

# THE ENERGY NEW DEAL RELATED TO SUBSURFACE ENERGY OPTIONS

Derek Elsworth (Pennsylvania State University)

## Some Key Issues in Energy Supply

- Needs
- Constraints
- Solutions

## Low Carbon Fuel Solutions

- Gas Shales
- Coalbed Methane (CBM/Coalseam gas)
- Methane Hydrates

## Carbon Management Solutions

- CO<sub>2</sub> sequestration

## Zero Carbon Solutions

- EGS Geothermal
- Nuclear power
- Hydropower/Pumped Storage/CAES
- Wind
- Solar PV and Thermal

## New Zealand Energy Picture



# Sustainable Energy in New Zealand

## Sustainable Energy in New Zealand EGEE 497 – Sp 2019

**What:** This course will examine methods of energy recovery and conversion from conventional fossil fuels through renewables. Students will investigate the political, economic, scientific and technological factors driving the recovery and utilization of energy using New Zealand as an archetypical example – one where unusually 40% of primary energy is supplied by renewables. This compares with approximately 6% in the United States and an average of 8% in OECD countries.

**When:** Spring semester with a field trip to New Zealand during spring break.

**How:** This course will use occasional guest lectures, instructor-guided discussions, student presentations, and research to address the important contemporary issues of energy supply and use, and the environmental consequences of energy choices.

**Where:** Principally at University Park, but including the field of New Zealand during the break.

## CAUSE 2013 – Energy, Environment and Society



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[Syllabus](#)

[Perspective on Petroleum & Natural Gas](#)  
[Perspective on Nuclear Energy](#)  
[Perspective on Non-Depletable Energy Resources](#)



[Flyer](#)

[Syllabus](#)

Derek Elsworth, Energy and Mineral Engineering and Geosciences

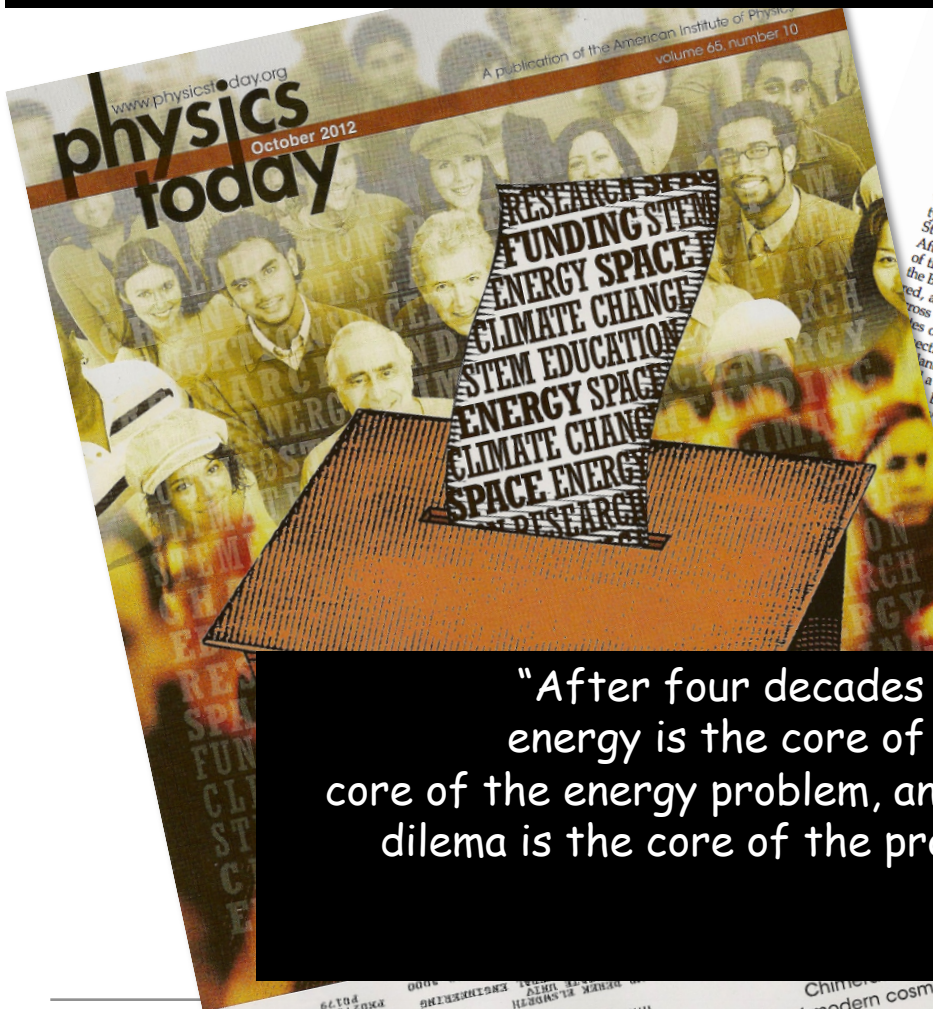
This course examines methods of energy recovery and conversion from conventional fossil fuels through renewables. Students investigate the political, economic, scientific and technological factors driving the recovery and utilization of energy using New Zealand as an archetypical example – one where unusually 40% of primary energy is supplied by renewables. This compares with approximately 6% in the United States and an average of 8% in OECD countries.

[Resources](#)

ough  
e recovery

# Energy-Environment-Economy Nexus

"... we can see how energy is the key to solving all of the rest of the problems - from water to population"  
--Richard E. Smalley



## Future Global Energy Prosperity: The Terawatt Challenge

Richard E. Smalley

The following article is an edited transcript based on the Symposium X—Frontiers of Materials Research presentation given by Richard E. Smalley of Rice University on December 2, 2004, at the Materials Research Society Fall Meeting in Boston.

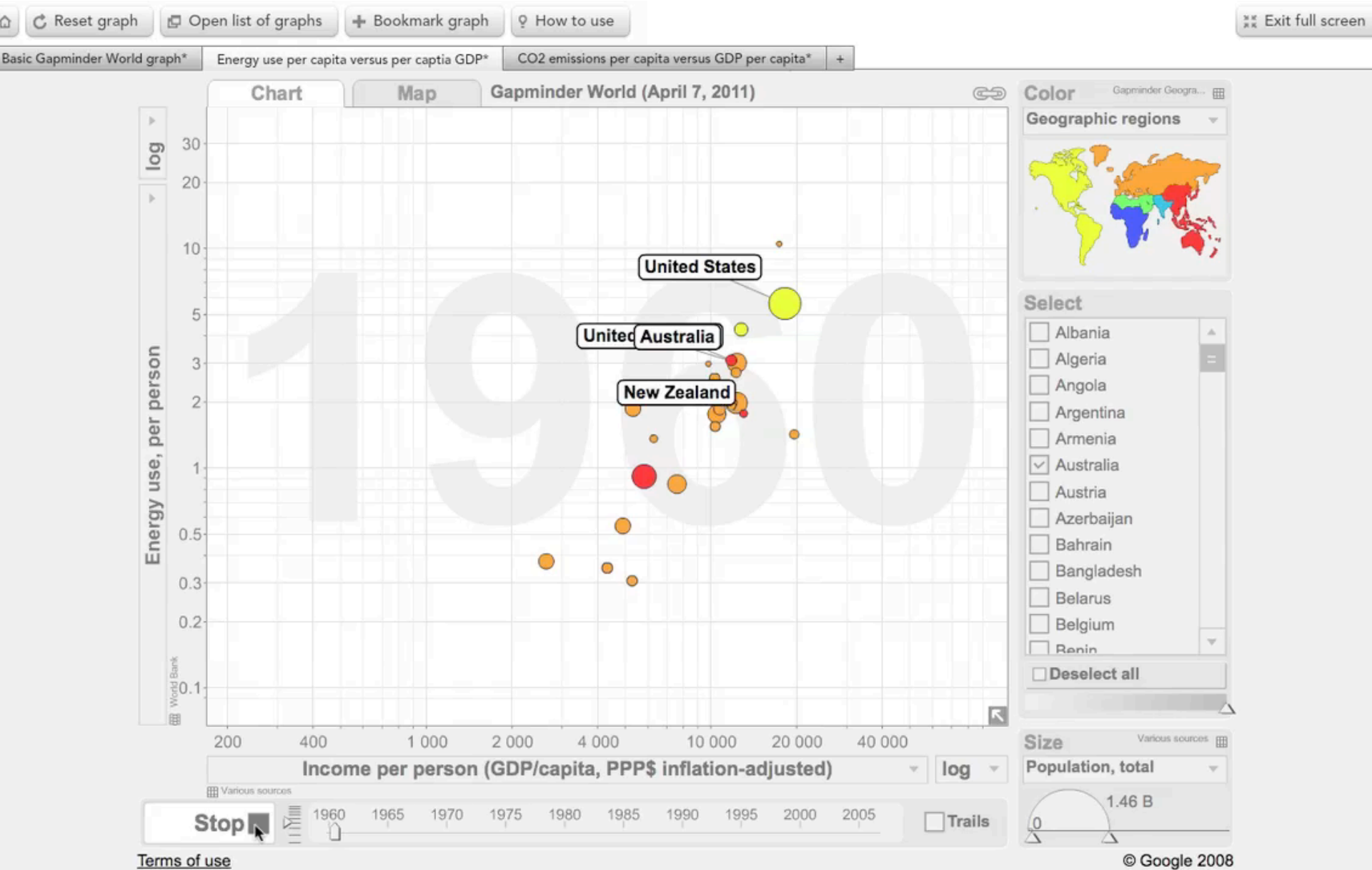
Recently, I watched a humorous news segment on CNN about the U.S. election, specifically about the Blue States and Red States. In this piece, CNN correspondent Jeanne Moos was touring New York City, interviewing people in downtown Manhattan. Many of them felt rather disenchanted from the rest of the country, while some actually felt much more affinity for Canada than for what the United States seems to have become for them. After the interviews, up popped this map of the North American continent, with all the Blue States in blue, all the Red States in red, and all of Canada in blue. Written across the top of Canada was "The United States of Canada" and written across the bottom of the United States, it said, "The United States of America." It was funny, of course, but it had a serious side. I have just finished a book called *The Faith of George Washington*, by Stephen Mansfield (Stargate Communications/Penguin Group, New York). I highly recommend it for those who are interested in the insight into why the United States was created and what motivated this man, and what motivated him.

and remarked that he had a personal connection to this painting. The subject of the work is a lone horseman riding western saddle up over a difficult hill, probably someplace out in Texas. The horseman is actually a Methodist circuit rider, and the whole notion is that this rider is on a mission to go out and do good work, specifically, to spread the early Western religion, and the more I think about that experience and the significance of that painting, the more I believe that the concept of "mission" is at the core of what really does motivate our president. Now that we are embarking on four more years of the Bush administration, I have also been pondering just what implications that mission might have for us. With a Republican majority in both the House and the Senate, and four years to move his agenda forward, President Bush has an excellent opportunity to make his mark on history.

"At some point, almost certainly within this decade, we will peak in the amount of oil that is produced worldwide."

"After four decades of studying these issues, I've concluded that energy is the core of the environment problem, environment is the core of the energy problem, and resolving the energy-economy-environment dilemma is the core of the problem of sustainable well-being for industrial and developing countries alike."  
--John Holdren

# Energy & Environment: Complementary Drivers?



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

# 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

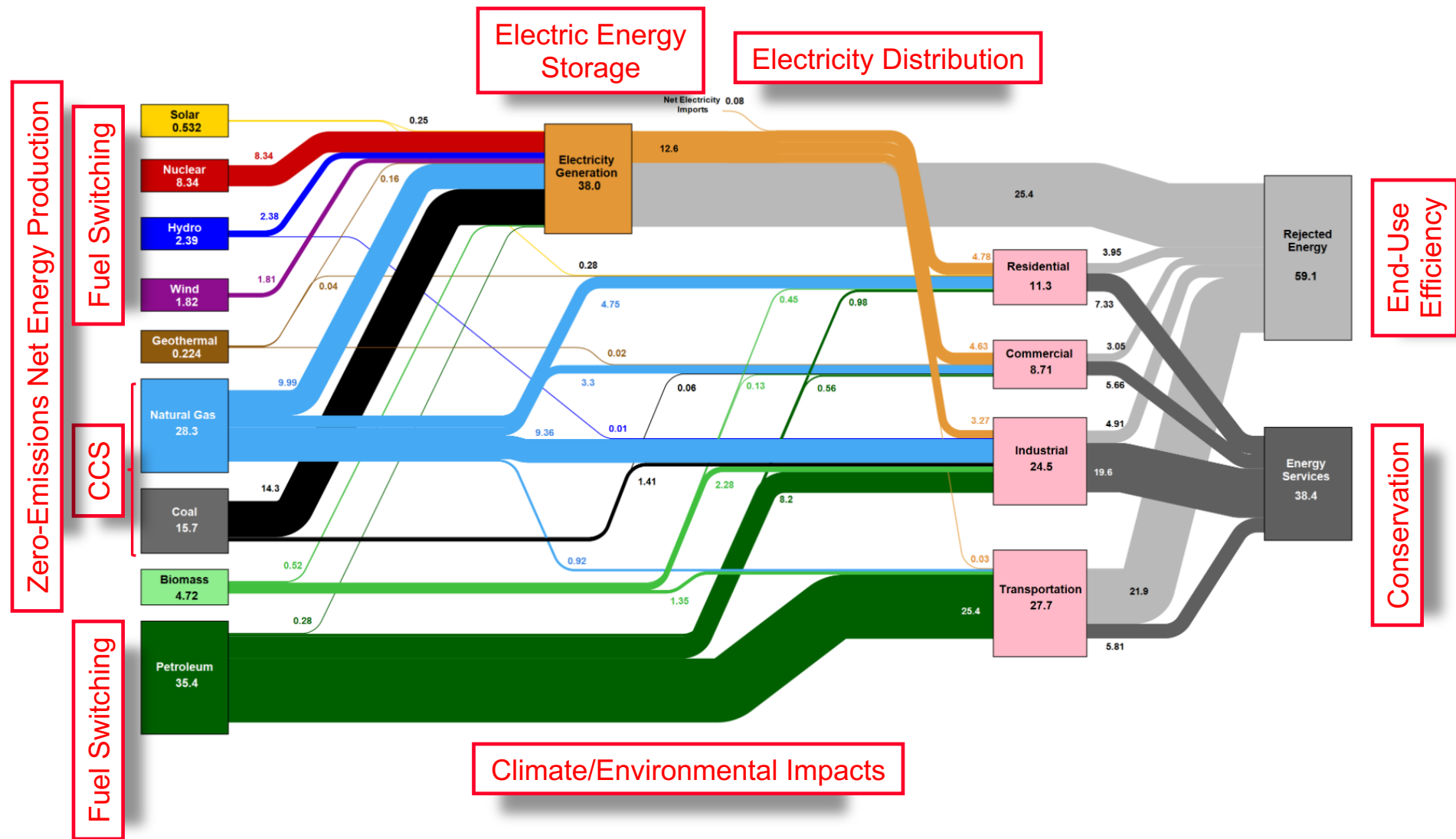
10% larger

[Obama, Science, 2017]



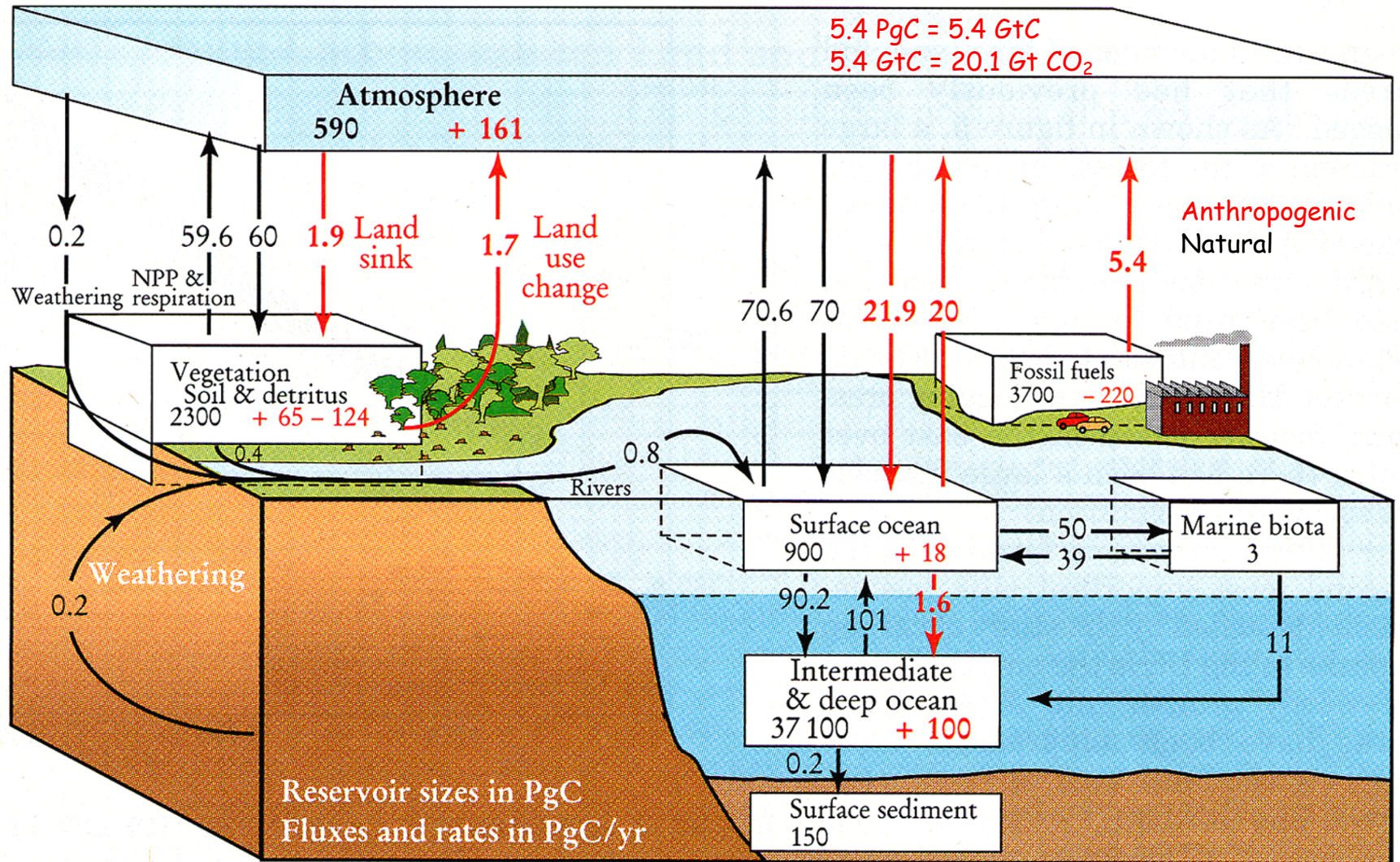
# US Energy Consumption 2015 - Key R&D Strategies

~100 Quads = 100 EJ = 100 tcf CH<sub>4</sub> (~20% of World)



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

# Global Carbon Cycle



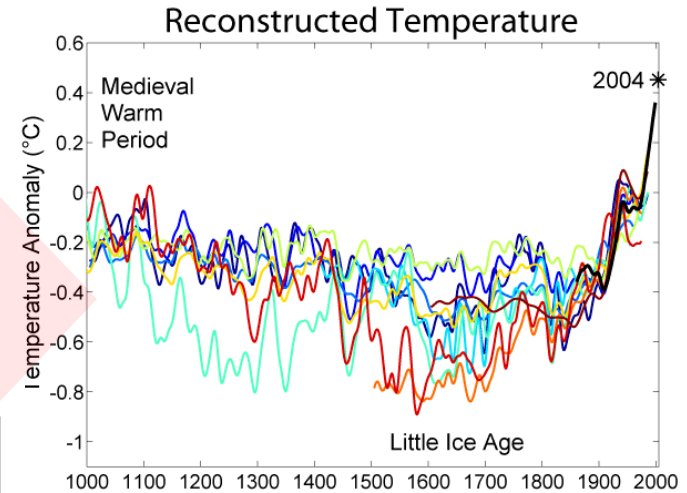
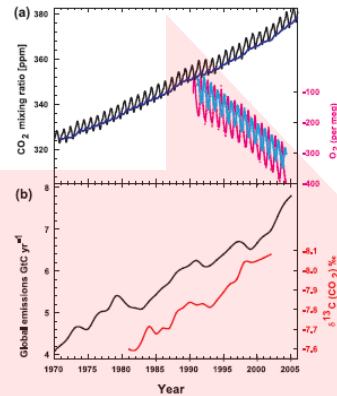
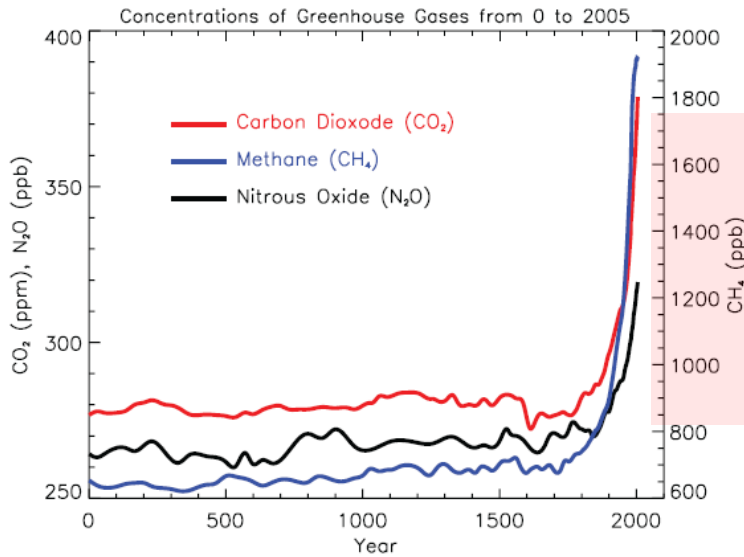
[Sarmiento and Gruber, *Physics Today*, 2002.]

# Climate Change - Equivocal -versus- Unequivocal

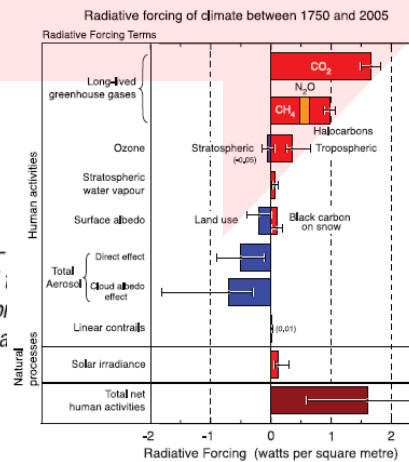
CO<sub>2</sub> versus historic time - IPCC

Parsing Filter

Global Mean Temperatures



**FAQ 2.1, Figure 1.** Atmospheric concentrations of important long-lived greenhouse gases over the last 2,000 years. Increases since about 1750 are attributed to human activities in the industrial era. Concentration units are parts per million (ppm) or parts per billion (ppb), indicating the number of molecules of the greenhouse gas per million or billion air molecules, respectively, in an atmospheric sample. (Data combined and simplified from Chapters 6 and 2 of this report.)



**FAQ 2.1, Figure 2.** Summary of the principal components of the radiative forcing of climate change. All these radiative forcings result from one or more factors that affect climate and are associated with human activities or natural processes as discussed in the text. The values represent the forcings in 2005 relative to the start of the industrial era (about 1750). Human activities cause significant changes in long-lived gases, ozone, water vapour, surface albedo, aerosols and contrails. The only increase in natural forcing of any significance between 1750 and 2005 occurred in solar irradiance. Positive forcings lead to warming of climate and negative forcings lead to a cooling. The thin black line attached to each coloured bar represents the range of uncertainty for the respective value. (Figure adapted from Figure 2.20 of this report.)



# Science is Parsed through a Legislative Filter

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# Science is Parsed through a Legislative Filter

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# *Administration's Energy Plan*

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- Within 10 years save more oil than we currently import from the Middle East and Venezuela combined.
- Put 1 million plug-in hybrid cars – cars that can get up to 150 miles per gallon – on the road by 2015.
- Generate 10 percent of our electricity from renewable sources by 2012, and 25 percent by 2025.
- Implement an economy-wide, cap-and-trade program to reduce greenhouse gas emissions 80% by 2050.

**Sub-Surface  
Baseload Energy**

## **Administration's Energy Plan**

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**Demand-Side  
Reduction**

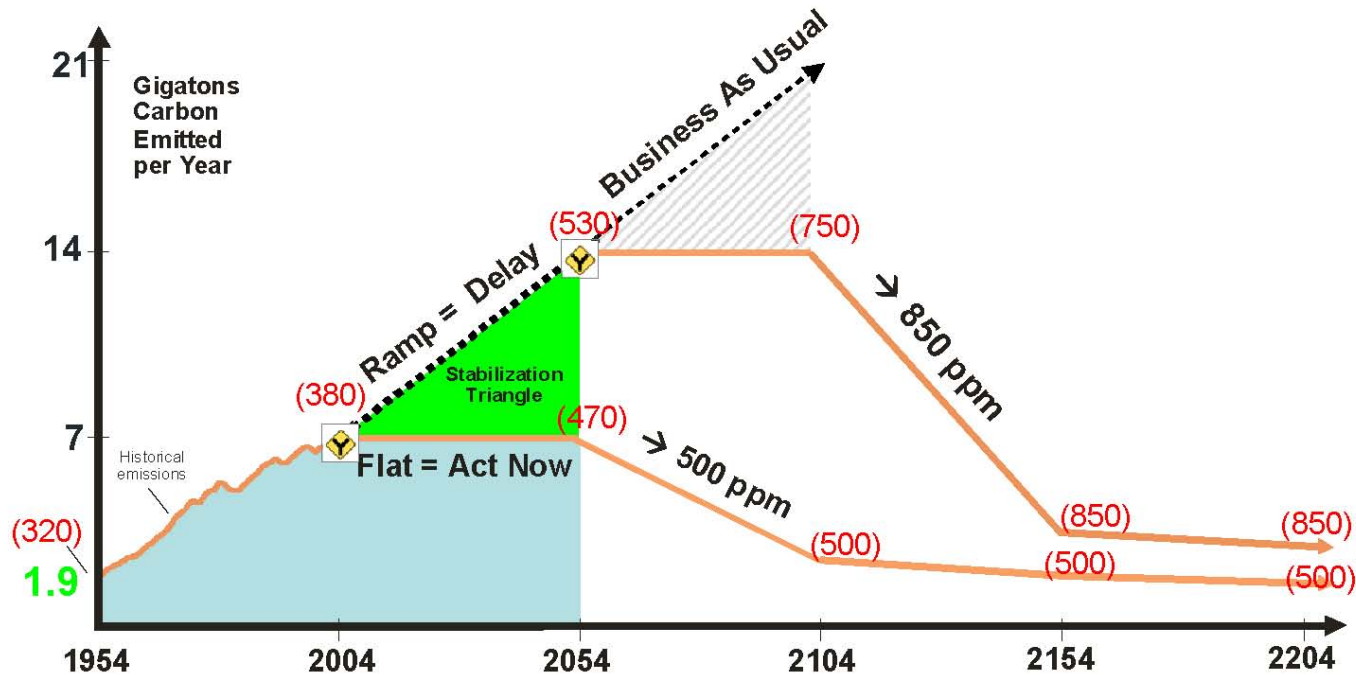
**Stationary Sources  
and CCS**

**Geothermal and  
Other Sources**

**Fuel Switching to  
low(er) Carbon fuels  
and Carbon Capture &  
Storage**

# Capacity Needs - Socolow Wedges

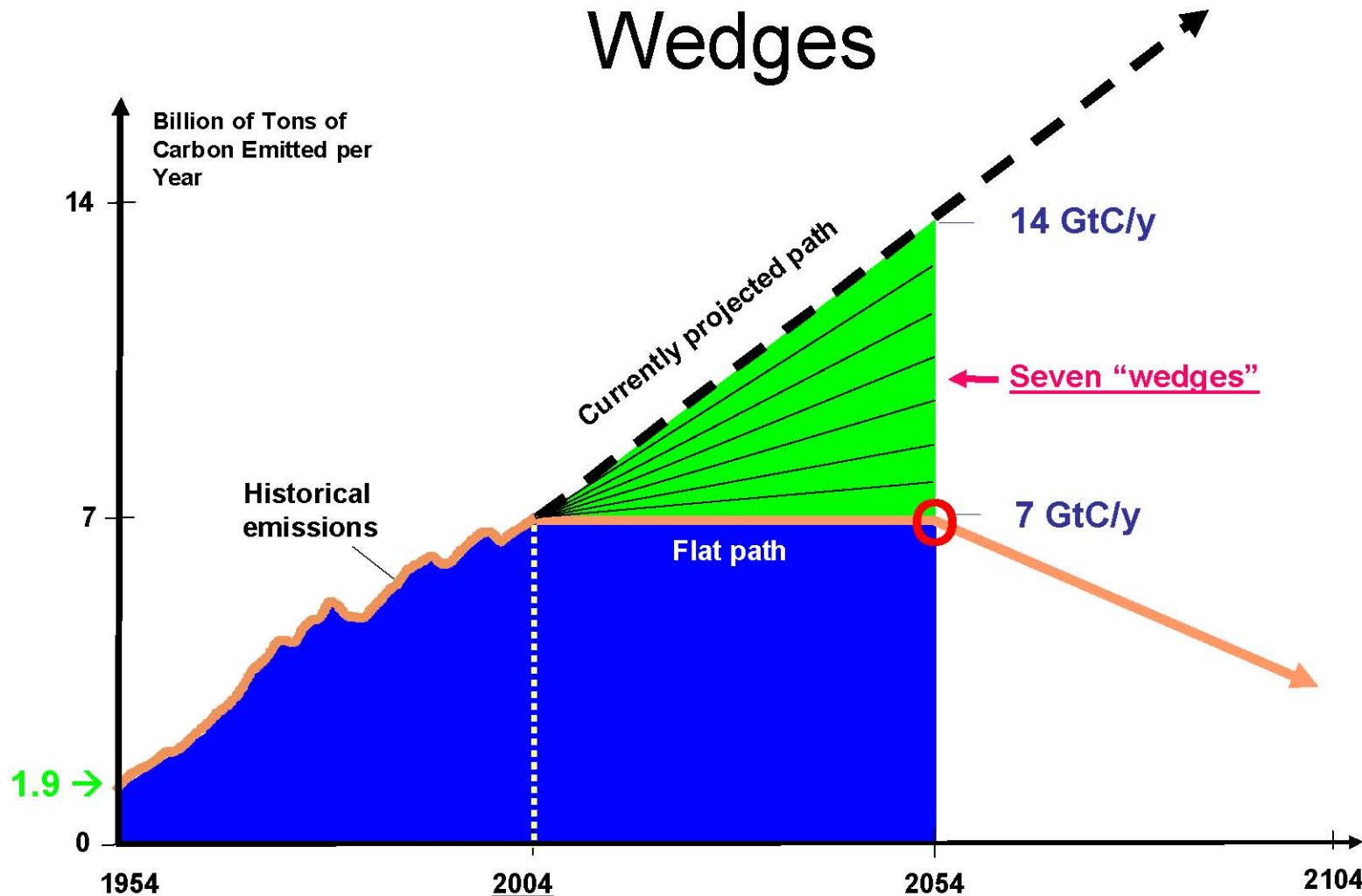
## The Stabilization Triangle: Beat doubling or accept tripling



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

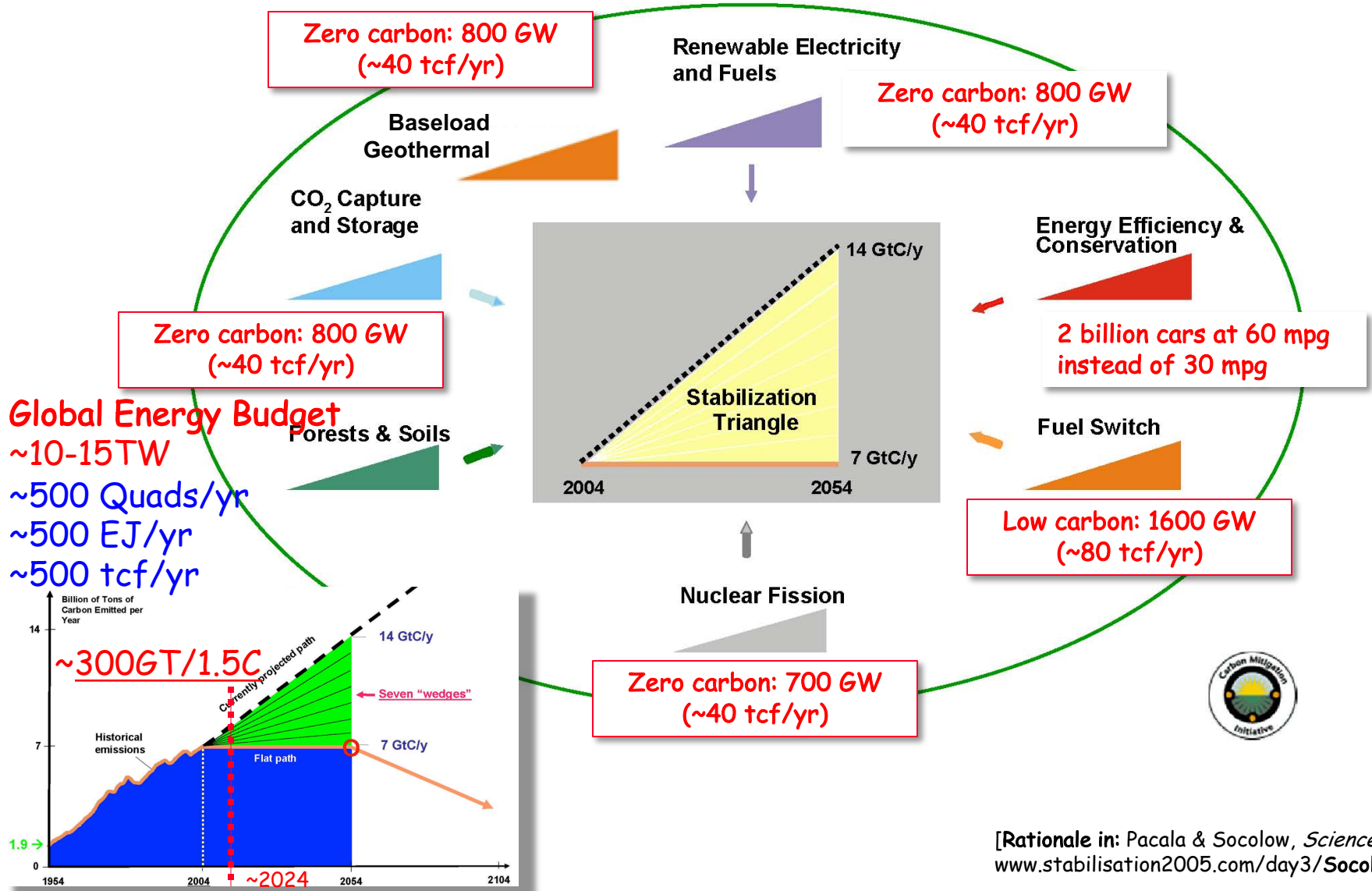
[Rationale in: Pacala & Socolow, *Science*, 2004, [www.stabilisation2005.com/day3/Socolow.pdf](http://www.stabilisation2005.com/day3/Socolow.pdf)]

# Capacity Needs - Socolow Wedges



# Capacity Needs - Stabilization Wedges

Fill the Stabilization Triangle with Seven Wedges



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

# Sub-Surface Energy/Engineering Solutions

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## Low-Carbon Fuel Solutions?

### Unconventional Hydrocarbons

- Gas shales
- Coalbed methane
- Methane hydrates

## Carbon Management Solutions?

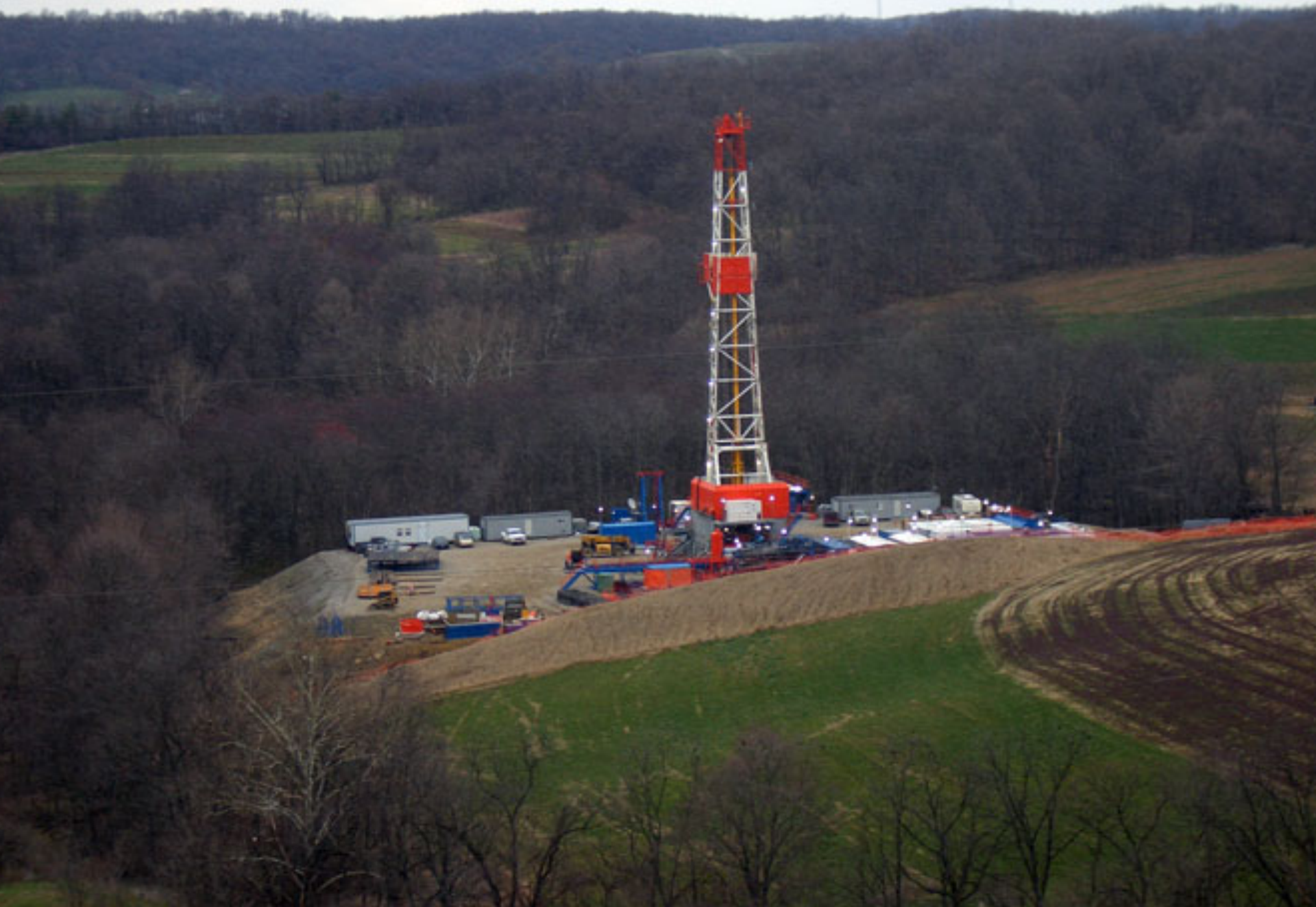
- Carbon Capture and Sequestration

## Zero-Carbon Solutions?

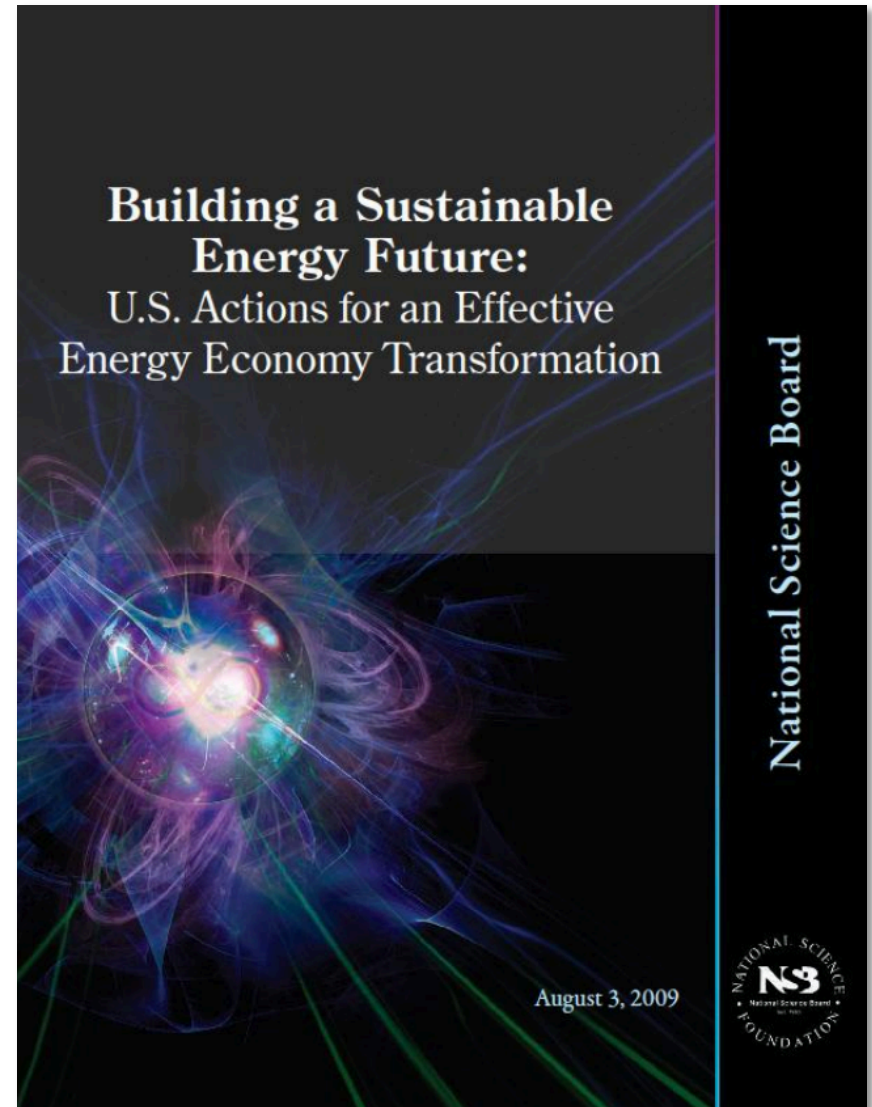
- EGS Geothermal - The new landscape
- Nuclear power
- Hydropower/Pumped storage/CAES
- Wind
- Solar PV and thermal



# Low-Carbon Fuel Solution? - Gas Shales



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

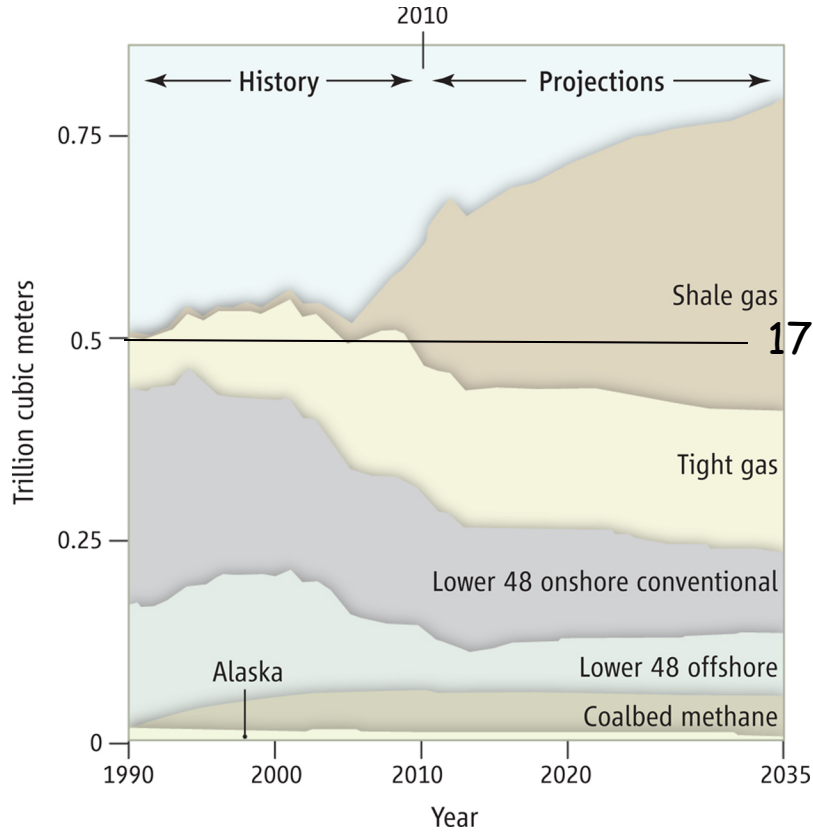


# North American shale plays (as of May 2011)

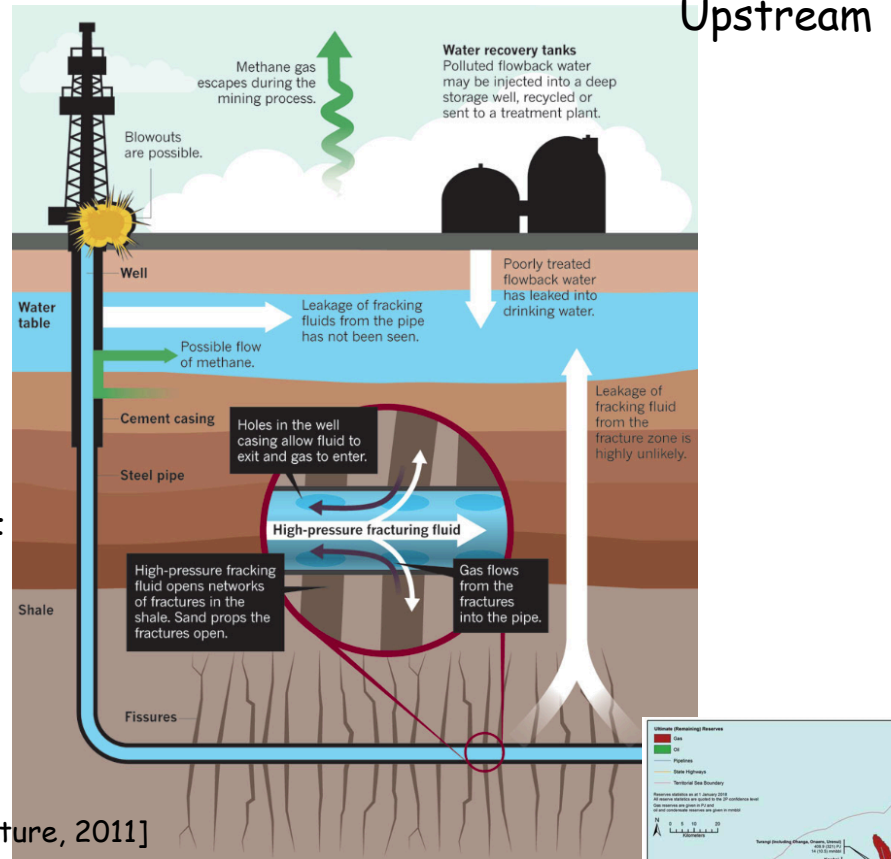


# Projected Growth and Opportunities

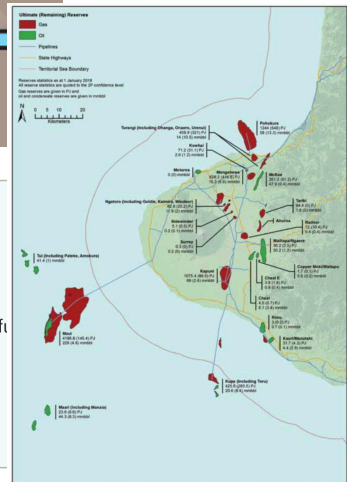
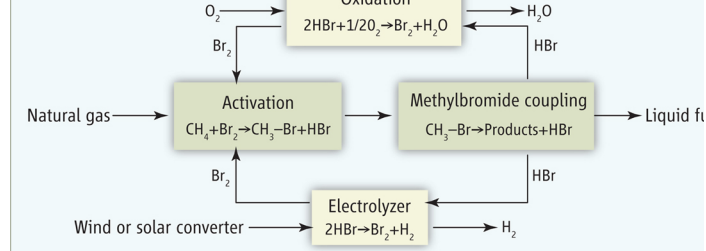
## Natural Gas Utilization



[Science, Oct 18, 2012]



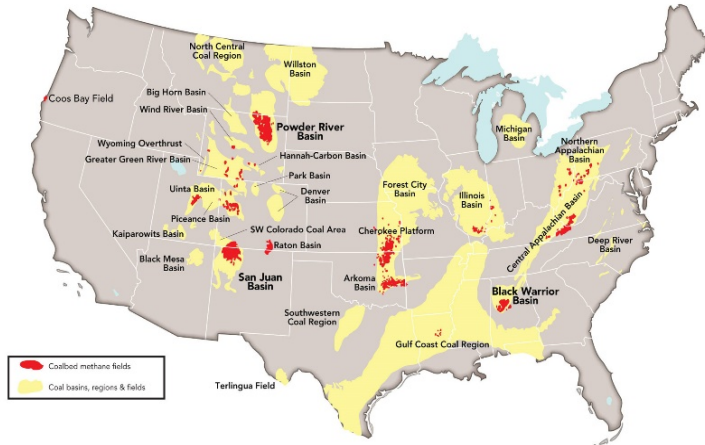
## Downstream



# Microbially-Enhanced CBM (MECBM)

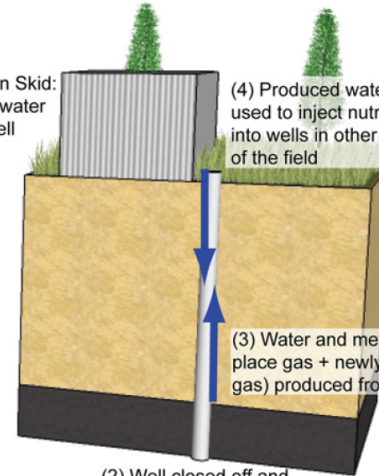
## Geographic Distribution

Coalbed methane fields, lower 48 states [~100 Tcf recoverable]



## Methods of production

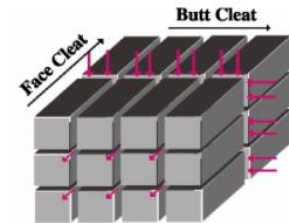
(1) Nutrient Injection Skid: Nutrients added to water and injected into well using gravity



(3) Water and methane (in place gas + newly generated gas) produced from well

(2) Well closed off and nutrients allowed to soak for several years

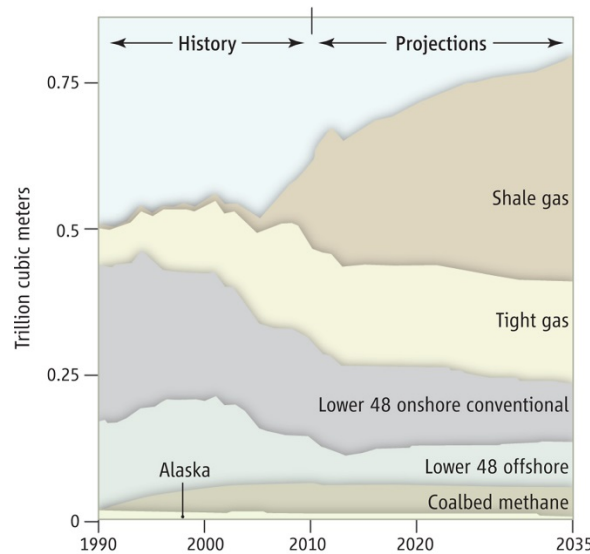
(4) Produced water used to inject nutrient into wells in other parts of the field



Production through natural fractures

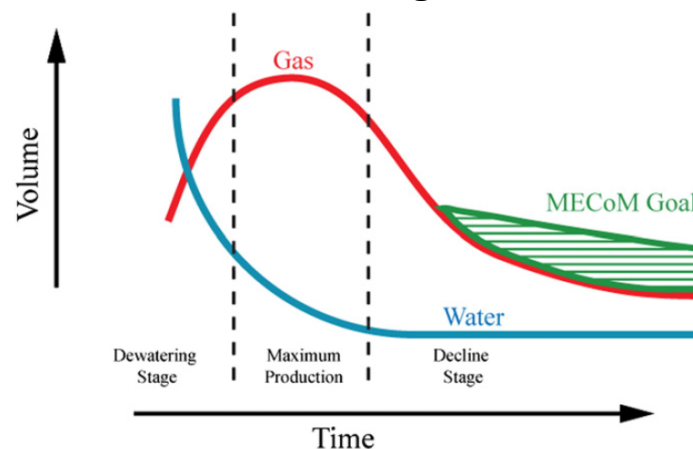
Figure 1. Coalbed Methane Development

## Projected US Gas Production



[Science, Oct 18, 2012]

## MECBM Scheduling



[Nuccio, 2000]

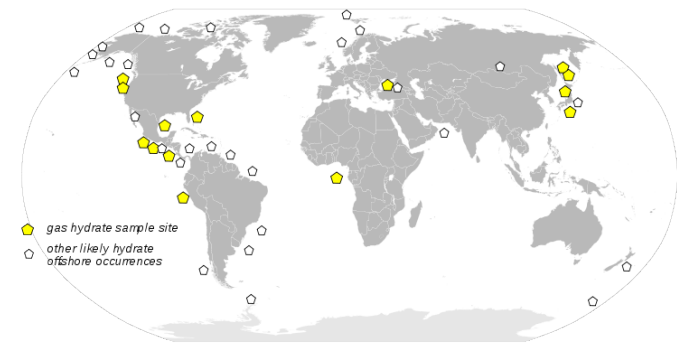
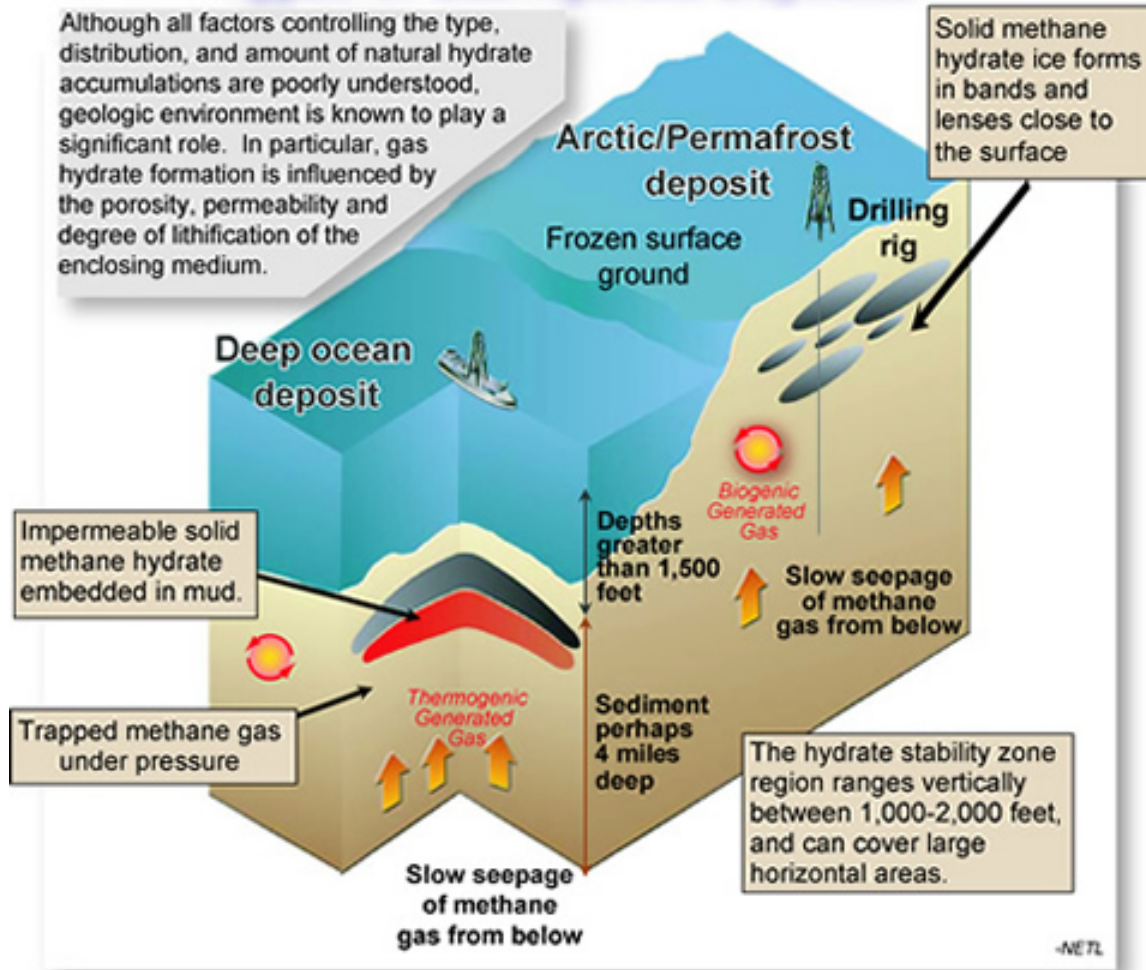
## Principal Issues

- Environmental Effects
- Rate Limits on Production
- Dewatering
- Desorption - Capacity
- Advection - Perm Evolution
- Sequestration

# Low-Carbon Fuel Solution? - Methane Hydrates

## Types of Gas Hydrate Deposits

Although all factors controlling the type, distribution, and amount of natural hydrate accumulations are poorly understood, geologic environment is known to play a significant role. In particular, gas hydrate formation is influenced by the porosity, permeability and degree of lithification of the enclosing medium.



**Projected Clathrate Reserve/Resource: - /  $10^5$ - $10^6$  Tscf**

# Capacity Needs - Socolow Wedges

## Replace Coal Fired Plants with Gas-Fired Generation



Effort needed by 2054 for 1 wedge:

1600 GW of coal-fired generating capacity

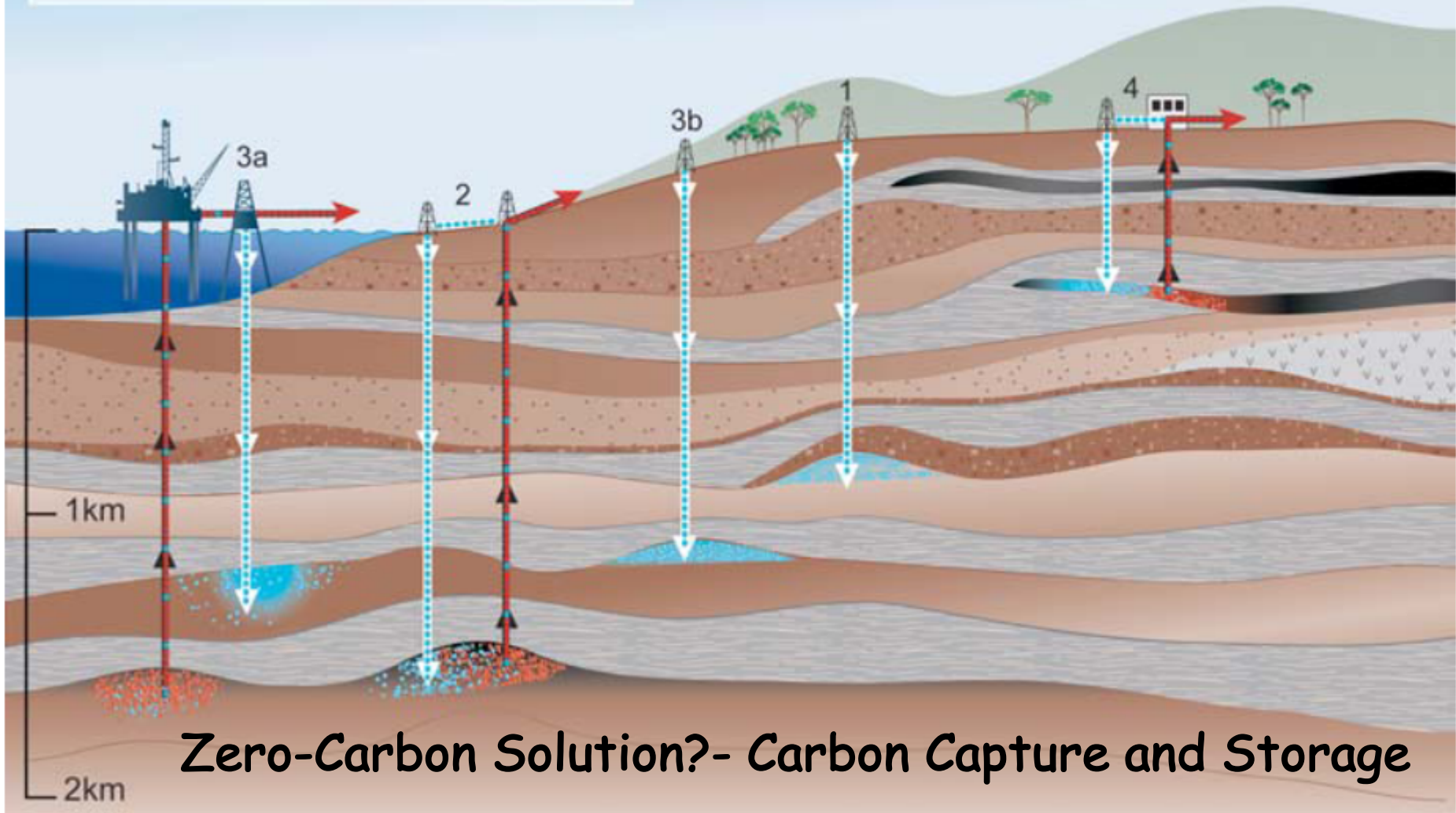
**~80 Tcf/yr Natural gas**

$CO_{2\text{coal}}/CO_{2\text{gas}}$  ratio is ~1.78 for equivalent thermal energy

Pulrose Gas Power Station, Isle of Man, UK

## Overview of Geological Storage Options

- 1 Depleted oil and gas reservoirs
- 2 Use of CO<sub>2</sub> in enhanced oil and gas recovery
- 3 Deep saline formations — (a) offshore (b) onshore
- 4 Use of CO<sub>2</sub> in enhanced coal bed methane recovery



Zero-Carbon Solution?- Carbon Capture and Storage



# Capacity Needs - Socolow Wedges

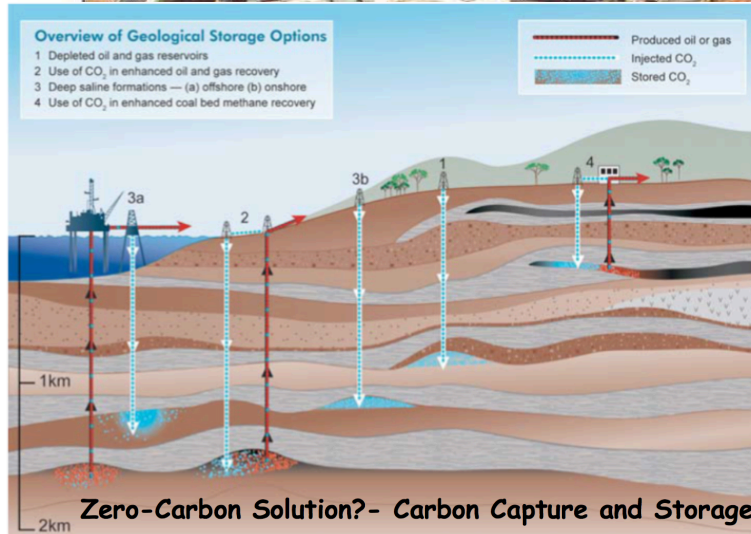
## Power with Carbon Capture and Storage



Effort needed by 2054 for 1 wedge:

Carbon capture and storage at 800 GW coal power plants.

**~40 Tcf/yr Natural gas**



Courtesy of CO2CRC, <http://www.co2crc.com.au/>

Project



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

# Zero-Carbon Solution? - Enhanced Geothermal Systems

## Challenges

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

## Observation

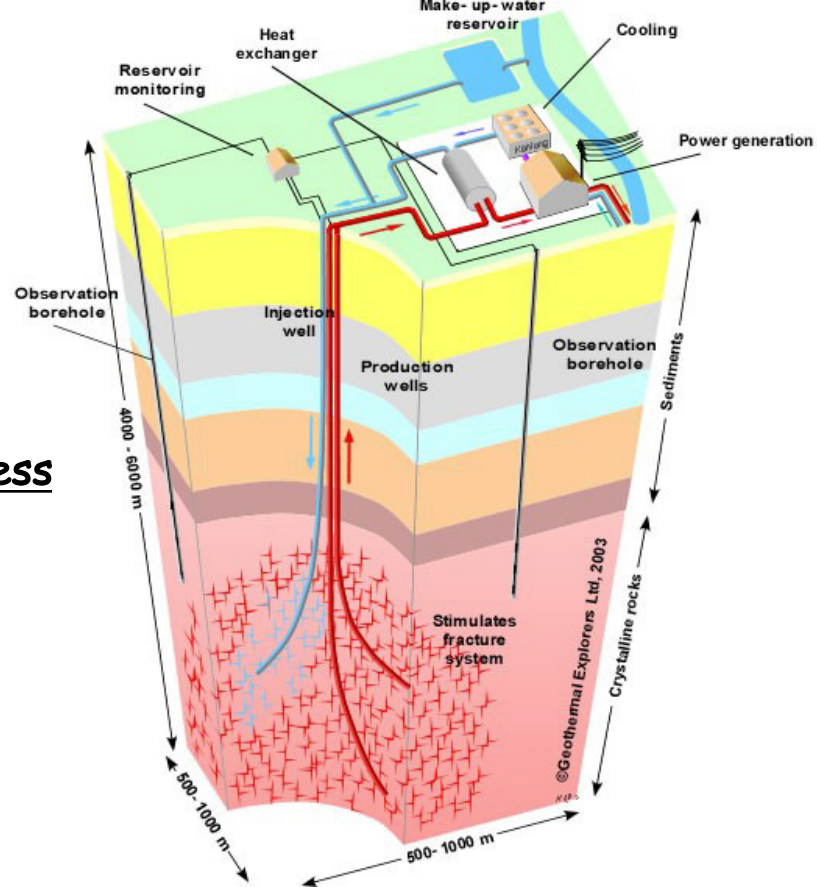
- Stress-sensitive reservoirs
- T H M C all influence via effective stress
- Effective stresses influence
  - Permeability
  - Reactive surface area
  - Induced seismicity

## 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

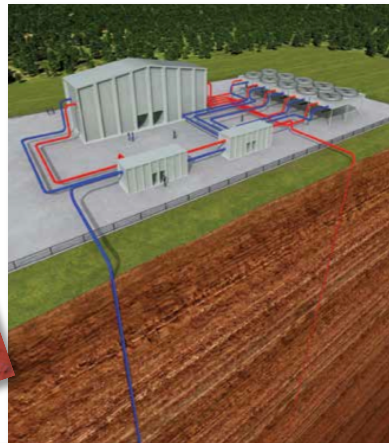
## Resource

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



- Permeability
- Reactive surface area
- Induced seismicity

# Hydrothermal v Engineered Geothermal Reservoirs



SedHeat Initiative  
<http://geothermal.tcu.edu>

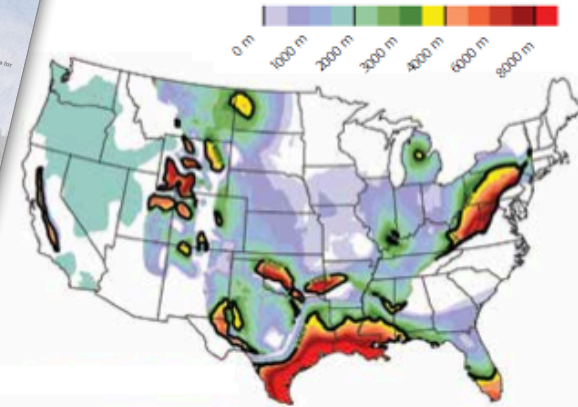


Figure 1: Distribution of sediment thickness in the conterminous U.S. 4 km isopach in black. Numerous Basin and Range basins over 4 km excluded for small resolution (Tester, et al., 2006)

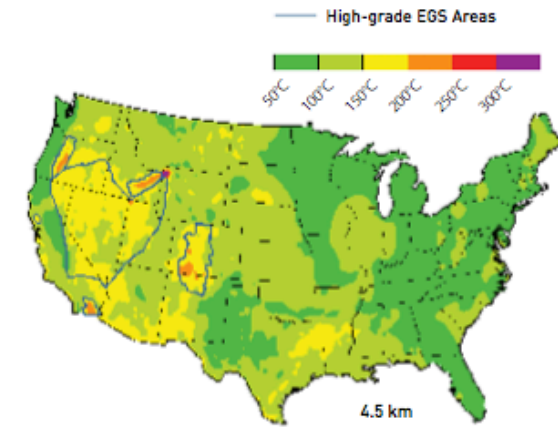
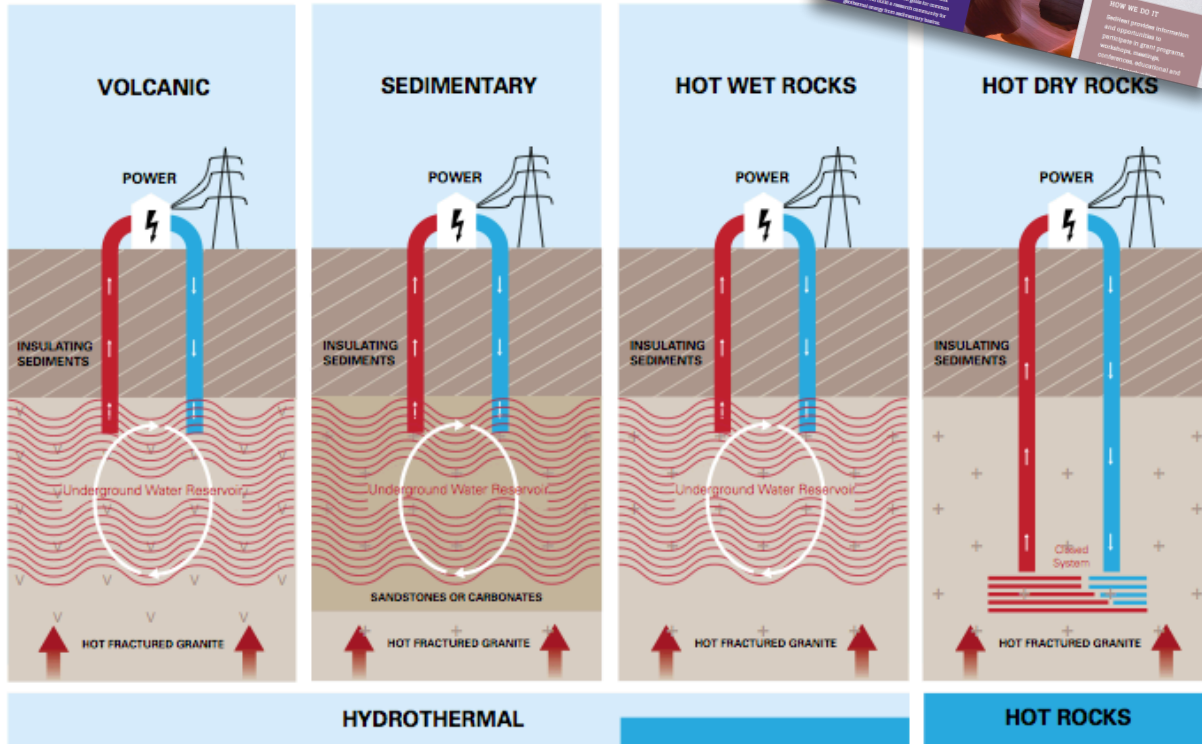
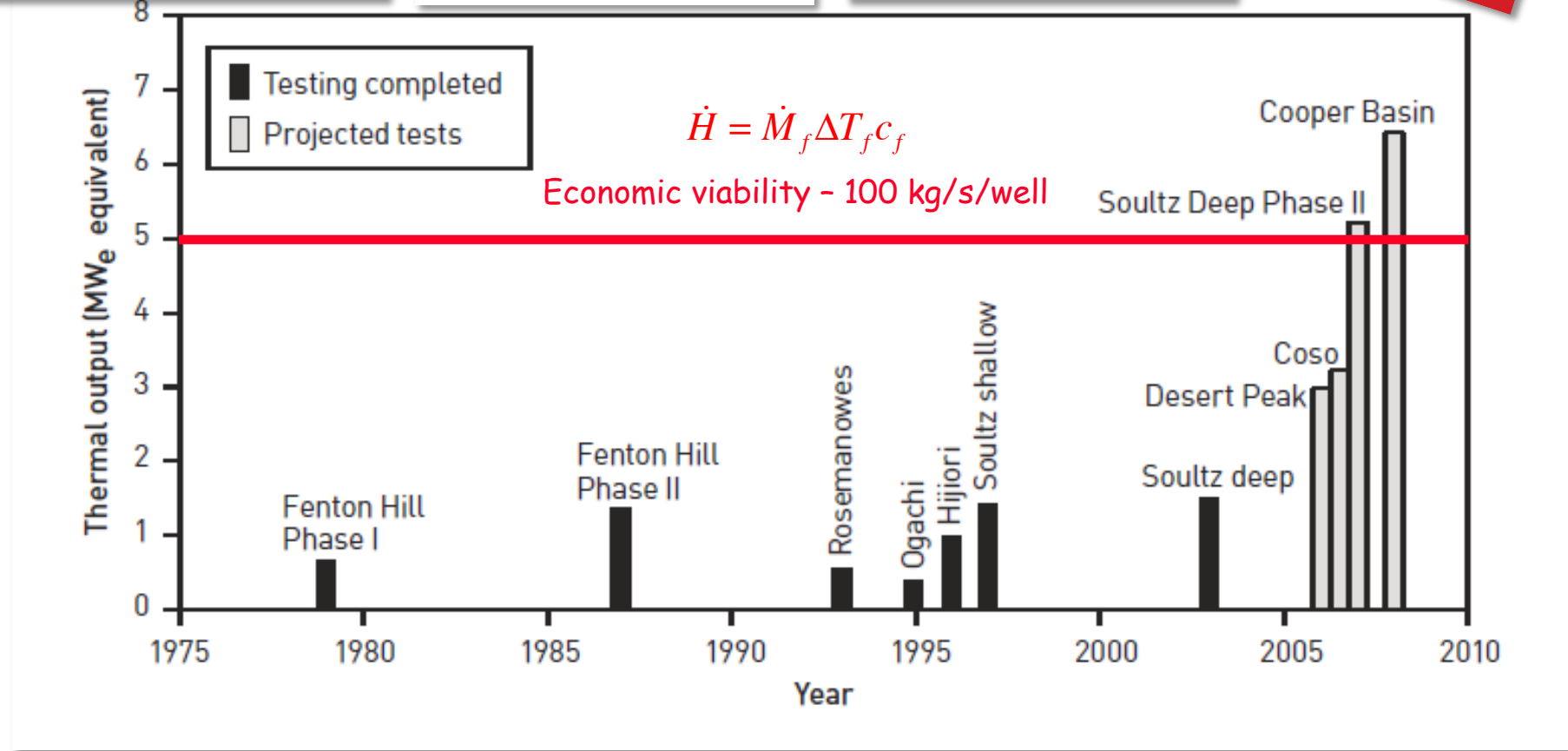
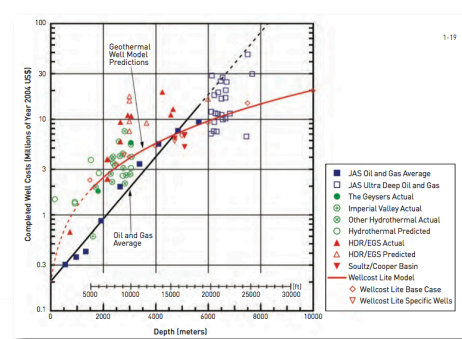
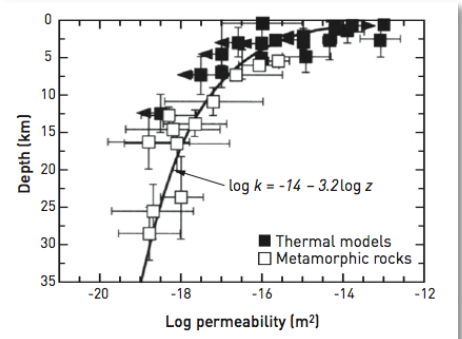
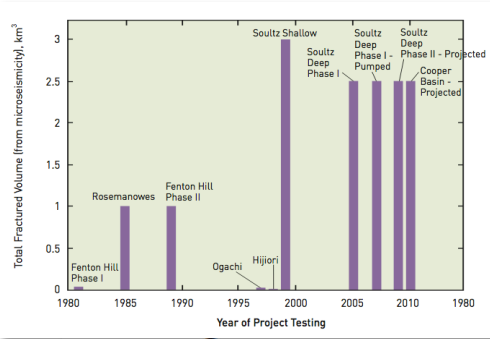


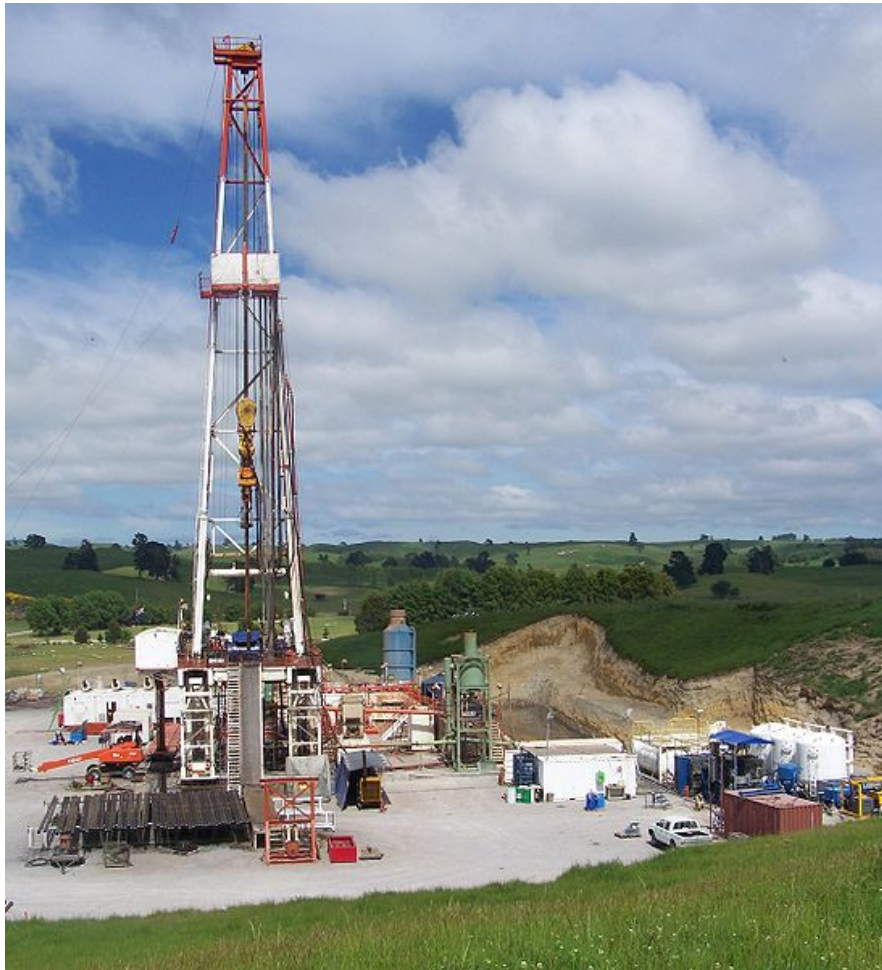
Figure 2: Average temperature at 4.5 km, conterminous United States. (Tester, et al., 2006, after Blackwell and Richards, 2004)

# Can EGS ever be Viable?



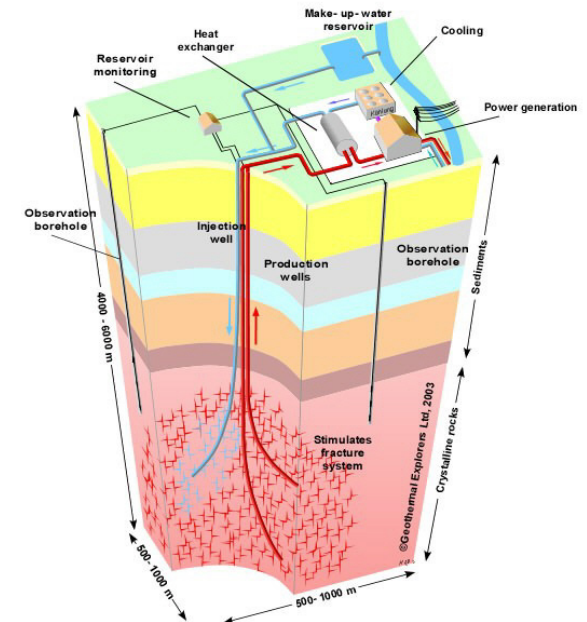
# Capacity Needs - Socolow Wedges

## Retire Coal Fired Plants and Replace with EGS



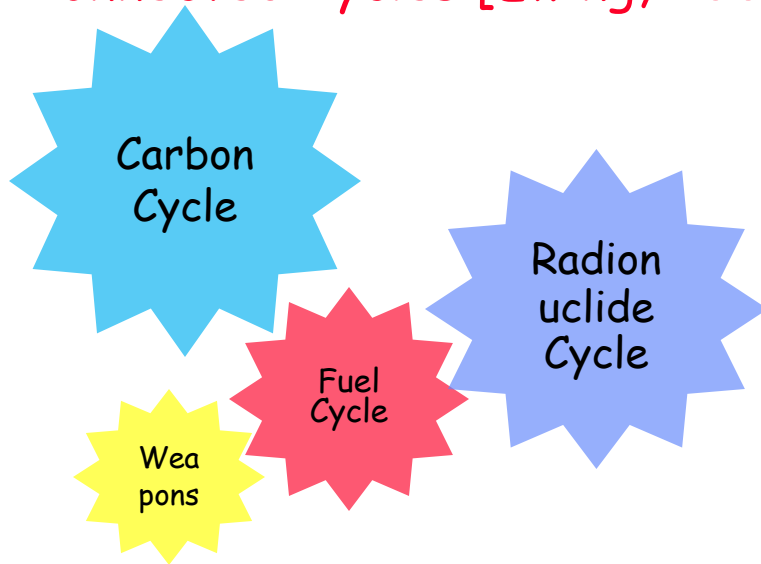
Effort needed by 2054 for 1 wedge:

800 GW of EGS capacity  
~40 Tcf/yr Natural gas



# Zero Carbon Solution? - Nuclear Power

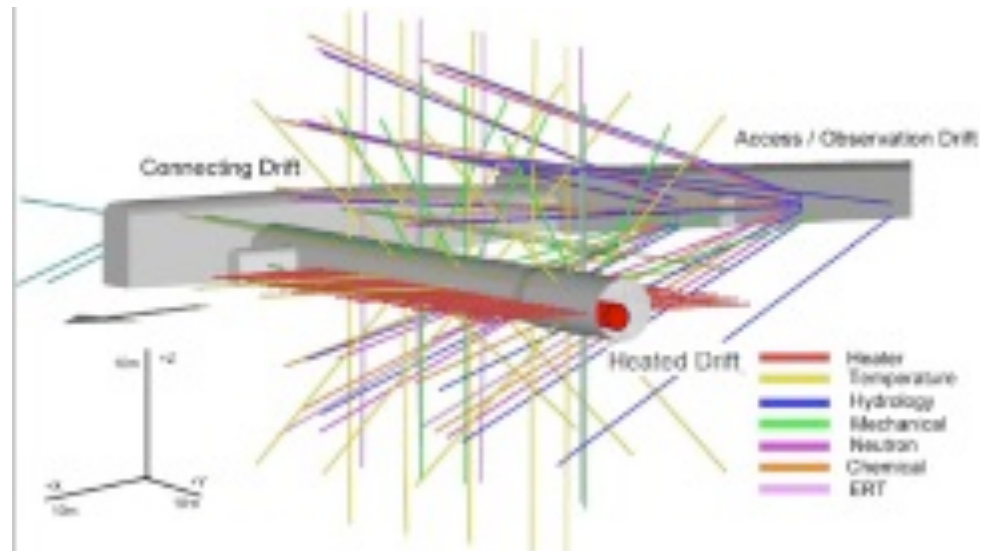
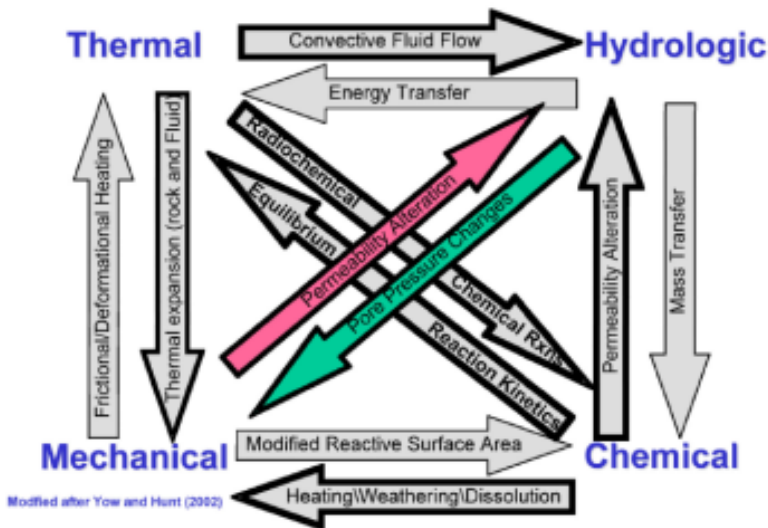
Connected Cycles [Ewing, 2007]



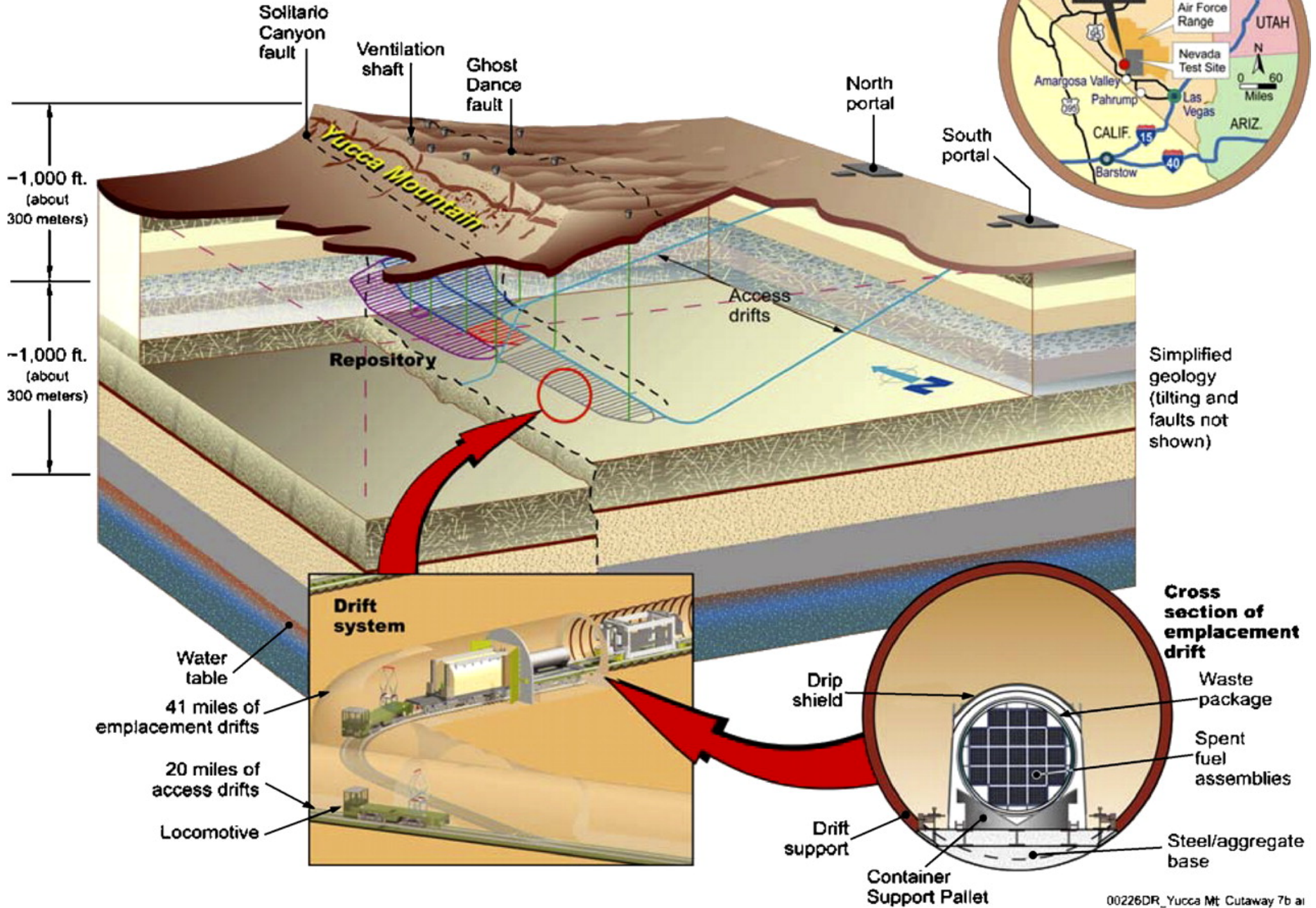
Waste Disposal and Politics

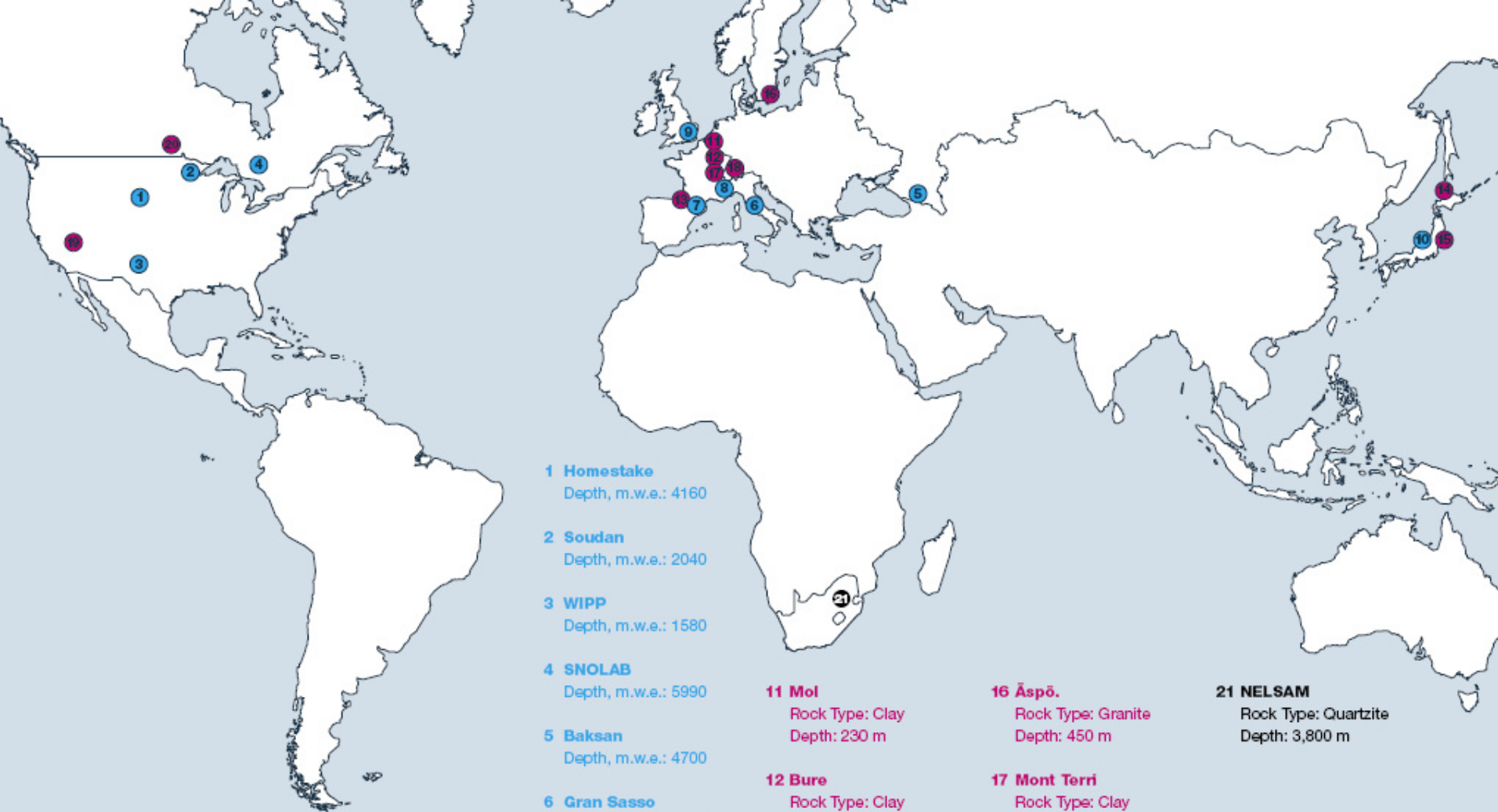


Intense Process Feedbacks



# Zero Carbon Solution? - Nuclear Power





**1 Homestake**  
Depth, m.w.e.: 4160

**2 Soudan**  
Depth, m.w.e.: 2040

**3 WIPP**  
Depth, m.w.e.: 1580

**4 SNOLAB**  
Depth, m.w.e.: 5990

**5 Baksan**  
Depth, m.w.e.: 4700

**6 Gran Sasso**  
Depth, m.w.e.: 3030

**7 Canfranc**  
Depth, m.w.e.: 2450

**8 Fréjus/Modane**  
Depth, m.w.e.: 4150

**9 Boulby**  
Depth, m.w.e.: 2805

**10 Kamioka**  
Depth, m.w.e.: 2050

**11 Mol**  
Rock Type: Clay  
Depth: 230 m

**12 Bure**  
Rock Type: Clay  
Depth: 450 m

**13 Toumemire**  
Rock Type: Clay  
Depth: 300 m

**14 Horonobe**  
Rock Type: Sedimentary  
Depth: 1,000 m

**15 Tono (Mizunami)**  
Rock Type: Granite  
Depth: 1,000 m

**16 Äspö.**  
Rock Type: Granite  
Depth: 450 m

**17 Mont Terri**  
Rock Type: Clay  
Depth: 300 m

**18 Grimsel**  
Rock Type: Granite  
Depth: 450 m

**19 Yucca Mountain**  
Rock Type: Volcanic tuff  
Depth: 300 m

**20 Pinawa**  
Rock Type: Granite  
Depth: 450 m

**21 NELSAM**  
Rock Type: Quartzite  
Depth: 3,800 m

Figure 1: Underground laboratories worldwide. Physics laboratories (blue) are listed with their depths in meters water equivalent. Laboratories for research into the long-term (~million-year) isolation of high-level nuclear waste, shown in red, are listed with actual depth. The NELSAM laboratory (black) is for earthquake research.



# Yucca Mountain in the News

## Off-Again?

[NYT, January 29, 2009]

### New Panel Will Study Disposal Of Waste

By MATTHEW L. WALD  
Published: January 29, 2010

#### WASHINGTON








The Energy Department plans to announce on Friday the formation of a "blue ribbon" commission to study the disposal of nuclear waste.

The commission is to be led by Lee H. Hamilton, a former member of Congress and co-chairman of the Sept. 11 commission, and Brent Scowcroft, a retired Air Force general and former presidential adviser, said a staff member of a member of Congress from Nevada.

The Obama administration promised to appoint such a study group almost a year ago, after announcing that it would cease study of Yucca Mountain, a volcanic structure about 100 miles from Las Vegas that had been chosen by Congress as the leading candidate for nuclear waste disposal.

The Senate majority leader, Harry Reid, Democrat of Nevada, had made killing the Yucca Mountain option a priority. Energy Secretary Steven Chu has said that the commission will not consider Yucca Mountain. Dr. Chu has spoken of alternatives to the burial of nuclear waste, including new reactors that might reuse some of the waste by turning it into energy, and the commission will consider those possibilities.

The federal government faces billions of dollars in damages in lawsuits by utilities, because in the early 1980s it signed contracts agreeing to begin taking the waste in 1998. The utilities, in exchange, paid the government one-tenth of a cent per kilowatt-hour produced by the reactors. On Jan. 12, the United States Court of Appeals for the Federal Circuit ruled against the Energy Department's most recent argument, that it could not be forced to pay because the delay was unavoidable.

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# Yucca Mountain in the News

## Or On-Again?

[NYT, June 29, 2010]

### Administration Cannot Drop Bid for Nuclear Waste Dump in Nevada, Panel Finds

By MATTHEW L. WALD

Published: June 29, 2010

WASHINGTON — In a setback for the Obama administration, a panel of judges at the [Nuclear Regulatory Commission](#) ruled on Tuesday that the Energy Department could not withdraw its application to open a nuclear waste dump at [Yucca Mountain](#) in Nevada.



Congress selected the Yucca Mountain location in 1987.

Making good on a campaign pledge by [President Obama](#), the Energy Department had formally sought to drop its plan for [Yucca Mountain](#), a volcanic structure about 100 miles from Las Vegas. But states with major accumulations of waste from [nuclear weapons](#) production had petitioned to prevent the department from doing so.

In a 47-page [decision](#), the three-member panel of administrative judges said the Energy Department lacked the authority to drop the petition because it would flout a law passed by Congress.

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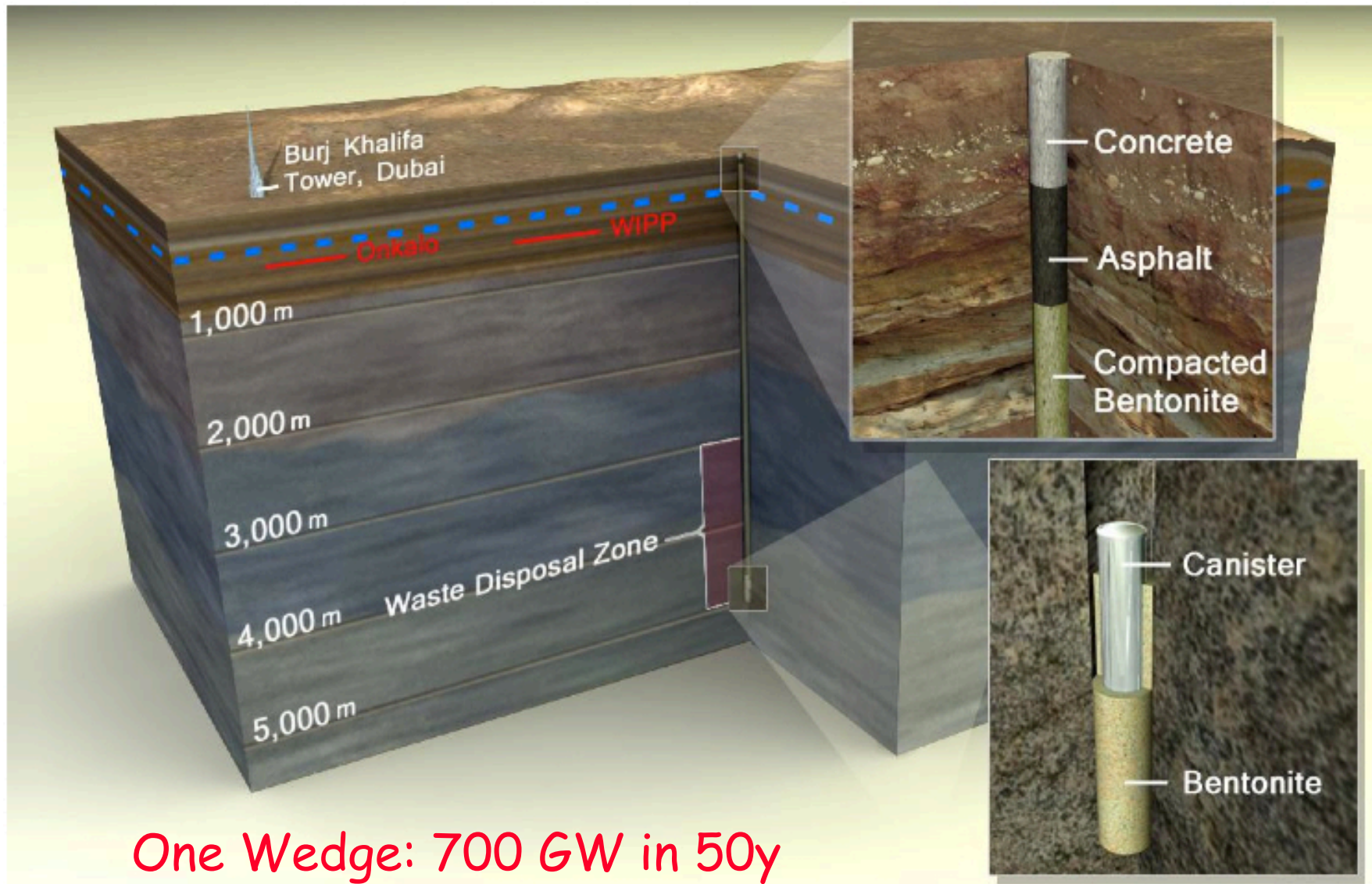
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**CONVICTION**  
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# The New US Plan



One Wedge: 700 GW in 50y  
40 Tcf/y

[<http://www.forbes.com/>]

# Sub-Surface Energy/Engineering Solutions

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## Low-Carbon Fuel Solutions?

### Unconventional Hydrocarbons

- Gas shales
- Coalbed methane
- Methane hydrates

## Carbon Management Solutions?

- Carbon Capture and Sequestration

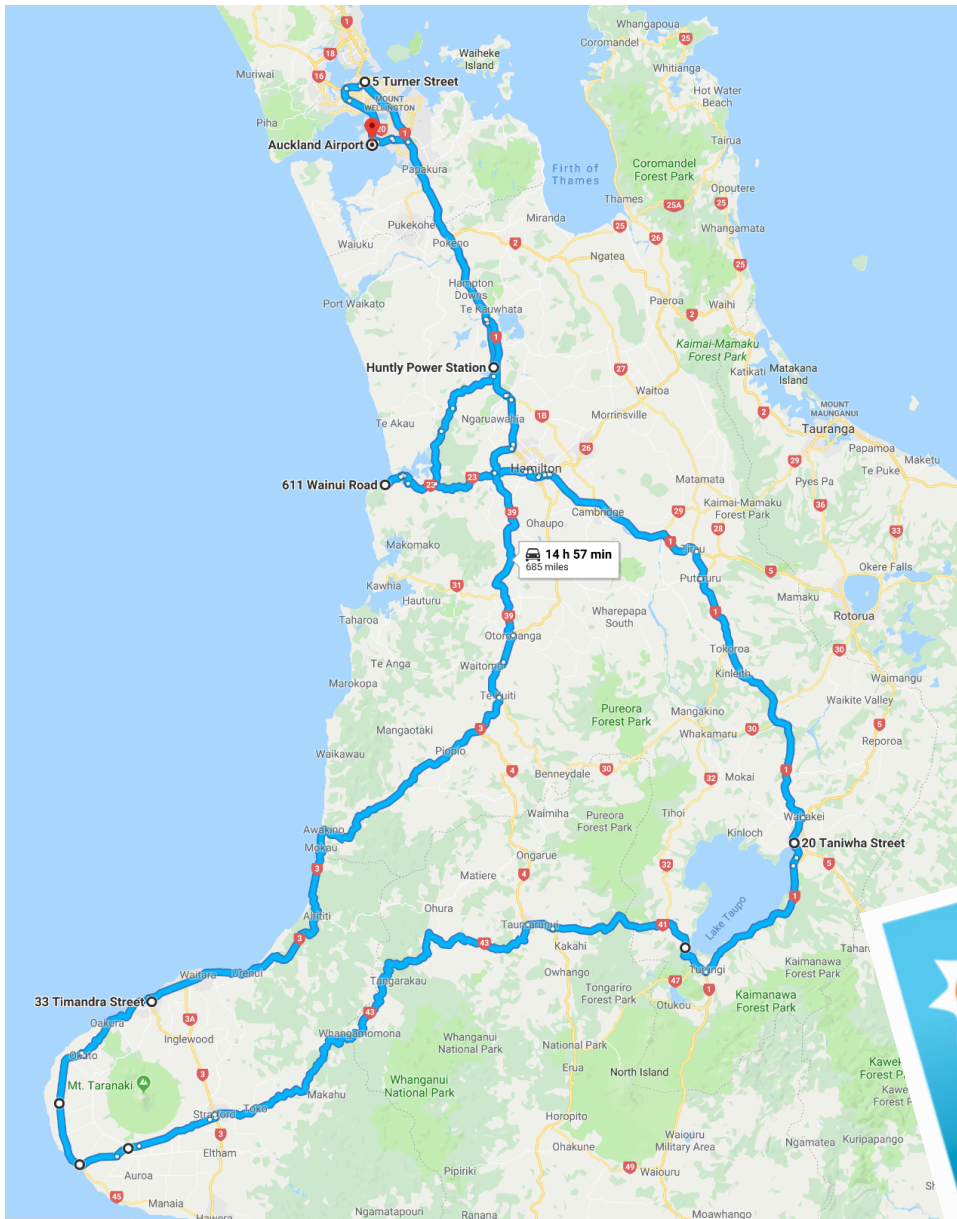
## Zero-Carbon Solutions?

- EGS Geothermal - The new landscape
- Nuclear power
- Hydropower/Pumped storage/CAES
- Wind
- Solar PV and thermal

# The Green New Deal



# Sustainable Energy in New Zealand



Annual Consumption - 1 EJ (NZ)  
100 EJ (USA)

NZ Energy consumption 1 EJ/yr ~ 30 GW

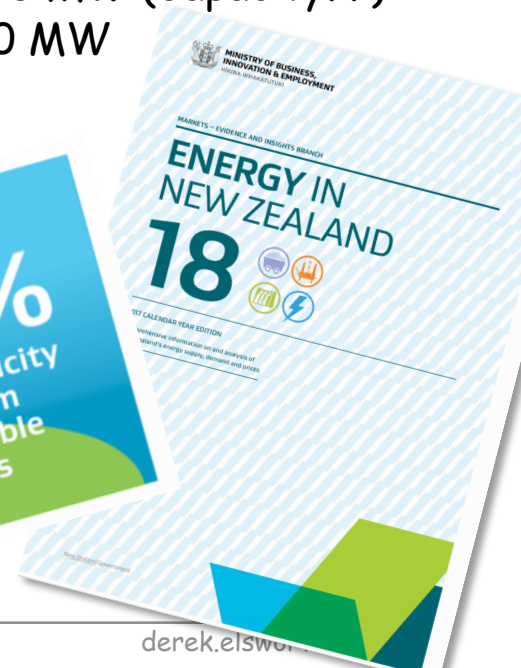
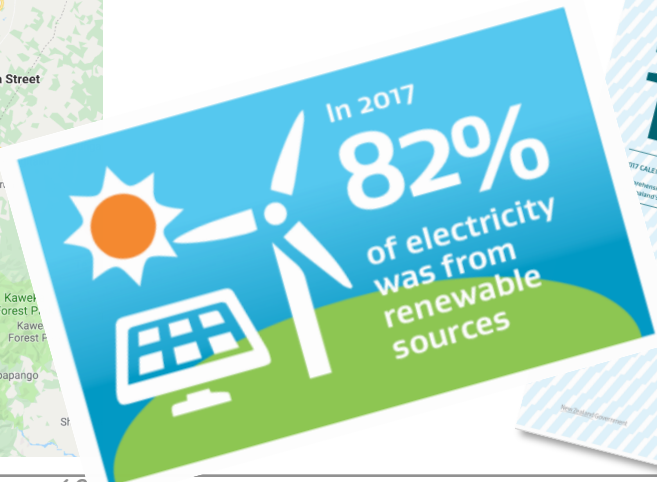
Typically 50/50 Electricity/Transportation

Thermal - 1400 MW (Huntly)  
Gas (360 MW)  
Coal (4 x 250 MW)

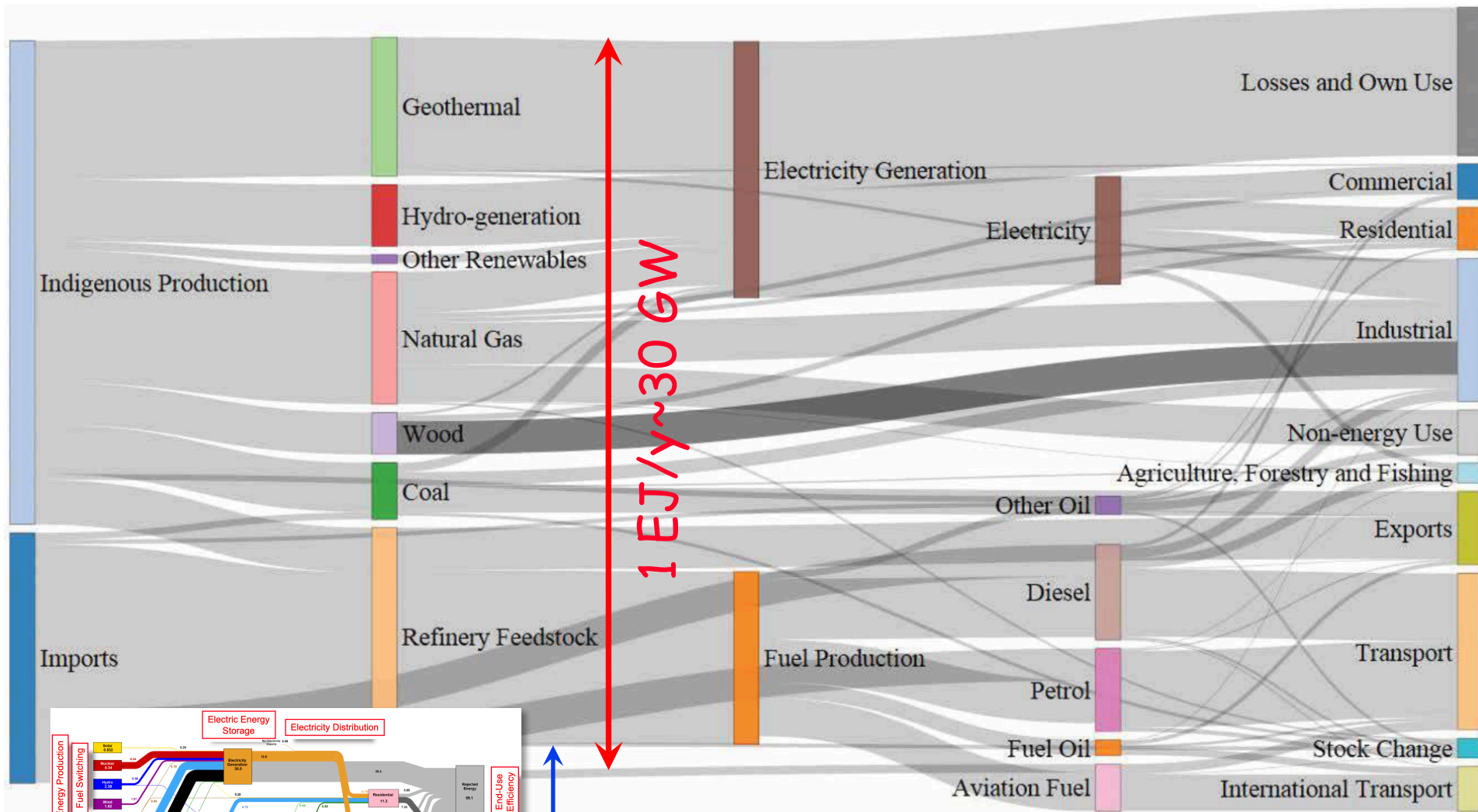
Wind - 2000 MW (Capacity??)

Hydropower - 2000 MW (Capacity??)

Geothermal - 1040 MW

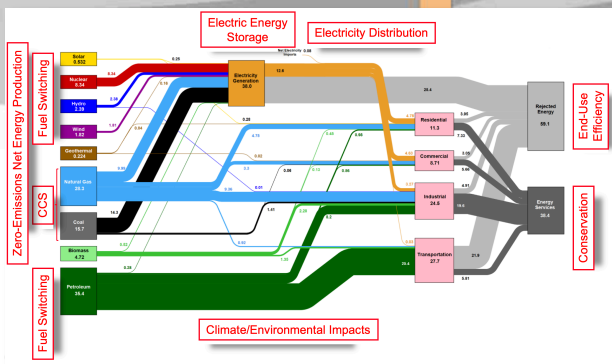


# Sankey Chart for NZ Energy Consumption



1 EJ/y ~ 30 GW

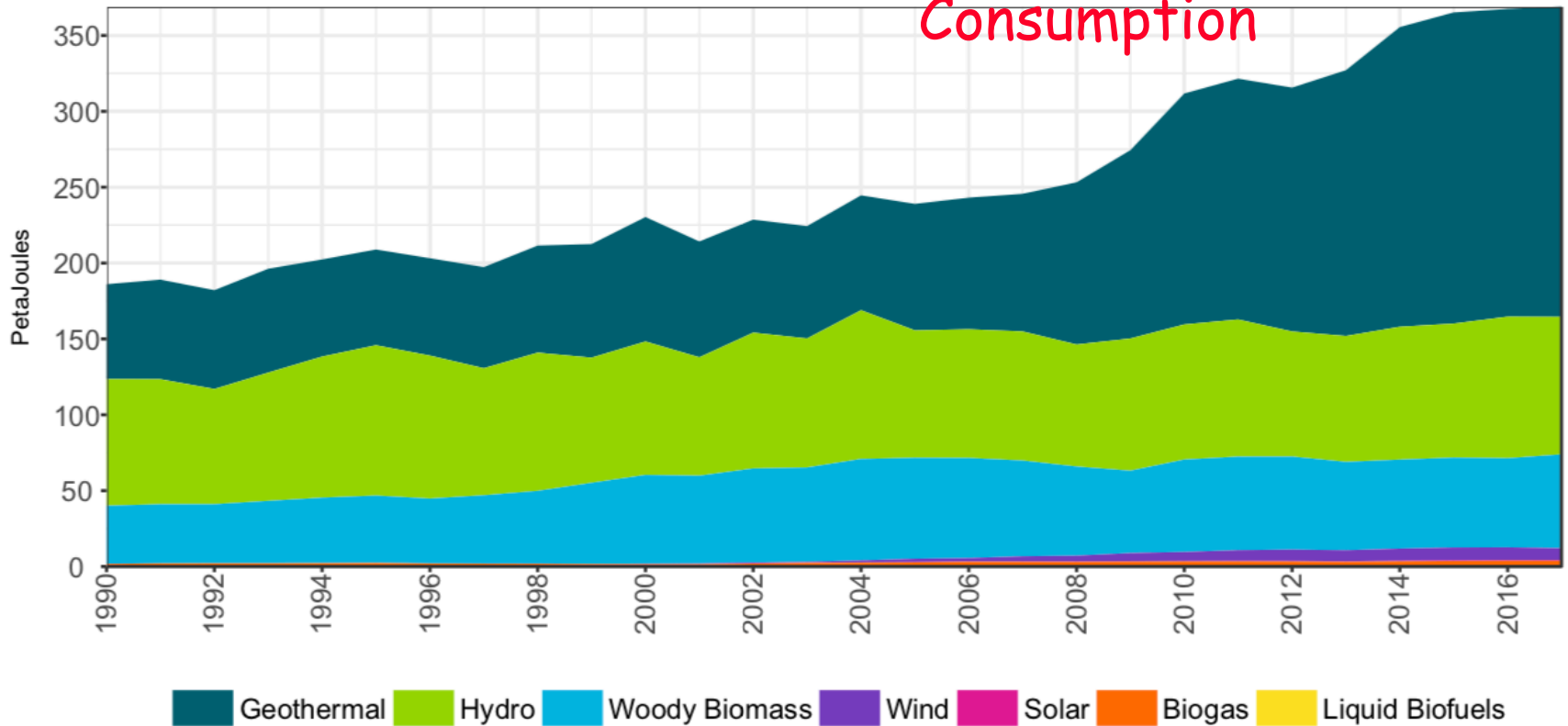
USA 100 EJ/y ~ 3000 GW (3 TW)



# Renewable Energy in NZ (1000 PJ total)

Figure 23: Total Renewable Primary Energy Supply

0.35 EJ of 1 EJ total NZ  
Consumption





# Concluding Remarks

Our current predicament is carbon-energy constrained.....

Low-carbon, carbon-neutral and carbon-negative solutions offer a potential path forward that:

May mitigate climate change issues

Are an orderly - non-Malthusian solution

For low(er)-carbon fuels (Natural gas)

Avoids the policy-based "tragedy of the commons"

Industry driven with an appropriate profit motive

For others (CCS/EGS/Nuclear/Intermittency Solving)

Significant investment needed (sub-economic)

Government-sponsored R&D/legislated/subsidy-abating

Fascinating science-based problems to solve (IS..)

Your choice for which are Good, Bad or Ugly.... but

..... any selection is ultimately subject to policy choices

.....(hopefully) based on sound scientific input.....

