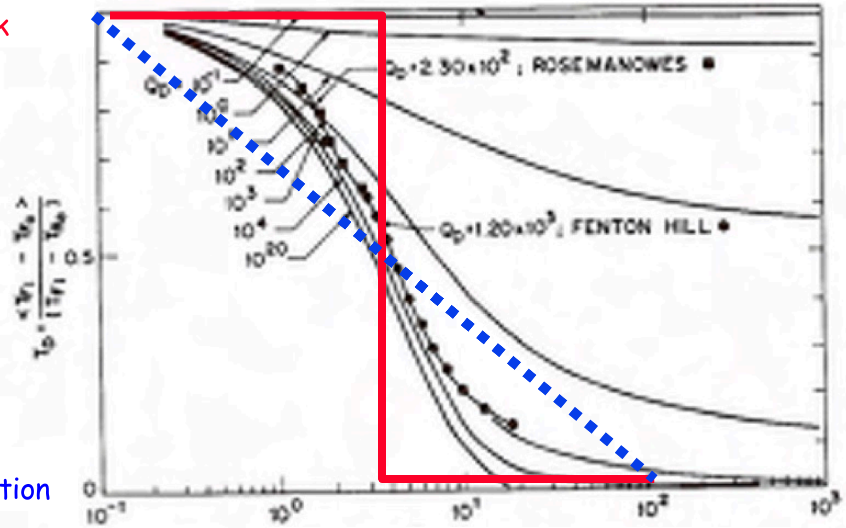
Spacing, s, is small

T_{rock}



[Note: not linear in log-time]

Spacing, s, is large



$T_{injection}$

Dimensionless temperature

Dimensionless time

[Elsworth, JVGR, 1990]

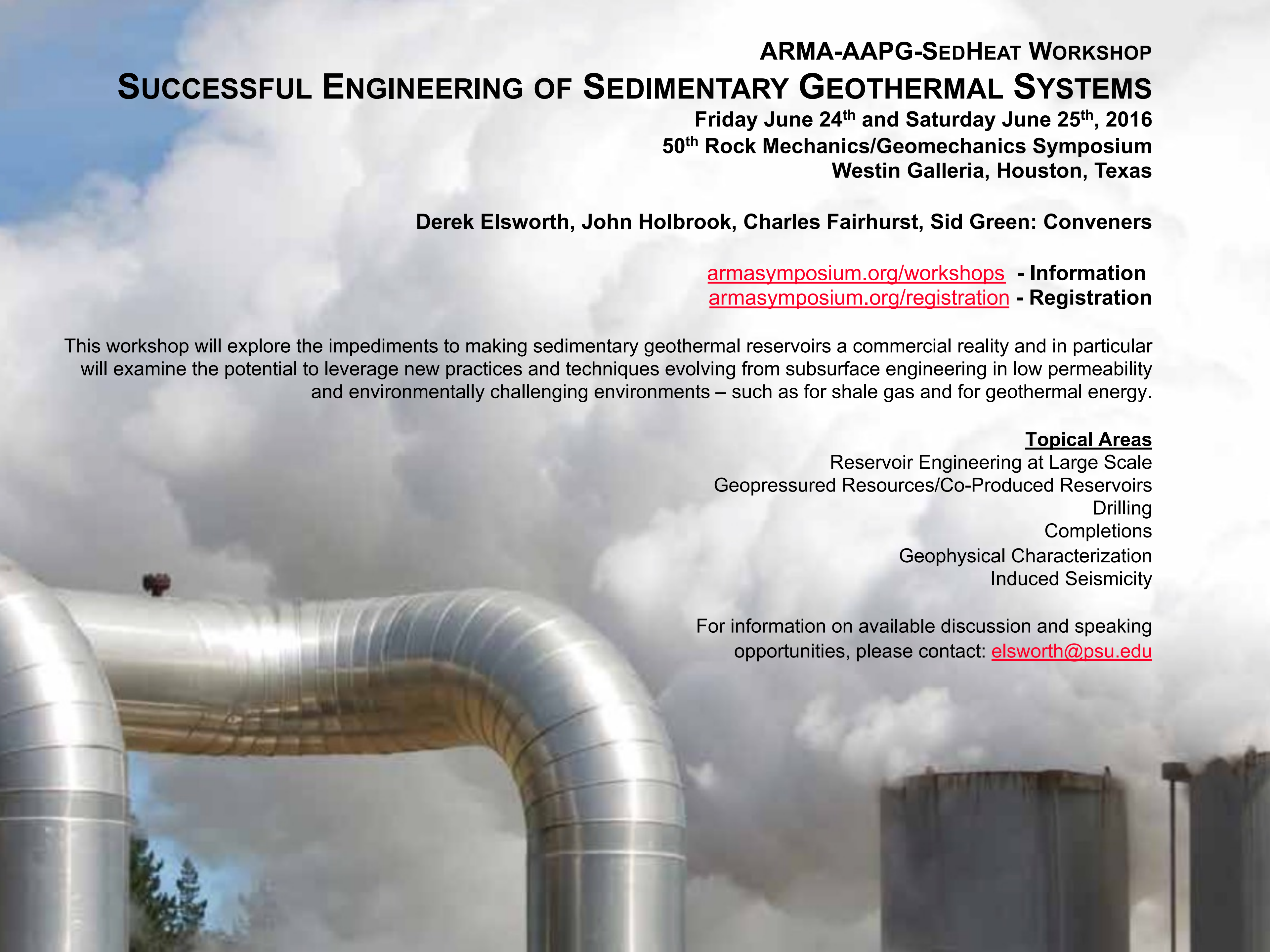
Dimensionless time

Key Questions in EGS and SGRs

Needs

$$\dot{H} = \dot{M}_f \Delta T_f c_f$$

- Fluid availability
  - Native or introduced – fluid/geochemical compatibility
  - H_2O/CO_2 working fluids? – arid envts.
- Fluid transmission
  - Permeability microD to milliD? – high enough?
  - Distributed permeability
    - Characterizing location and magnitude
    - Defining mechanisms of perm evolution (chem/mech/thermal)
    - Well configurations for sweep efficiency and isolating short-circuits
- Thermal efficiency
  - Large heat transfer area – better for SGRs than EGS?
  - Small conduction length – better for SGRs than EGS?
- Long-lived
  - Maintain mD and HT-area – better understanding diagenetic effects?
  - Chemistry - complex
- Environment
  - Induced seismicity - Event size (max)/timing/processes (THMCB)
  - Fugitive fluids – Fluid loss on production and environment – seal integrity
- Ubiquitous



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

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

armasymposium.org/workshops **- Information**
armasymposium.org/registration **- Registration**

This workshop will explore the impediments to making sedimentary geothermal reservoirs a commercial reality and in particular will examine the potential to leverage new practices and techniques evolving from subsurface engineering in low permeability and environmentally challenging environments – such as for shale gas and for geothermal energy.

Topical Areas

Reservoir Engineering at Large Scale
Geopressured Resources/Co-Produced Reservoirs
Drilling
Completions
Geophysical Characterization
Induced Seismicity

For information on available discussion and speaking opportunities, please contact: elsworth@psu.edu

ARMA-AAPG-SEDHEAT WORKSHOP
SUCCESSFUL ENGINEERING OF SEDIMENTARY GEOTHERMAL SYSTEMS

Derek Elsworth (Penn State), John Holbrook (TCU), Charles Fairhurst (UMN), Sid Green (Utah)

WHAT DO WE HOPE TO ACHIEVE HERE?

What are the Key Issues in Developing the Resource Base of Sedimentary Geothermal Reservoirs (SGRs)?

What are the Prospects for Applying Innovations from Rapidly Evolving Oil and Gas Engineering?

Reservoir Engineering
Co-Produced Reservoirs
Drilling
Completions
Subsurface Characterization
Induced Seismicity

SUMMARIZED NEEDS

Define "Key Needs" as closing slide and re-visit in discussion

ARMA-AAPG-SEDHEAT WORKSHOP

SUCCESSFUL ENGINEERING OF SEDIMENTARY GEOTHERMAL SYSTEMS

50th Rock Mechanics/Geomechanics Symposium, Houston, Texas 2016
Conveners: Derek Elsworth, John Holbrook, Charles Fairhurst, Sid Green

FRIDAY AM – Derek Elsworth

8:00 – 9:50 Introduction and Setting-the-Stage

Welcome, Overview and Goals of the Meeting – The Conveners

The SedHeat Initiative – John Holbrook (TCU)

Newberry EGS Demonstration; Results and Future Plans – Mike Swyer (AltaRock)

10:10 – 12:10 Reservoir Engineering at Large Scale [1]

Cornell Geothermal District Heating Trade-offs: Hot Sed Aquifers or Basement EGS? – Teresa Jordan (Cornell)

CO_2 Plume Geothermal – Jimmy Randolph (UMN)/Jeff Bielicki (OSU)

N_2 Plume Geothermal – Tom Buscheck (LLNL)

FRIDAY PM – John Holbrook

1:30 – 3:30 Reservoir Engineering at Large Scale [2]

Influence of Heterogeneity on EGS performance – Tom Doe (Golder)

Reservoir Geomechanics for SedHeat – Peter Connolly (Chevron)

The Radiator-Enhanced Geothermal System: Emulating a Natural Hydrothermal System – Markus Hilpert (JHU)

3:50 – 5:50 Co-Produced Reservoirs

The UND-DOE Low Temperature Geothermal Power Plant – Will Gosnold (UND)

A Sedimentary Enhanced Geothermal Reservoir: Lyons Sandstone, Wattenberg Field, CO – Luis Zerpa (CSM)

50 years of CO_2 EOR experience benefits CO_2 storage – Larry Lake (UT)

ARMA-AAPG-SEDHEAT WORKSHOP
SUCCESSFUL ENGINEERING OF SEDIMENTARY GEOTHERMAL SYSTEMS

SATURDAY AM – Sid Green

8:00 – 9:50 Drilling
Drain Holes and Mud Motors for Geothermal Applications – Bill Maurer (Maurer Engineering)
Drilling Challenges in Geothermal Reservoirs – Doug Blankenship (Sandia)
Directional Drilling: Historical Developments, Current Technology, Future Challenges – Emmanuel Detournay (UMN)

10:10 – 12:10 Completions
Long-term Cold Water Injectivity at Raft River and Implications for Fracture Evolution – Mitch Plummer (INL)
New Hydraulic-Natural Fracture Interaction Mechanisms Unique to 3D Hydraulic Fracturing – Pengcheng Fu (LLNL)
Hydraulic Fracturing – Ernie Brown (Schlumberger)
ARMA Fracturing Workshop Summary - John McLennan (UU)

SATURDAY PM – Charles Fairhurst

1:30 – 3:30 Geophysical Characterization of Completions
Fracture Network Engineering: Optimizing Production using Geomechanical Sensitivity Analyses – Will Pettitt (Itasca)
Microseismic Geomechanical Interpretation of HFStimulation of Unconventional Reservoirs – Shawn Maxwell (IMaGE)
Induced Seismicity: Fluid Migration and Earthquake Nucleation in Oklahoma - Katie Keranen (Cornell)

3:50 – 5:50 Induced Seismicity
Hydromechanical and Active Seismic Monitoring to Characterize Stimulated Fracture Systems – Yves Guglielmi (LBNL)
Monitoring of Rock Fracturing Induced by Fluid Injection in the Laboratory – Sergey Stanchits (Schlumberger)
Simulation and forecasting of induced seismicity and its collective properties – David Dempsey (Auckland)

5:50 – 6:00 Consensus, Challenges and Needs – The Conveners

Closure and Adjournment

Implications for Energy Independence, Energy Security and for Climate Change?

APRIL 11, 2011

Libya's Civil War
A GRAVE SCANDAL AT ARLINGTON

People Power for Palestine
BY JOE KLEIN

BATTER UP!
YOUR GUIDE TO THE 2011 BASEBALL SEASON

The last great work of David Foster Wallace
BY LEV GROSSMAN

TIME

ENVIRONMENT SPECIAL

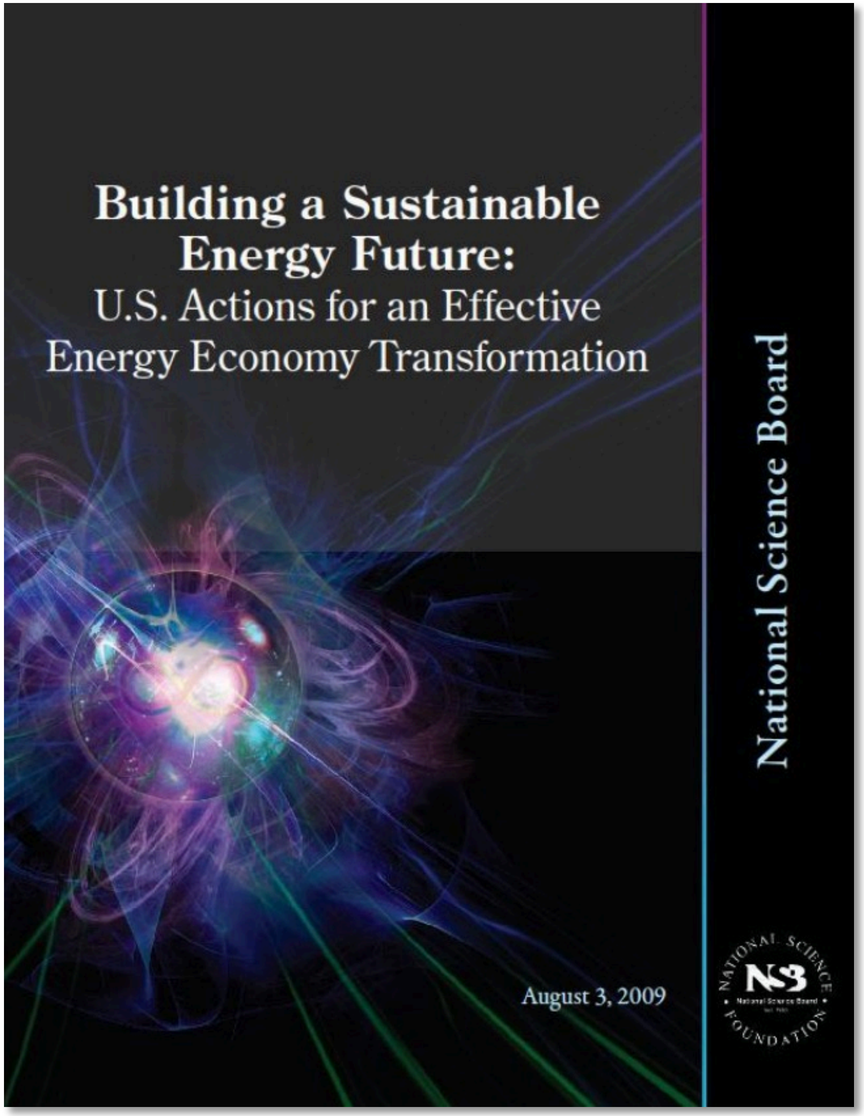
THIS ROCK COULD POWER THE WORLD

WHY SHALE CAN SOLVE THE ENERGY CRISIS
BY BRYAN WALSH

A century's worth is buried in our backyards ...

... but drilling for it threatens our land

www.time.com



Building a Sustainable Energy Future:
U.S. Actions for an Effective Energy Economy Transformation

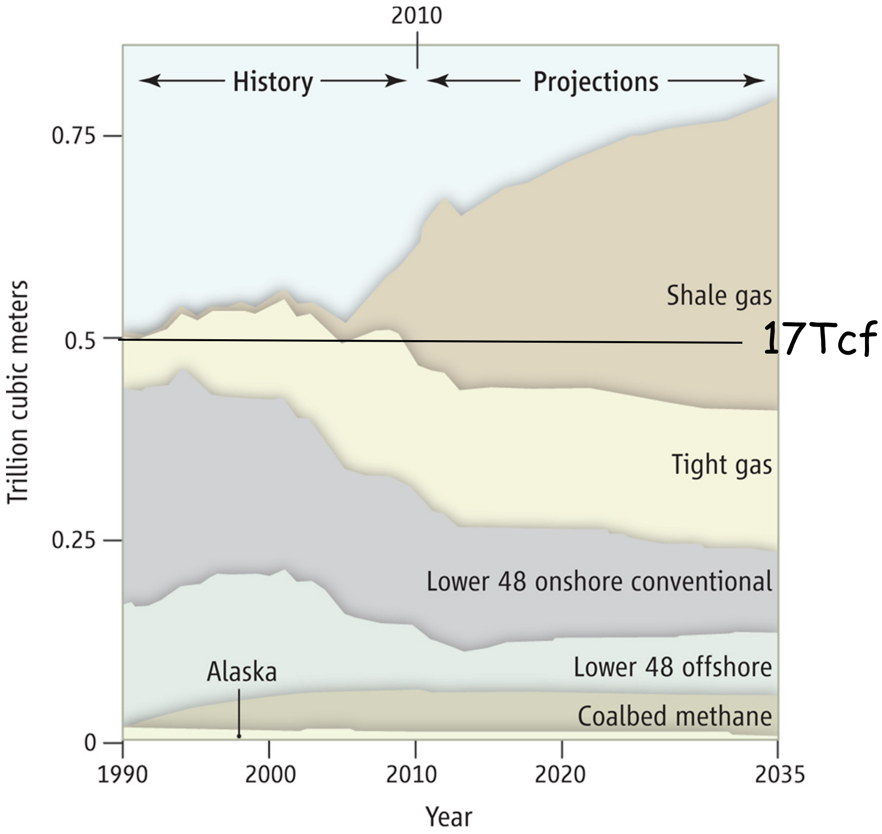
August 3, 2009

National Science Board

NATIONAL SCIENCE FOUNDATION
NSB

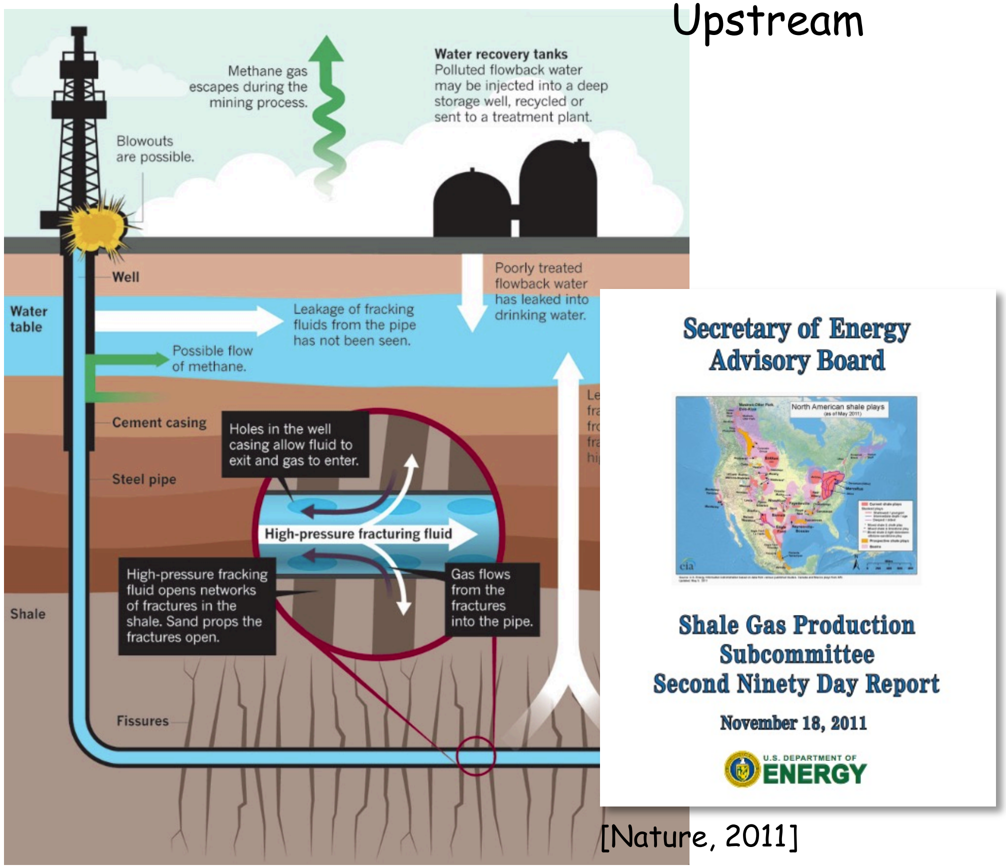
Projected Growth and Opportunities

Natural Gas Utilization



[Science, Oct 18, 2012]

Upstream



Secretary of Energy Advisory Board

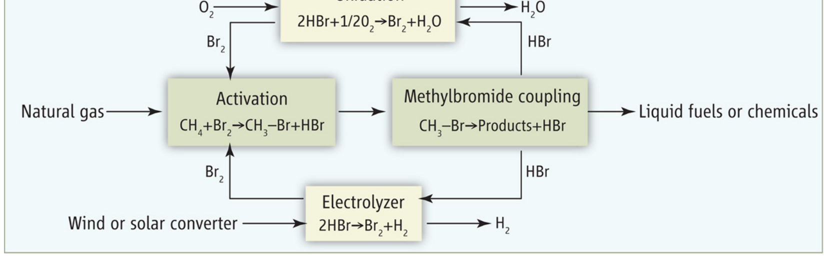
Shale Gas Production Subcommittee
Second Ninety Day Report

November 18, 2011

U.S. DEPARTMENT OF ENERGY

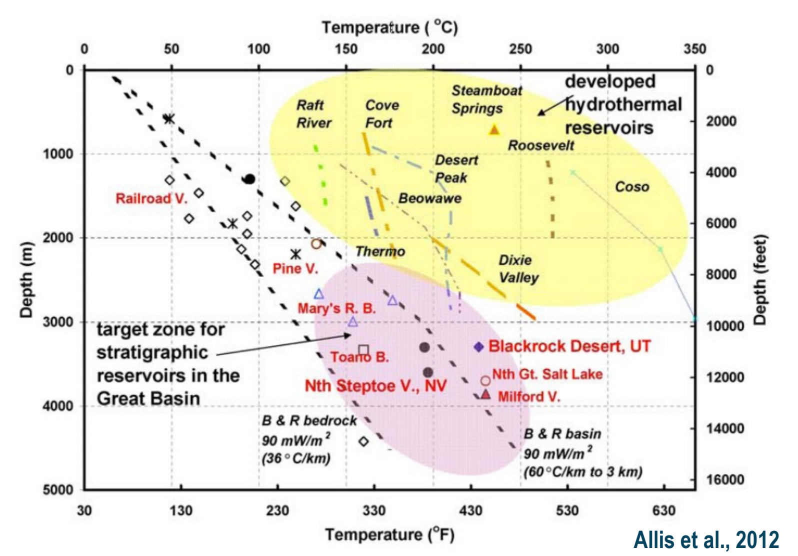
[Nature, 2011]

Downstream



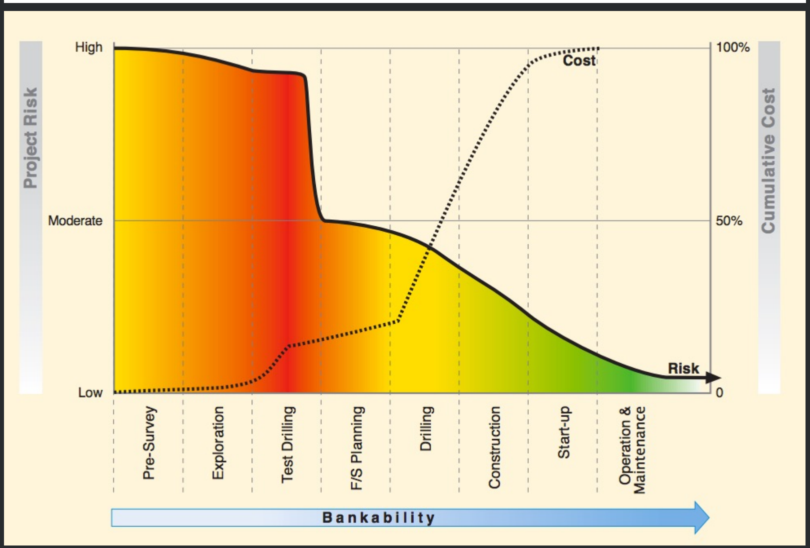
Key Issues for Sedimentary Hosted Geothermal Systems

- Establish the necessary boundary conditions
  - Sufficient temperature
  - Adequate perm, either current or induced
  - Threshold flow rate
- Define the engineering challenge



Allis et al., 2012

- Direct use as well as power applications
- Timelines/value of money and total costs are critical



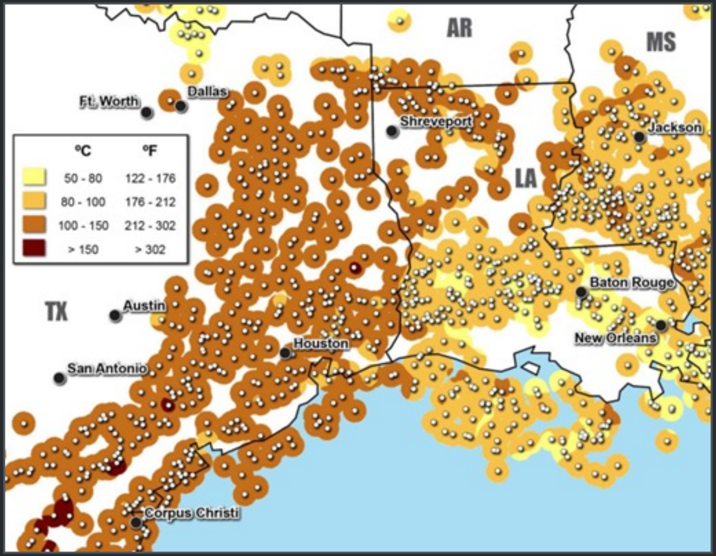
ESMAP, 2012 Geothermal handbook: Planning and Financing Power Generation

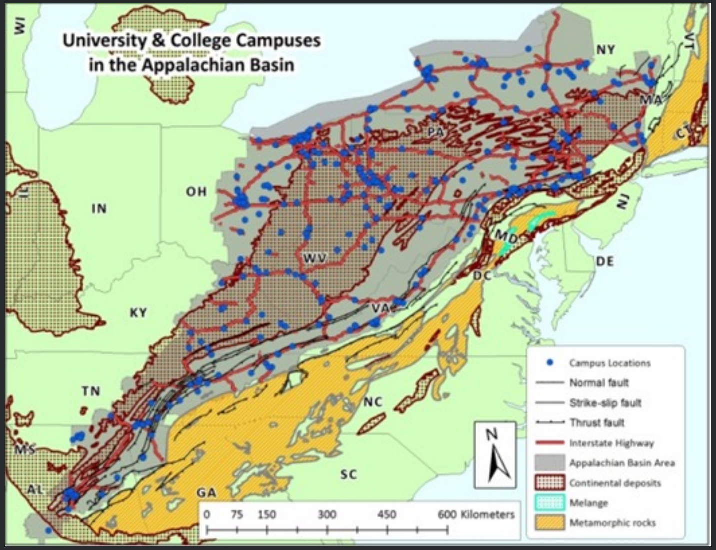
[Penrose, 2013, Dan King, GTP]

What's Next for Low Temp?

[Penrose, 2013, Dan King, GTP]

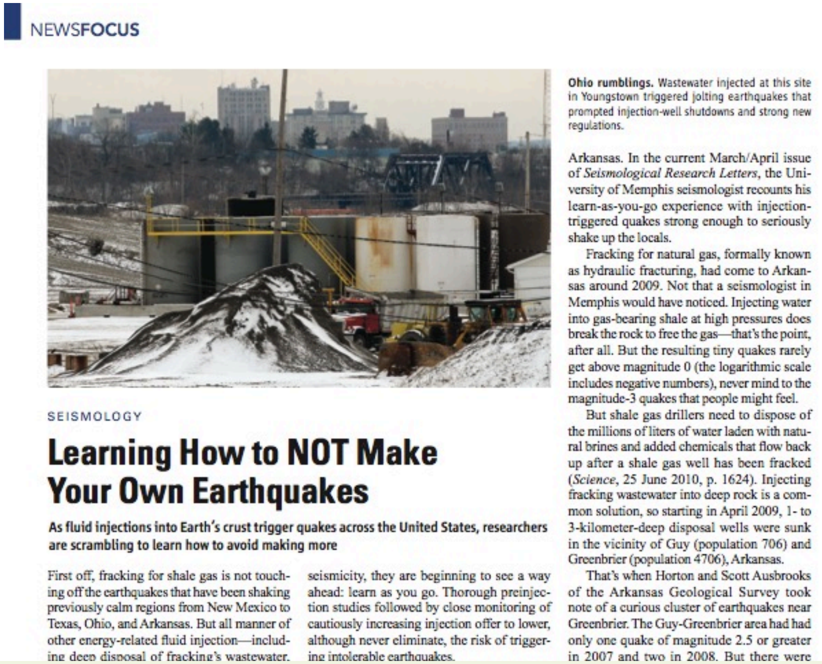
Materials Extraction, Direct-Use, Hybrid Systems





- Execute on **Co-production** initiative
- **Strategic Materials** - Resource assessment and feasibility
- Large-scale **Direct Use**: where does it make technical and commercial sense?
- R&D on innovative **Energy Conversion**

Induced Seismicity



NEWSFOCUS

Ohio rumblings. Wastewater injected at this site in Youngstown triggered jolting earthquakes that prompted injection-well shutdowns and strong new regulations.

SEISMOLOGY

Learning How to NOT Make Your Own Earthquakes

As fluid injections into Earth's crust trigger quakes across the United States, researchers are scrambling to learn how to avoid making more

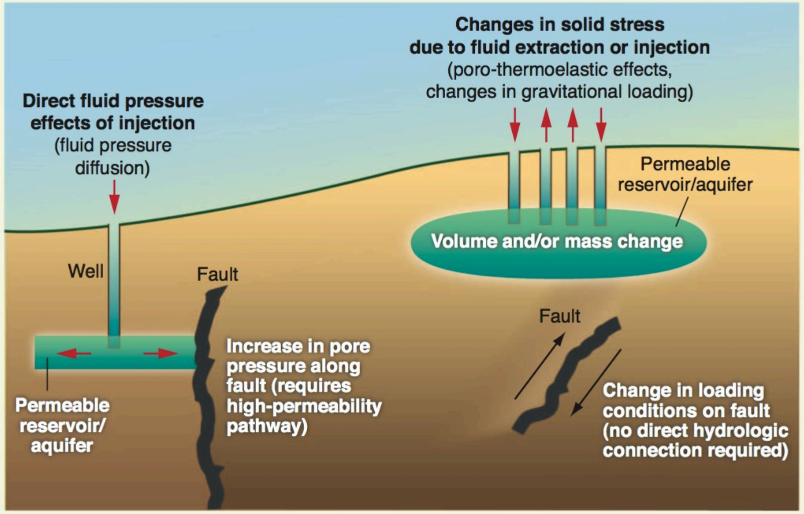
First off, fracking for shale gas is not touching off the earthquakes that have been shaking previously calm regions from New Mexico to Texas, Ohio, and Arkansas. But all manner of other energy-related fluid injection—including deep disposal of fracking's wastewater, seismicity, they are beginning to see a way ahead: learn as you go. Thorough preinjection studies followed by close monitoring of cautiously increasing injection offer to lower, although never eliminate, the risk of triggering intolerable earthquakes.

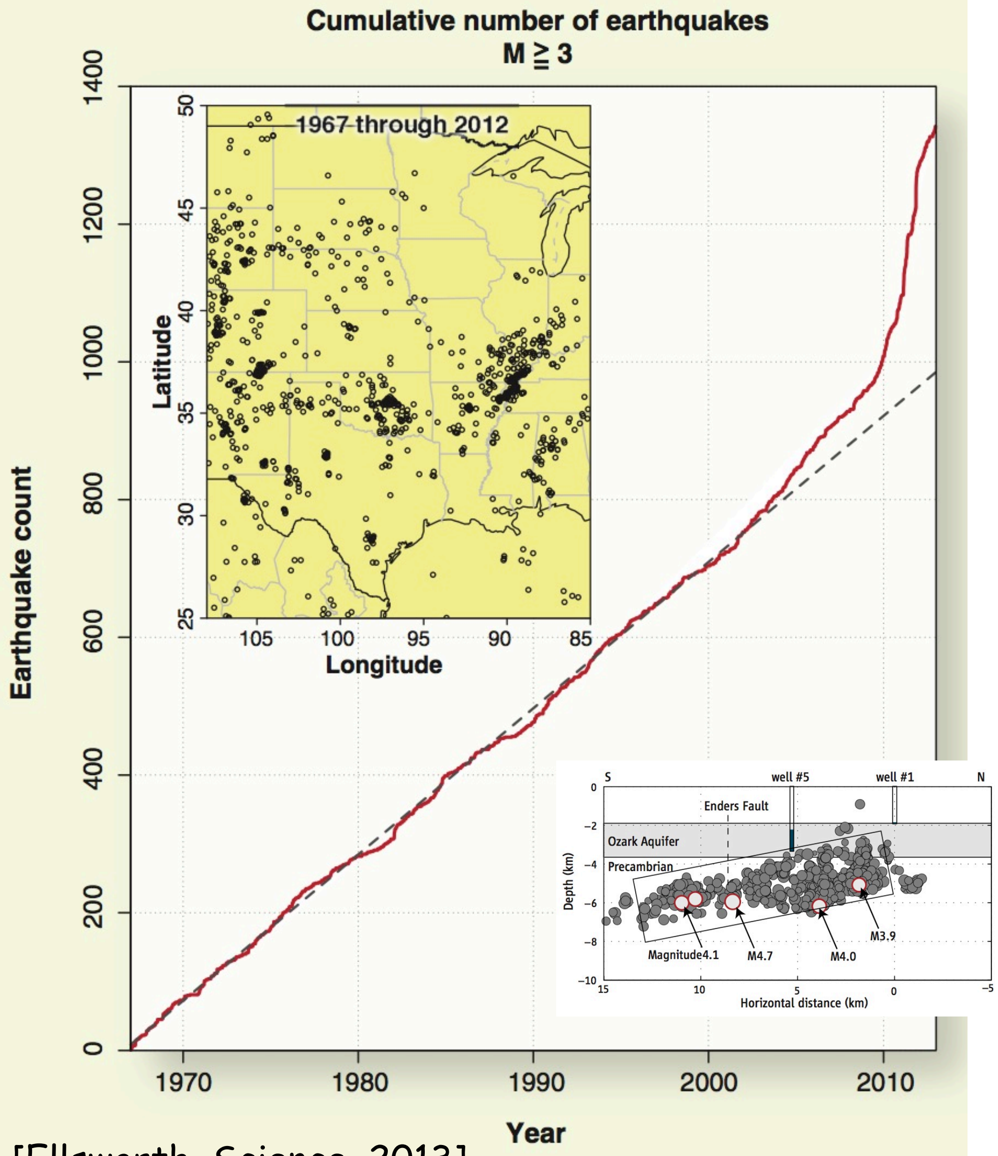
Arkansas. In the current March/April issue of *Seismological Research Letters*, the University of Memphis seismologist recounts his learn-as-you-go experience with injection-triggered quakes strong enough to seriously shake up the locals.

Fracking for natural gas, formally known as hydraulic fracturing, had come to Arkansas around 2009. Not that a seismologist in Memphis would have noticed. Injecting water into gas-bearing shale at high pressures does break the rock to free the gas—that's the point, after all. But the resulting tiny quakes rarely get above magnitude 0 (the logarithmic scale includes negative numbers), never mind to the magnitude-3 quakes that people might feel.

But shale gas drillers need to dispose of the millions of liters of water laden with natural brines and added chemicals that flow back up after a shale gas well has been fracked (*Science*, 25 June 2010, p. 1624). Injecting fracking wastewater into deep rock is a common solution, so starting in April 2009, 1- to 3-kilometer-deep disposal wells were sunk in the vicinity of Guy (population 706) and Greenbrier (population 4706), Arkansas.

That's when Horton and Scott Ausbrooks of the Arkansas Geological Survey took note of a curious cluster of earthquakes near Greenbrier. The Guy-Greenbrier area had had only one quake of magnitude 2.5 or greater in 2007 and two in 2008. But there were

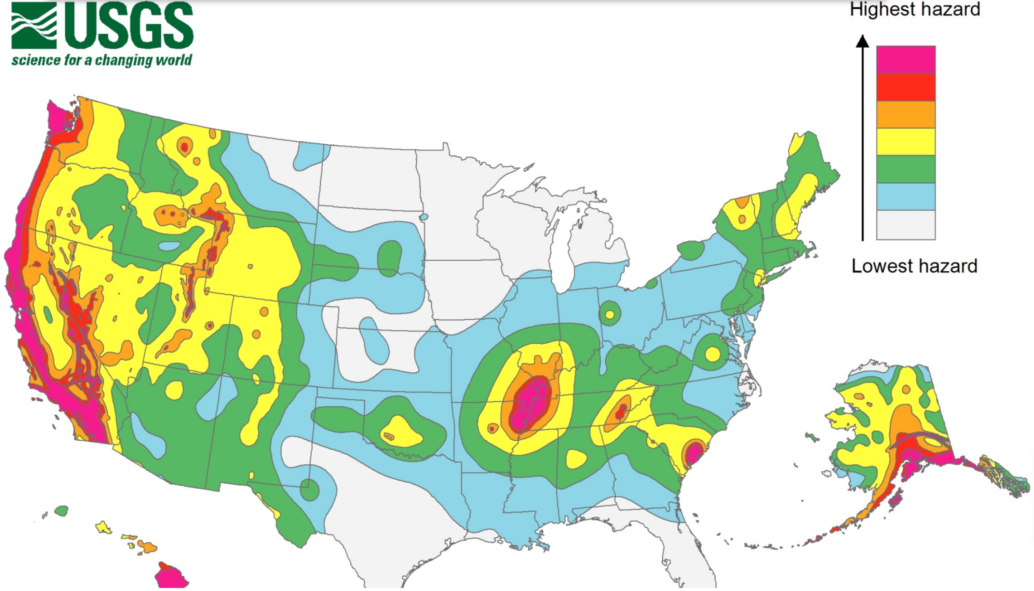


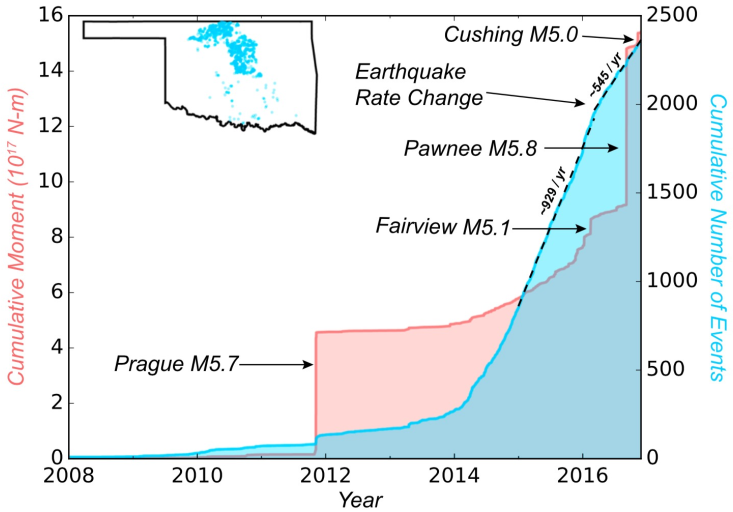


[Ellsworth, Science, 2013]

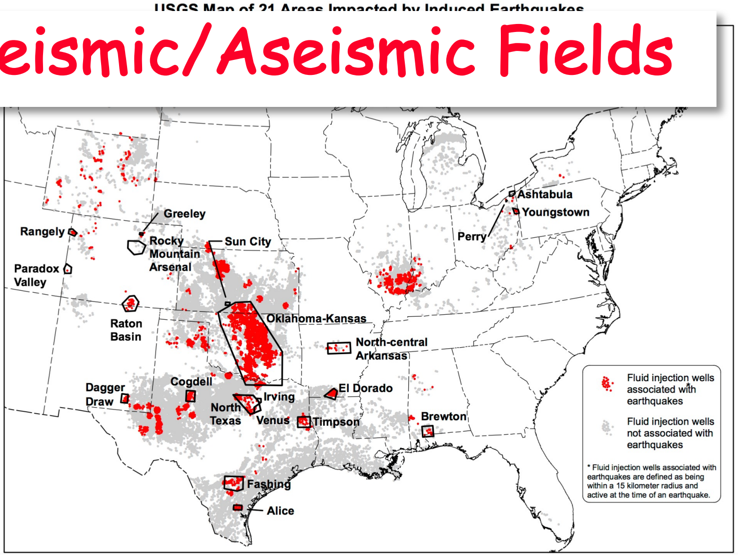
Induced Seismicity

US Seismic Hazard

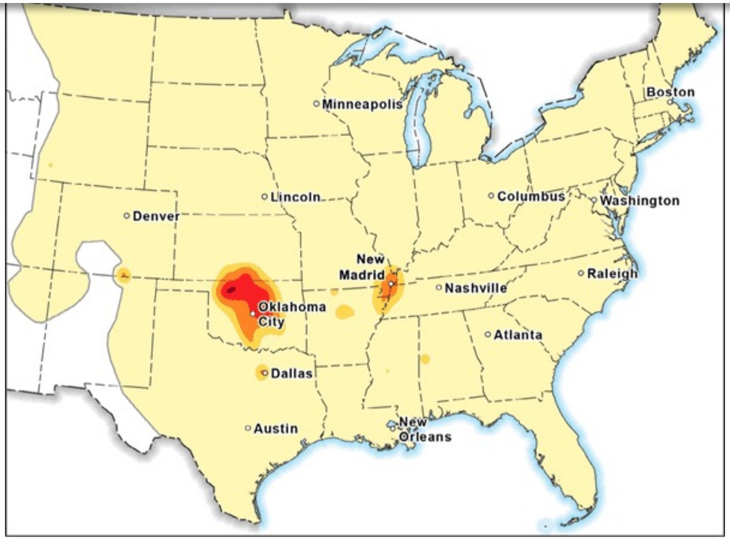




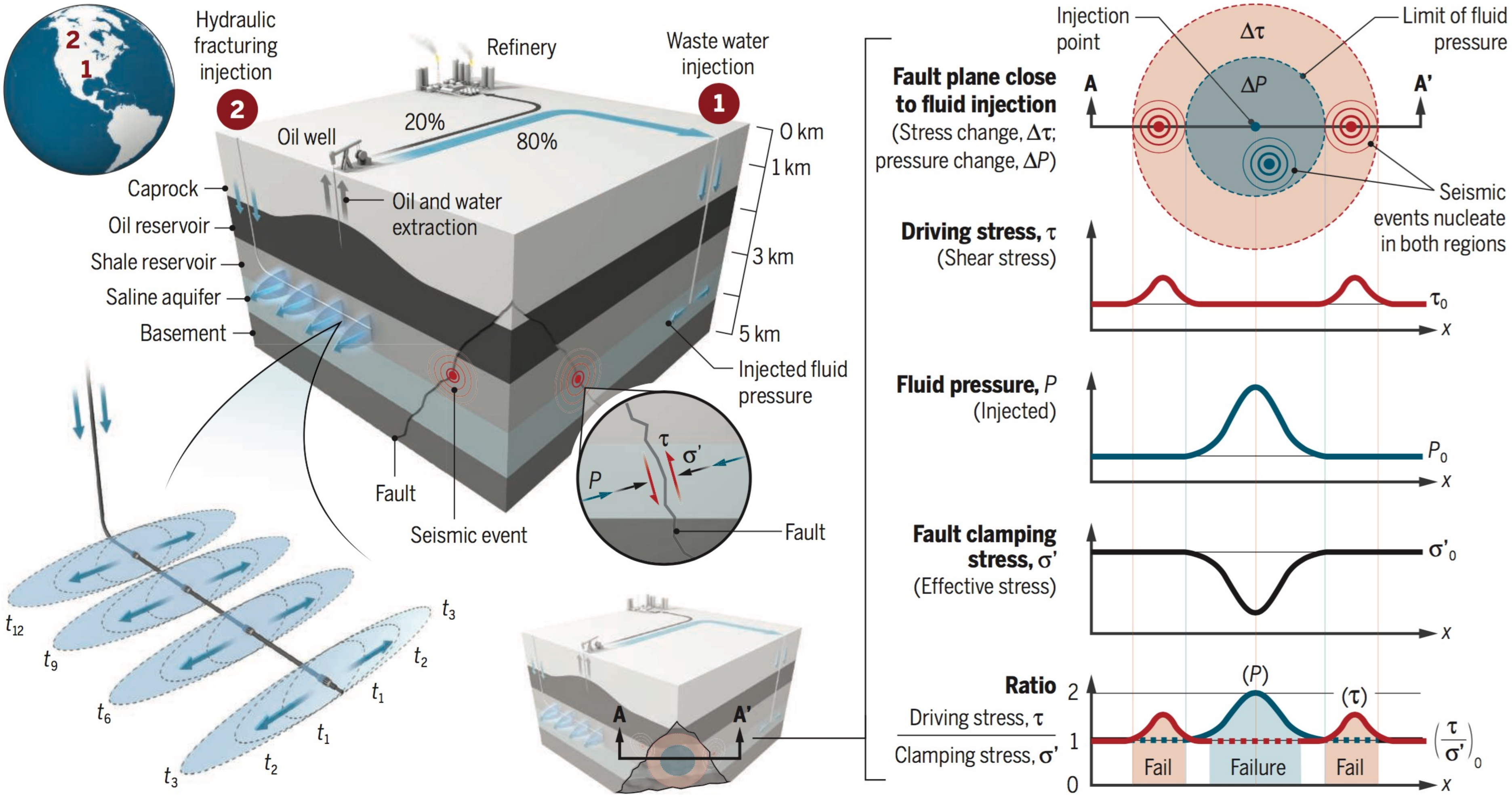
Seismic/Aseismic Fields



Mid-west Seismic Hazard

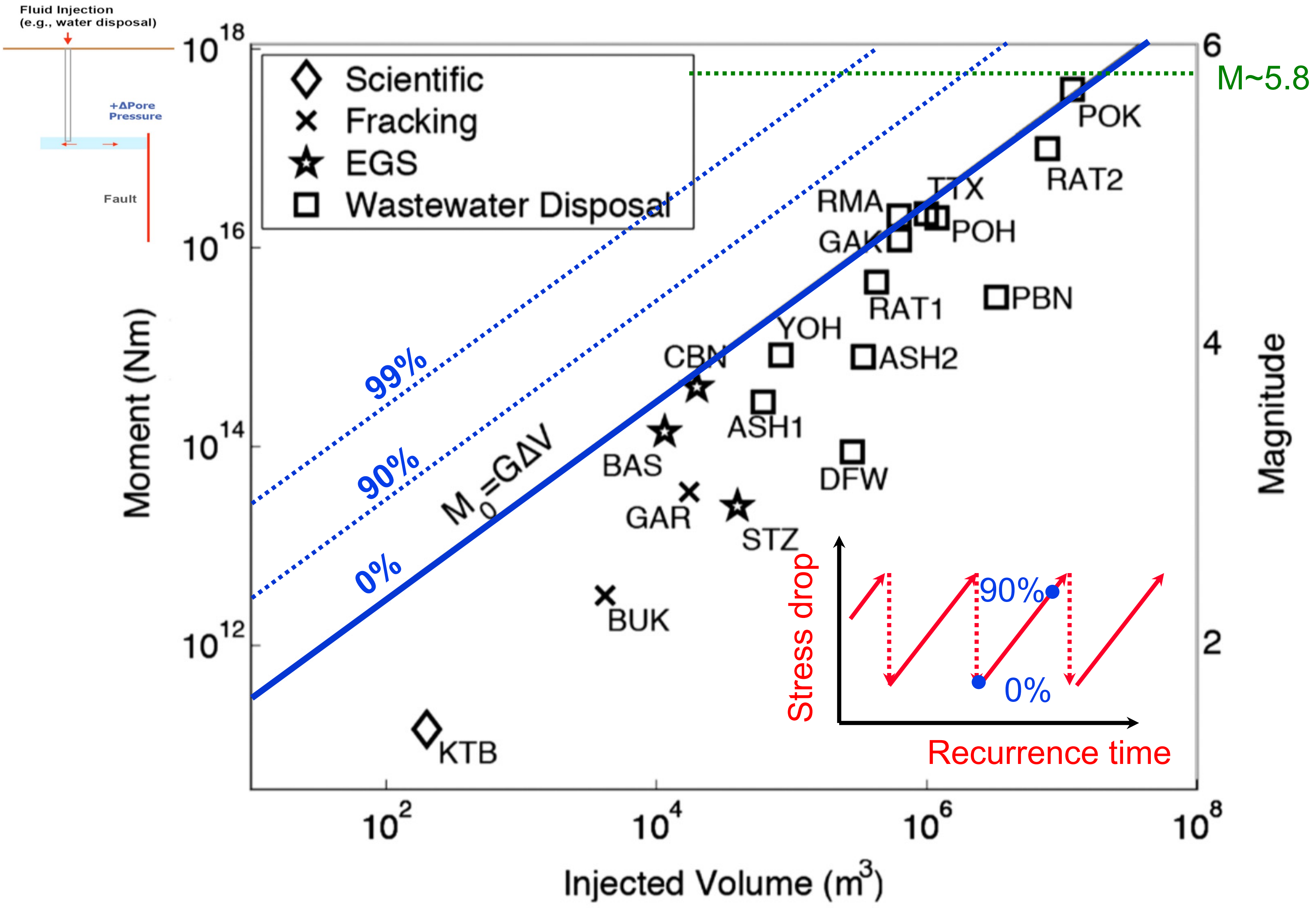


Induced Seismicity



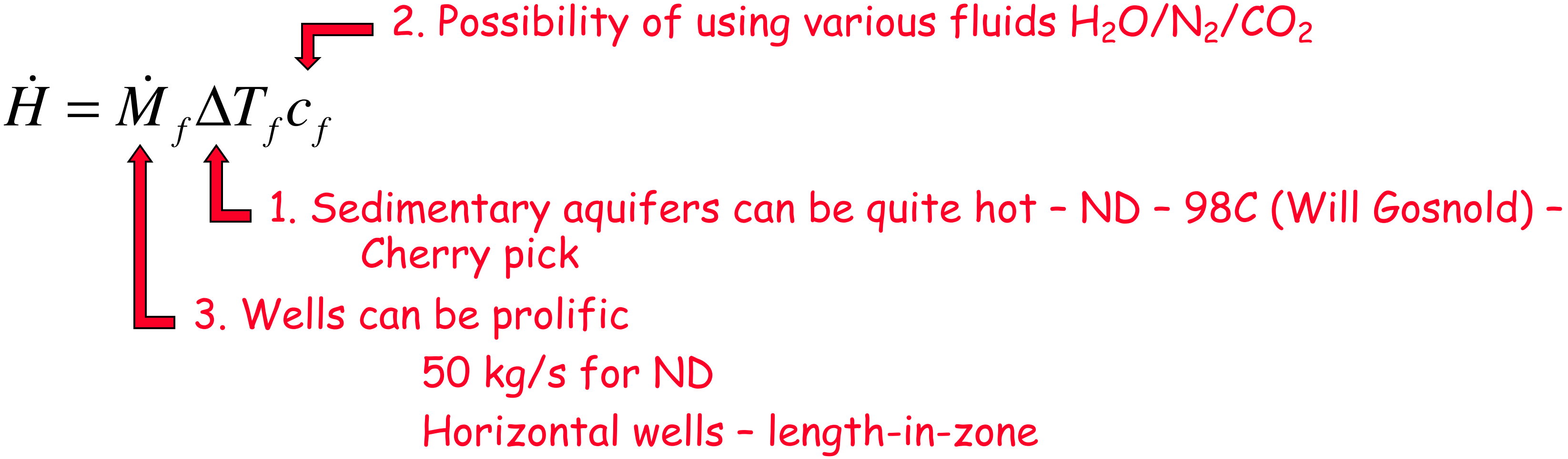
[Elsworth et al., Science, 2016]

Maximum Anticipated Moment Magnitude – M or M_dot? M_{Gross} or M_{Net}? Triggered -vs- Induced?



After [McGarr, JGR, 2014]

Summary of 2016 "Engineering Challenges" Meeting (DE)



2. Possibility of using various fluids $H_2O/N_2/CO_2$

$$\dot{H} = \dot{M}_f \Delta T_f c_f$$

1. Sedimentary aquifers can be quite hot – ND – 98C (Will Gosnold) – Cherry pick

3. Wells can be prolific

   50 kg/s for ND

   Horizontal wells – length-in-zone

$$\dot{H} = \dot{M}_f \Delta T_f c_f$$ Sedimentary Reservoirs – Porous/less fracture-dominated - Helpful

Environment: Induced Seismicity – conjectured small effects

dV_{net} is small – therefore dp is small?

dT_{net} is small – therefore dEpsilon is small?

These outcomes suggest that SedHeat should be straightforward?

So Why No/Sparing Adoption?

Value of resource?: 25c/BBL – ROI small in comparison to hydrocarbons with much larger energy density

Risk/Cost of failure: One unsuccessful well – geothermal versus hydrocarbon well

i.e. The “George Mitchell” Story….

Outcomes - 2017 SLC SedHeat Meeting (4th)
"Tracking the Energy Elephant"

What are opportunities in sedimentary geothermal?

Technically viable but economically challenged

Requires reduced costs or increased rates (revenues)

1. Co-Production with Oil & Gas Operations;
2. Retrofit or Re-Purpose Existing Petroleum Wells;
3. Drill New Wells Specifically for new SedHeat.

What are barriers to success?

Economic Challenges: e.g. Electricity pricing
Improved Business Models: e.g. Direct use
Induced Seismicity: Maybe
Regulations: Permitting and minerals management
Scientific Barriers: Permeability enhancement and risks
Drilling and completions
Play fairway analysis and characterization

A SEDHEAT WORKSHOP

Unlocking the Energy Elephant

March 1-4, 2017

A workshop that aims to foster the basic science and engineering of geothermal energy in high-temperature sedimentary basins, unifying themes of the SedHeat project and topics discussed at past meetings. It gathers experts in geothermal and related subsurface fields to identify challenges, issues, and potential resolutions associated with economically viable production of heat from sedimentary basins.

Marriott University Park Hotel
480 Wakara Way
Salt Lake City, Utah 84108
Phone: 1-801-581-1000

1

Outcomes - 2017 SLC SedHeat Meeting (4th) "Tracking the Energy Elephant" [Cont'd.]

What should we focus on to make sedimentary geothermal viable?

Use lower cost access to *existing oil & gas wells* and infrastructure;
Adapt *oil and gas technologies* as much as possible;
Focus on areas/countries with *high demand and high rates*;
Customers that *need base load power that is always on* (e.g. military, server farms);
Combined heat and power;
Efficiency-of-scale - *co-producing* power from large arrays of *existing oil & gas wells*;
Lobby local, State and Federal governments for RPS investment in geothermal.

Key risks:

Induced Seismicity;
The role of subsurface heterogeneity on fluid flow and sustainability;
The availability of water resources for circulation where needed;
The quality of the well completion when re-purposing old oil & gas wells.

Grand opportunities:

Advantages for the operator at oil & gas sites are where:
- lower-cost power is not available;
- produced water needs to be cooled;
- produced water is a liability and geothermal activities can assist (e.g. re-injection);
- use of wells can be economically justified through co-production or repurposing;
- the operator wants to increase renewable power into its energy mix.

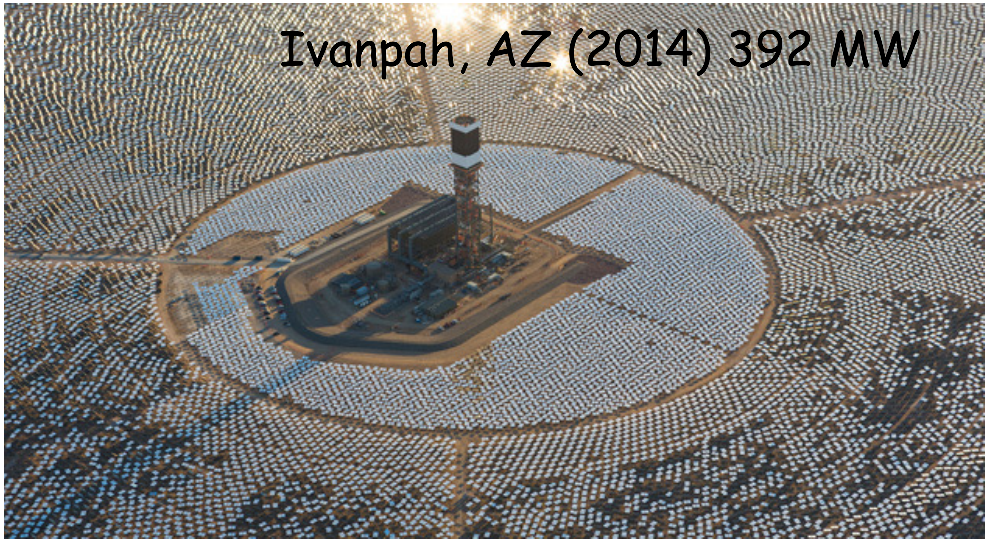
Necessary "Step-Changes"?

$\dot{H} = \dot{M}_f \Delta T_f c_f$ and Environment

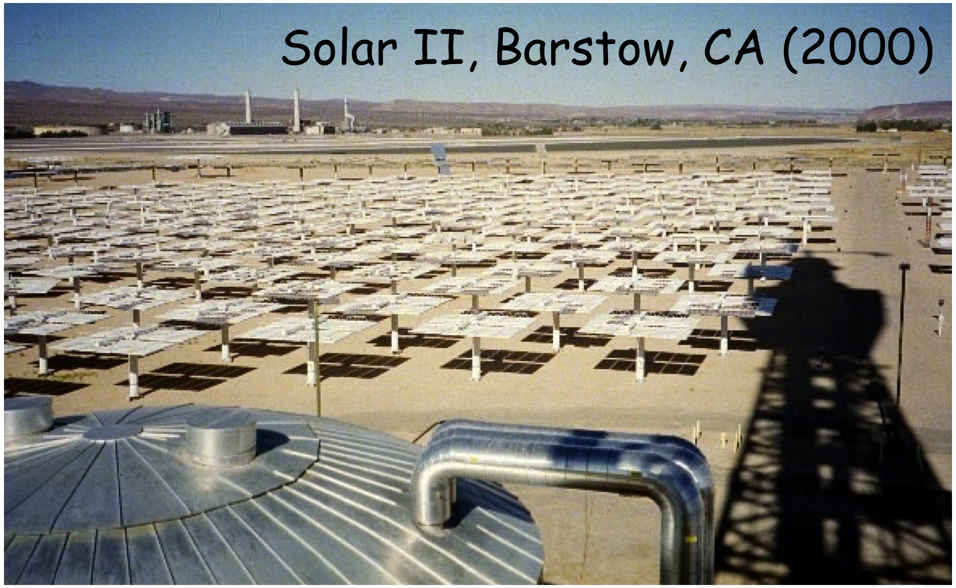
Systems (c_f):	CO_2/N_2 combinations – scale of 1 GW and 10c/kWh
Depth/Temp(dT):	Reduce drilling costs to depth (>60% of cost is drilling) Reduce tripping and casing or increase ROP Very high enthalpy wells (>600C)
Flow/Sweep(M):	Horizontal drilling – seems necessary Completions Cheaper methods for smart completions (<0.5M/system)
Environment:	Gross volumes of injection are large - but net volumes are small? Chemical limits over the long-term?

Geothermal Batteries for Solar Thermal Power

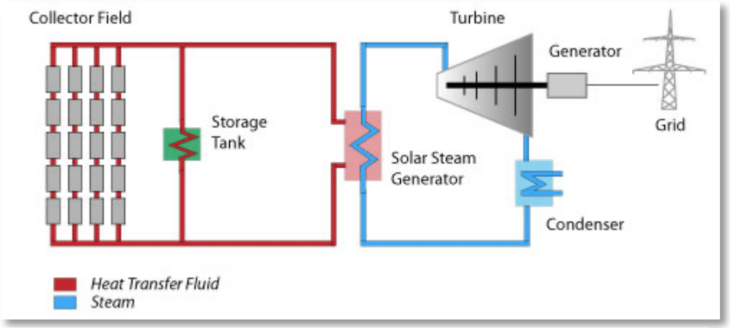

Abengoa (planned 2011), AZ 208 MW


Ivanpah, AZ (2014) 392 MW

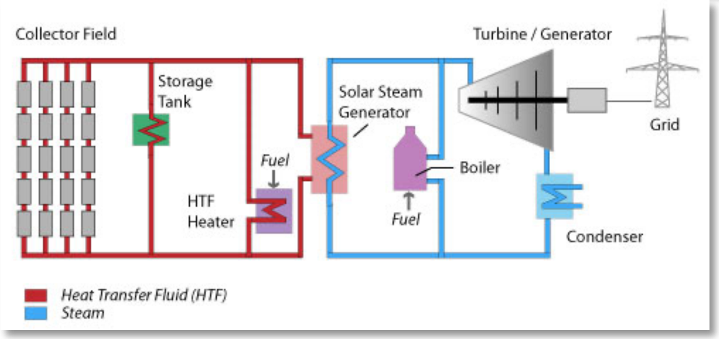

Mojave Desert, CA (2000)


Solar II, Barstow, CA (2000)

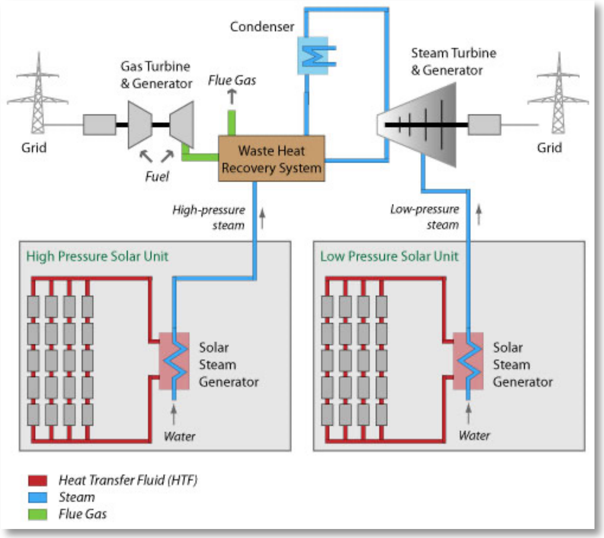
Concentrated Solar Thermal (CST) Power Systems



Stand-Alone Rankine System



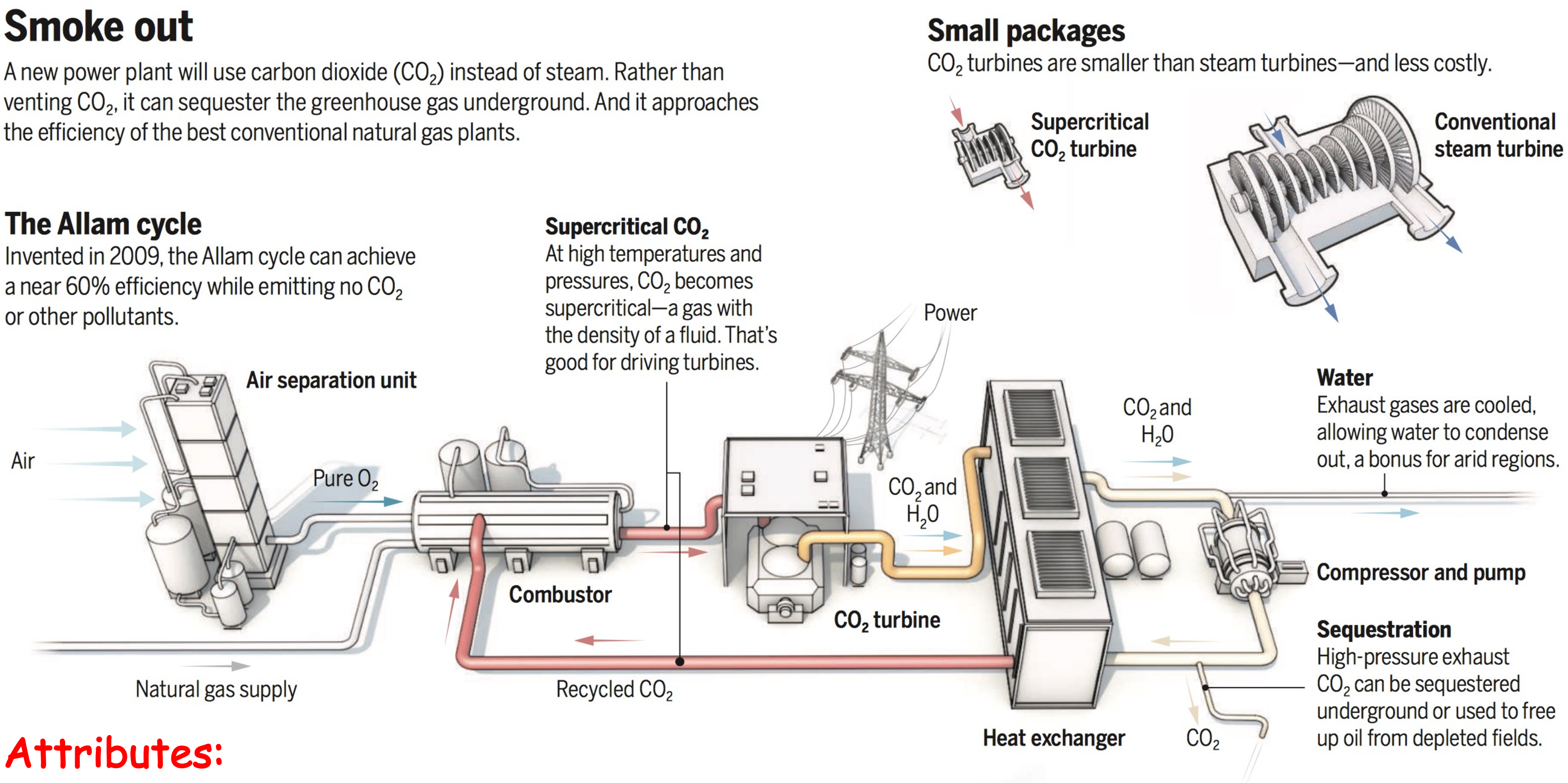
Hybrid CST System
with Fossil Fuel Backup



Hybrid CST System
with Integrated Solar Combined Cycle System
(ISCCS)

Combination with Natural Gas to Utilize Excess Heat

Efficient Conversion Heat to Electricity



Smoke out

A new power plant will use carbon dioxide (CO_2) instead of steam. Rather than venting CO_2, it can sequester the greenhouse gas underground. And it approaches the efficiency of the best conventional natural gas plants.

Small packages

CO_2 turbines are smaller than steam turbines—and less costly.

The Allam cycle

Invented in 2009, the Allam cycle can achieve a near 60% efficiency while emitting no CO_2 or other pollutants.

Supercritical CO_2

At high temperatures and pressures, CO_2 becomes supercritical—a gas with the density of a fluid. That's good for driving turbines.

Water

Exhaust gases are cooled, allowing water to condense out, a bonus for arid regions.

Sequestration

High-pressure exhaust CO_2 can be sequestered underground or used to free up oil from depleted fields.

Attributes:

Solar thermal – arid – no water needs

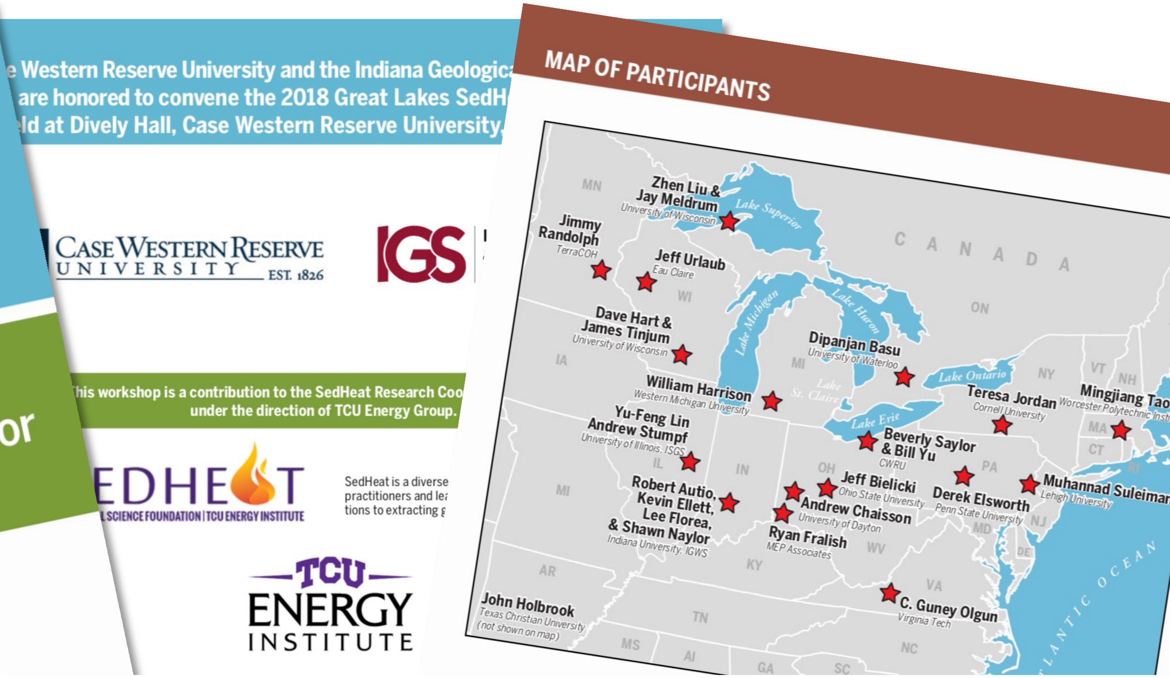
Heat drives cycle? – By pressurizing CO_2

Regional Applications..?

2018 Great Lakes SedHEAT Incubator Workshop

February 18–20, 2018

Case Western Reserve University, Cl



e Western Reserve University and the Indiana Geologica
are honored to convene the 2018 Great Lakes SedH
ld at Dively Hall, Case Western Reserve University.

his workshop is a contribution to the SedHeat Research Coo
under the direction of TCU Energy Group.

SedHeat is a diverse
practitioners and lea
tions to extracting g

MAP OF PARTICIPANTS

Scientifically Viable but Economically Challenged

Impetus to push over the top?:
- Cost of carbon avoided
- Entry into deep SedHeat:
  - Oil/gas pairing/levarage (2016)
  - Innovative combinations
- Shallow – already broadly viable