The Energy Challenge

What Can Rheologists Do?

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National direction in energy sometimes feels like this!

Why Is the Energy Issue So Complicated?

- Few people, other than energy specialists, are interested in gigajoules, kilowatt-hours, or quadrillions of BTU's…
- They are interested in **energy services**
  - Comfortable rooms, cold beer, cooked food, convenient transportation…
- As well as:
  - The state of the economy
  - The state of the environment
  - Their personal and national security
  - **And** energy choice if these values are at risk

An average American family spends only 3 to 4% of their income on energy!!

Outline

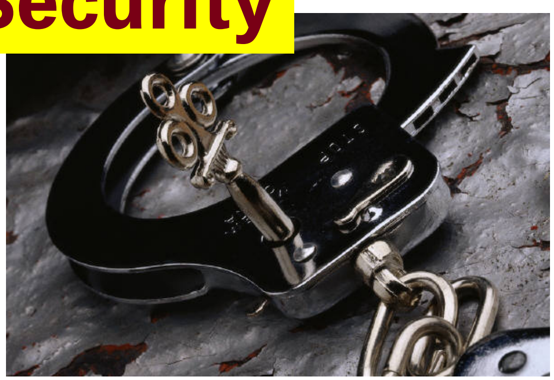
- The Energy Challenge
  - Energy supply and demand
  - Energy and security
  - Energy and the environment
- A Broad Response
  - Science and technology for a clean energy future
  - Improving today’s energy systems
  - Global climate change
- What Can Rheologists Do?
- Summary

The Perfect Storm

- Energy supply and demand
- Energy and security
- Energy and the environment

Supply

Security

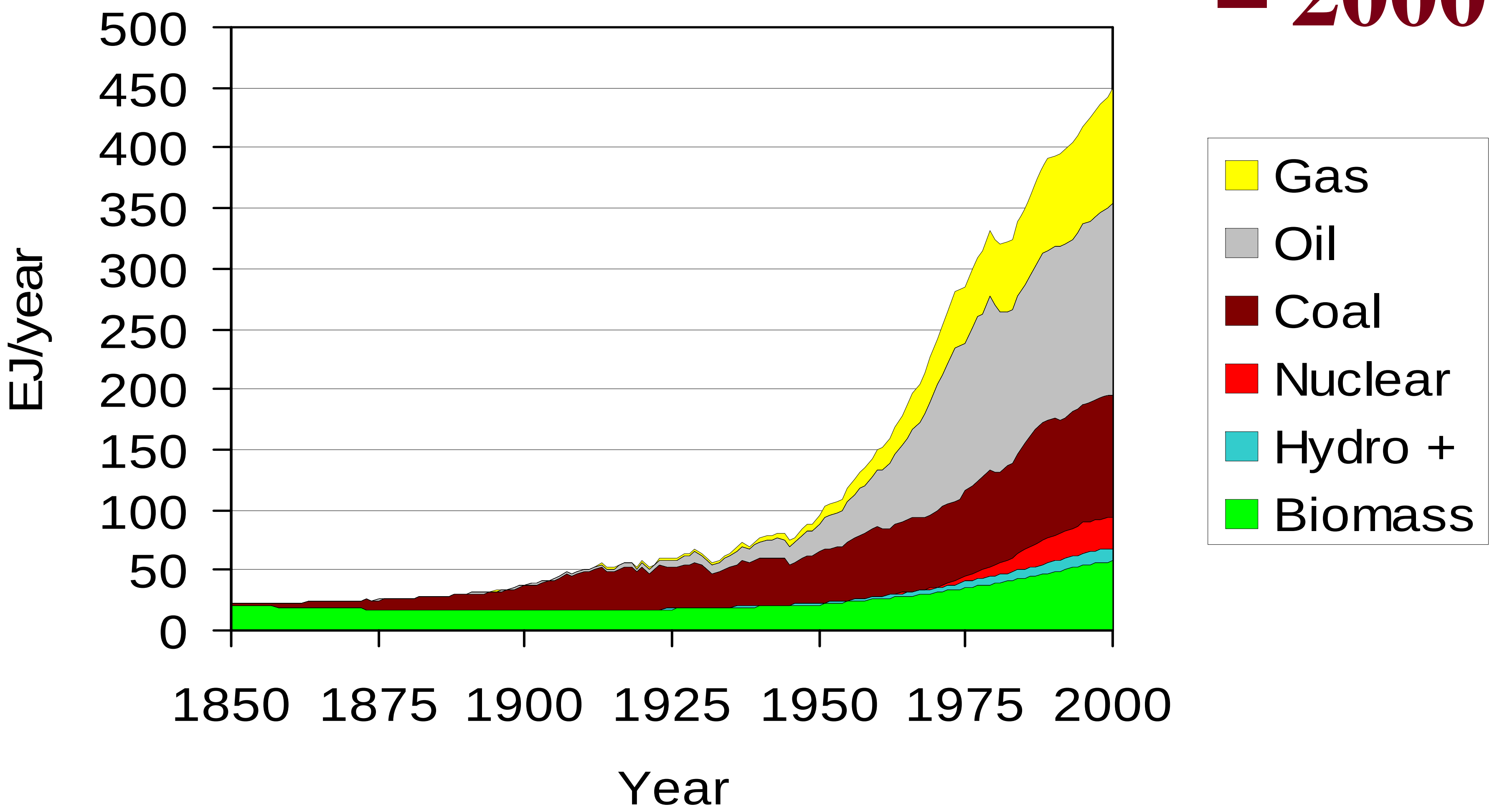


Impacts

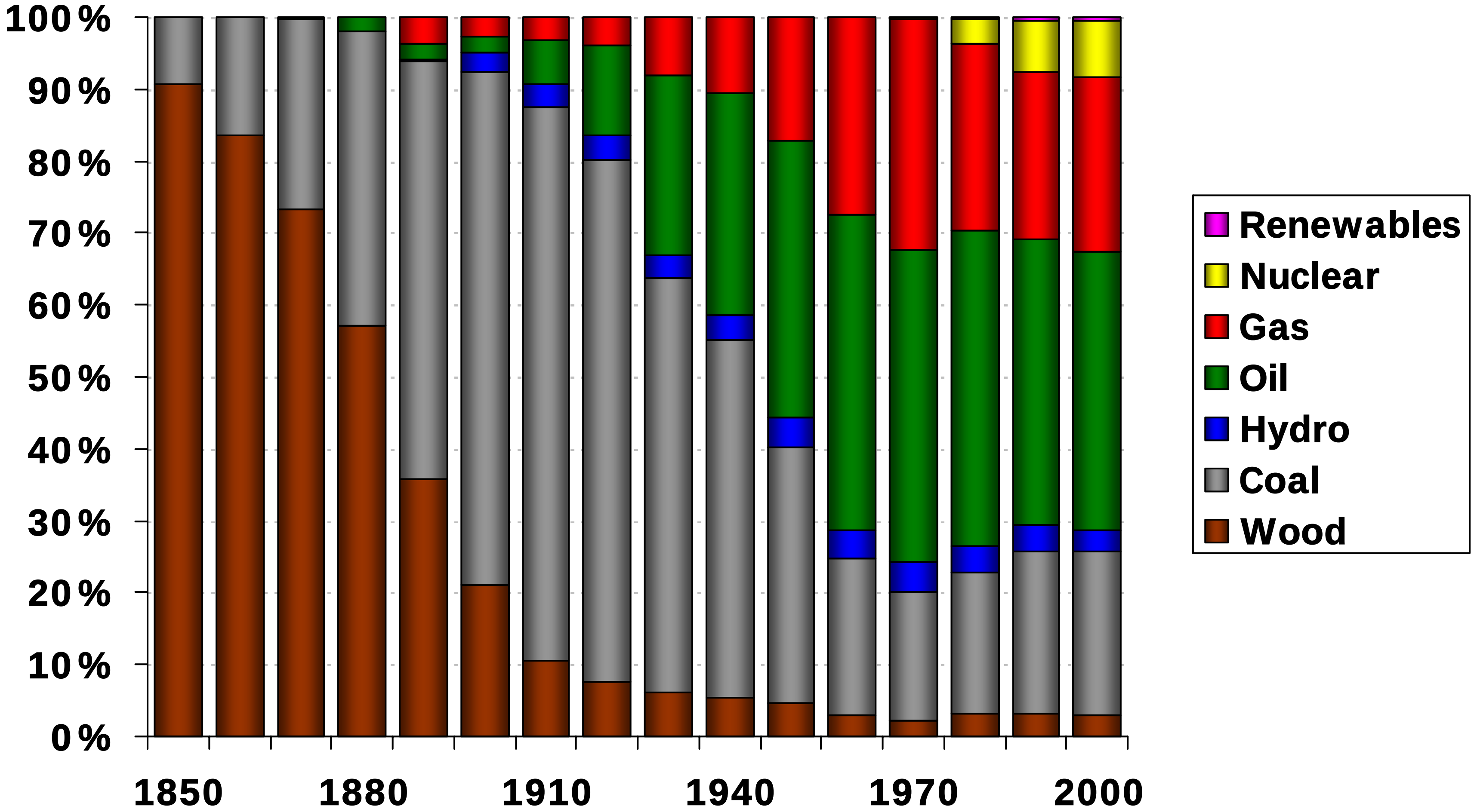
The "Perfect Storm"

- Energy supply and demand
  - 450 EJ/year (14.2 TW)/16 T kWh-electric/year
  - 86% fossil fuel/enough oil? enough air for coal?…
  - Projected doubling of energy use and tripling of electricity use by 2050 in business as usual
  - 1.4 Billion people without electricity in 2030
  - 50 year time scale for major shifts in energy

World Energy Consumption 1850 – 2000



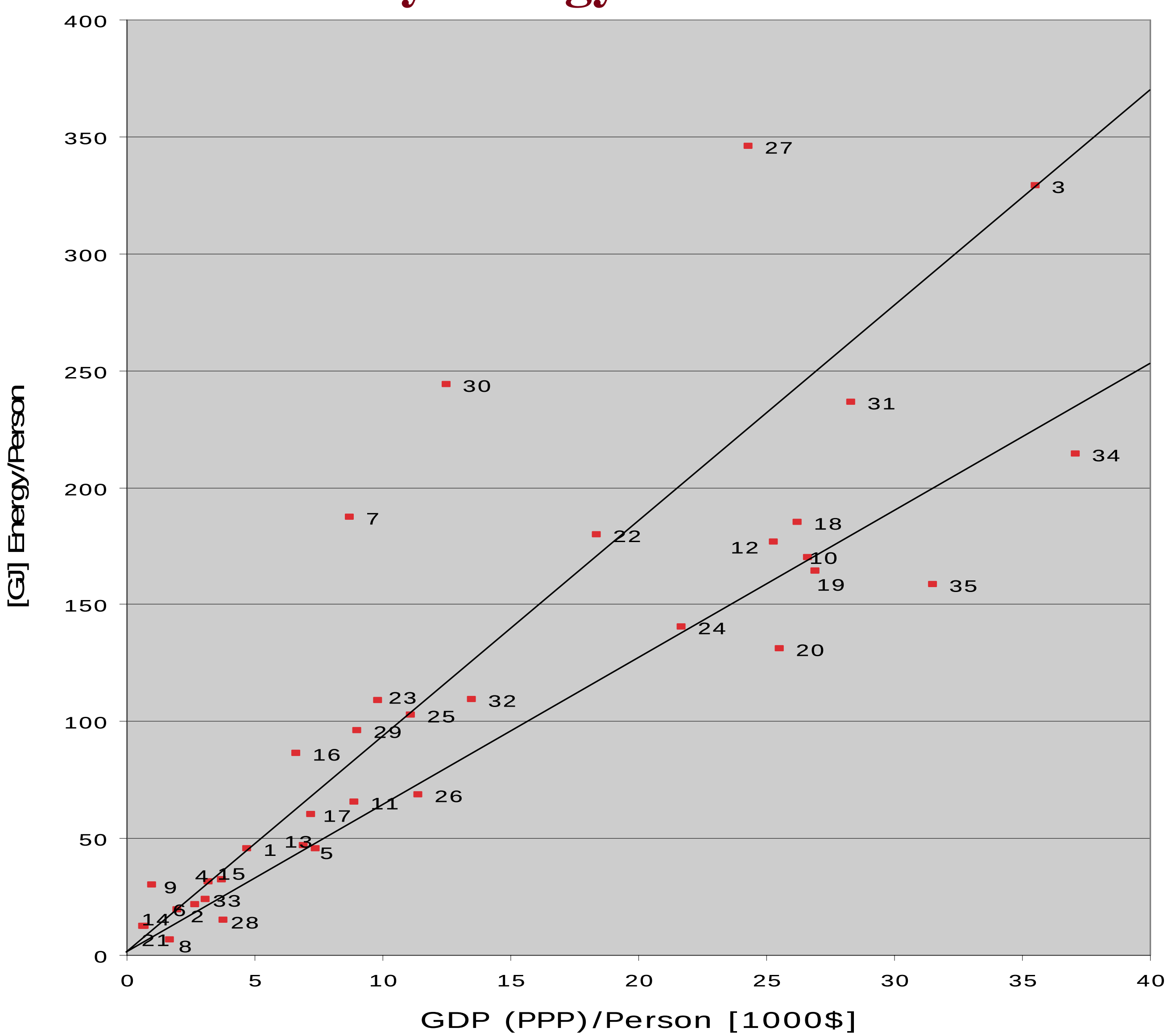
US Energy Supply Since 1850



Author: Koonin

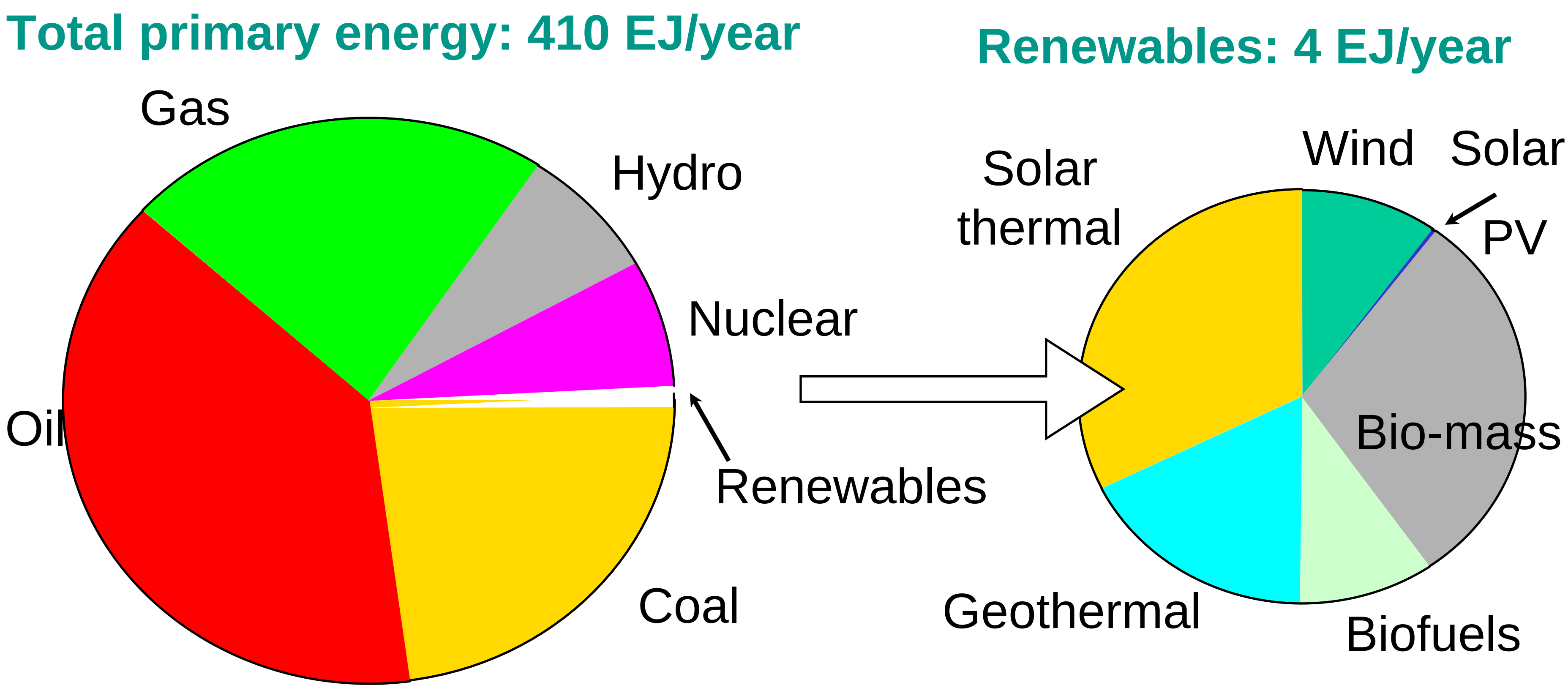
Source: EIA

Primary Energy Use Per Person



1 China
2 India
3 US
4 Indonesia
5 Brazil
6 Pakistan
7 Russia
8 Bangladesh
9 Nigeria
10 Japan
11 Mexico
12 Germany
13 Turkey
14 Ethiopia
15 Egypt
16 Iran
17 Thailand
18 France
19 UK
20 Italy
21 Dem Rep. Congo
22 South Korea
23 South Africa
24 Spain
25 Poland
26 Argentina
27 Canada
28 Morocco
29 Malaysia
30 Saudi Arabia
31 Australia
32 Hungary
33 Nicaragua
34 Norway
35 Ireland

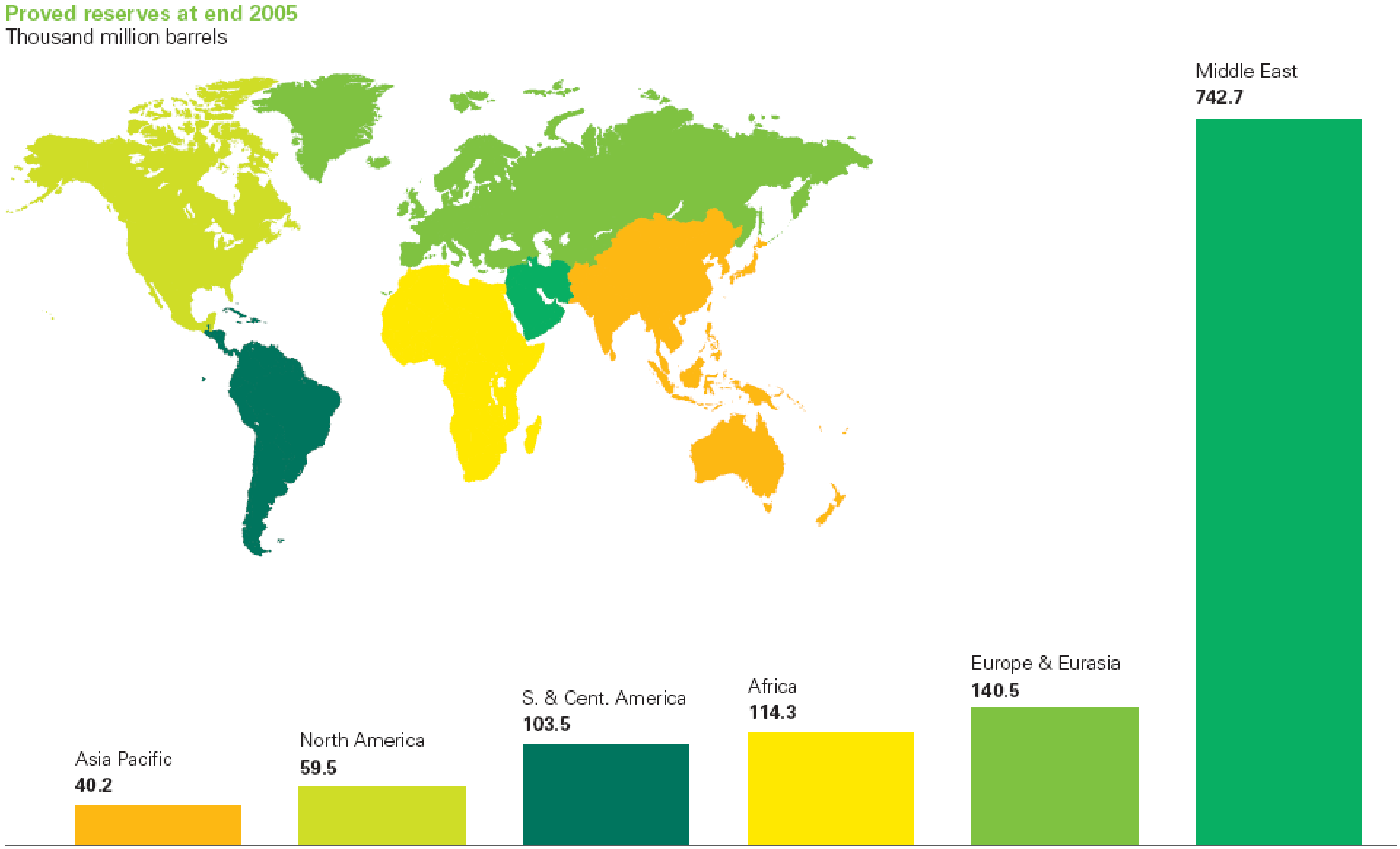
Scale Issues – Renewable Sources



The “Perfect Storm”

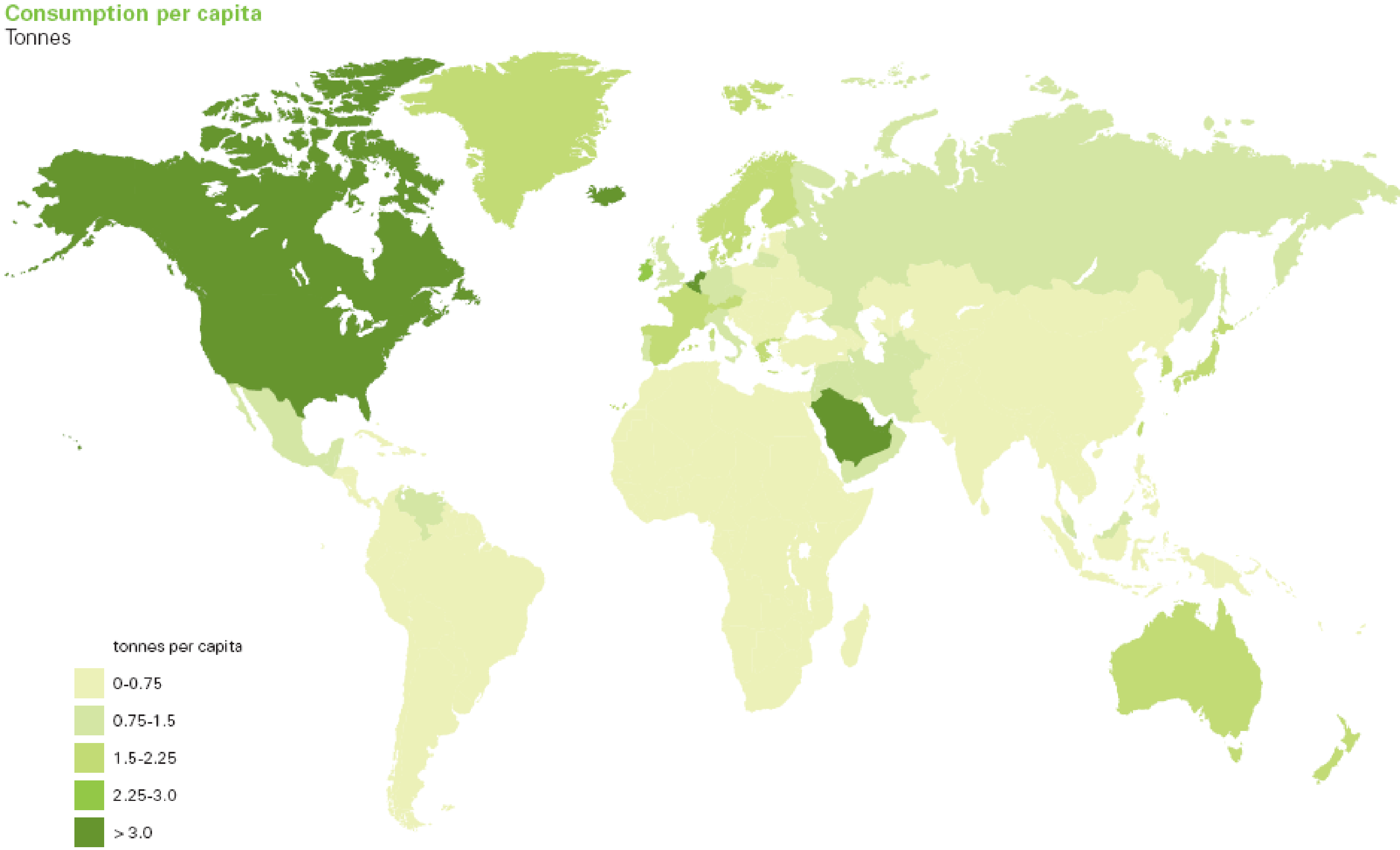
- Energy and security
  - Geological and geopolitical realities of oil and gas supply
  - Oil (and natural gas) adequate and reliable supply
  - Vulnerability of extended energy delivery systems
  - Nuclear weapons proliferation facilitated by worldwide nuclear power expansion
  - Dislocation from environmental impacts, such as from climate change

Proven oil reserves at end 2005



BP Statistical Review of World Energy (June 2006)

Oil consumption per capita



BP Statistical Review of World Energy (June 2006)

Oil and Energy Security

- Core Issue: inelasticity of transportation fuels market, together with geographical and geophysical realities of oil
- Addressing sudden disruptions
  - Strategic reserves
  - Well-functioning markets
- Increasing and diversifying supplies
  - Enhanced production from existing fields
  - Arctic E&P
  - "Unconventional" oil (tar sands,…)
- Weakening the "addiction"
  - Very efficient vehicles
  - Alternative fuels (coal, NG, biomass)
  - New transportation paradigm (electricity as "fuel"? H2?)

The "Perfect Storm"

- Energy and environment
  - Risk of climate change
  - 50+ years of CO_2 "emissions budget"
  - "De-carbonizing" of energy?

The Average Temperature of the Earth is Rising

- Up 0.8±0.4°C in last 140 years (instrumental records)
- 19 of the 20 warmest years since 1860 have all occurred since 1980, the 11 warmest all since 1990
- 1998 was the warmest year in the instrumental record and probably the warmest in 1,000 years (tree rings, ice cores); 2002 was the second warmest
- The last 50 years appear to have been the warmest half century in 6,000 years (ice cores)
- It is approximately as warm now as the Holocene maximum and within ~1°C of the maximum temperature of the past million years*

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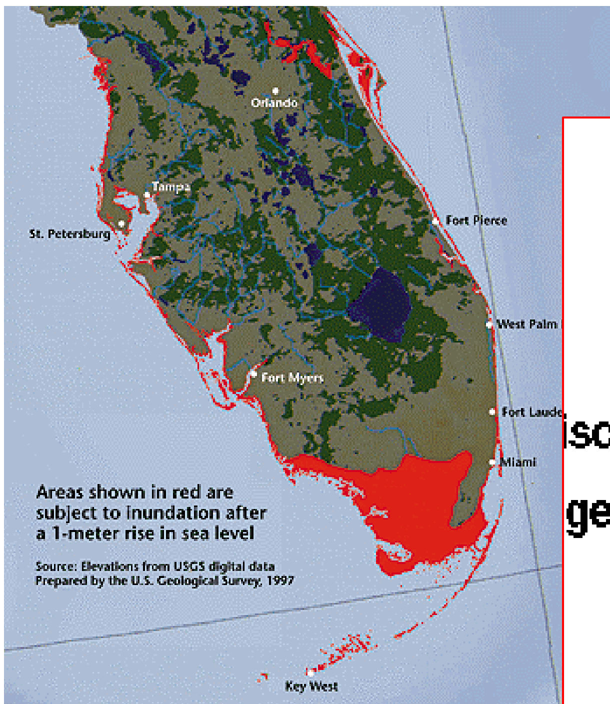
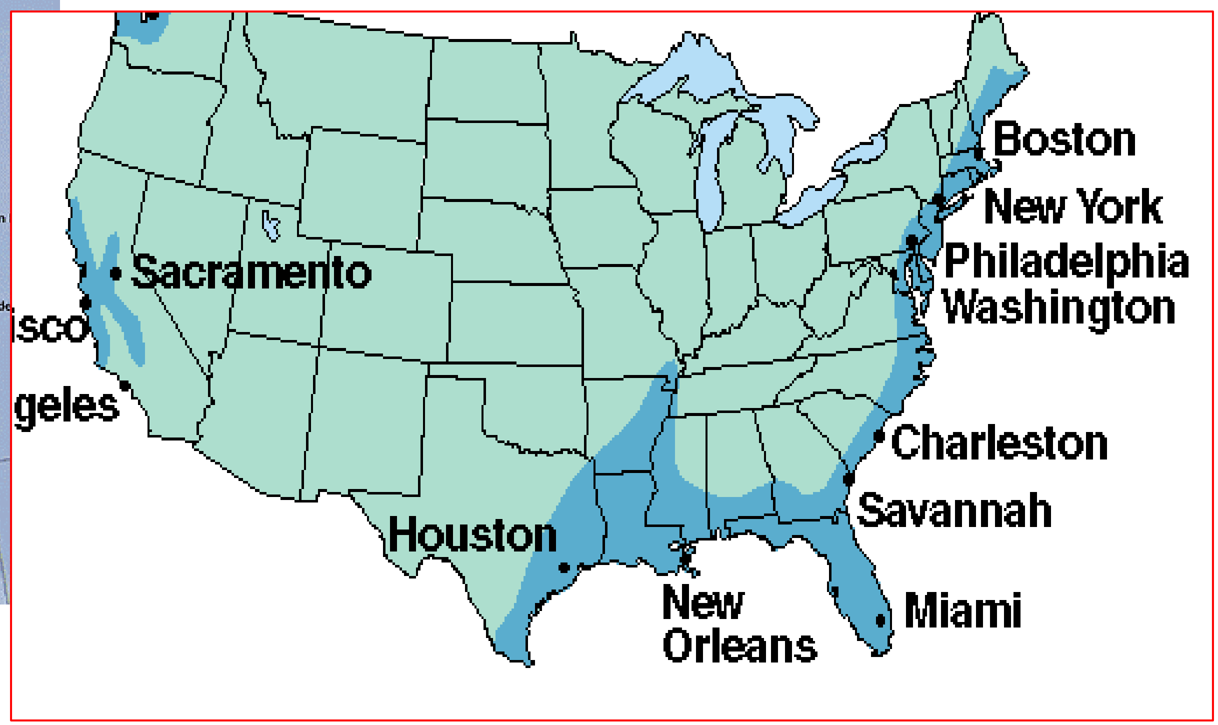
*Hansen, *et al.*, *PNAS*, **103**, 14288-14293 (2006).

Impacts of Climate Change – Coastal Flooding

1 Meter Rise
South Florida



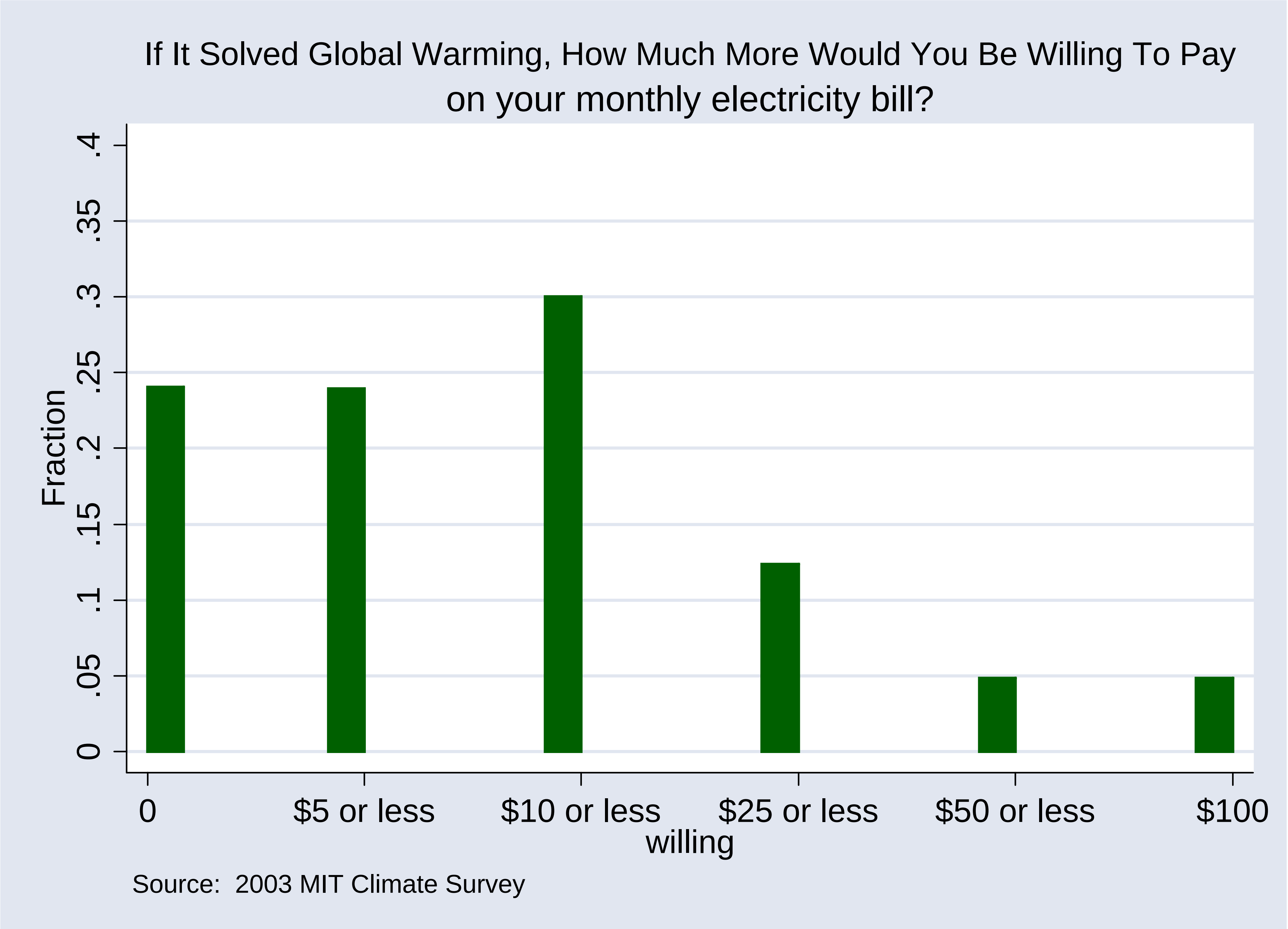
75 Meter Rise

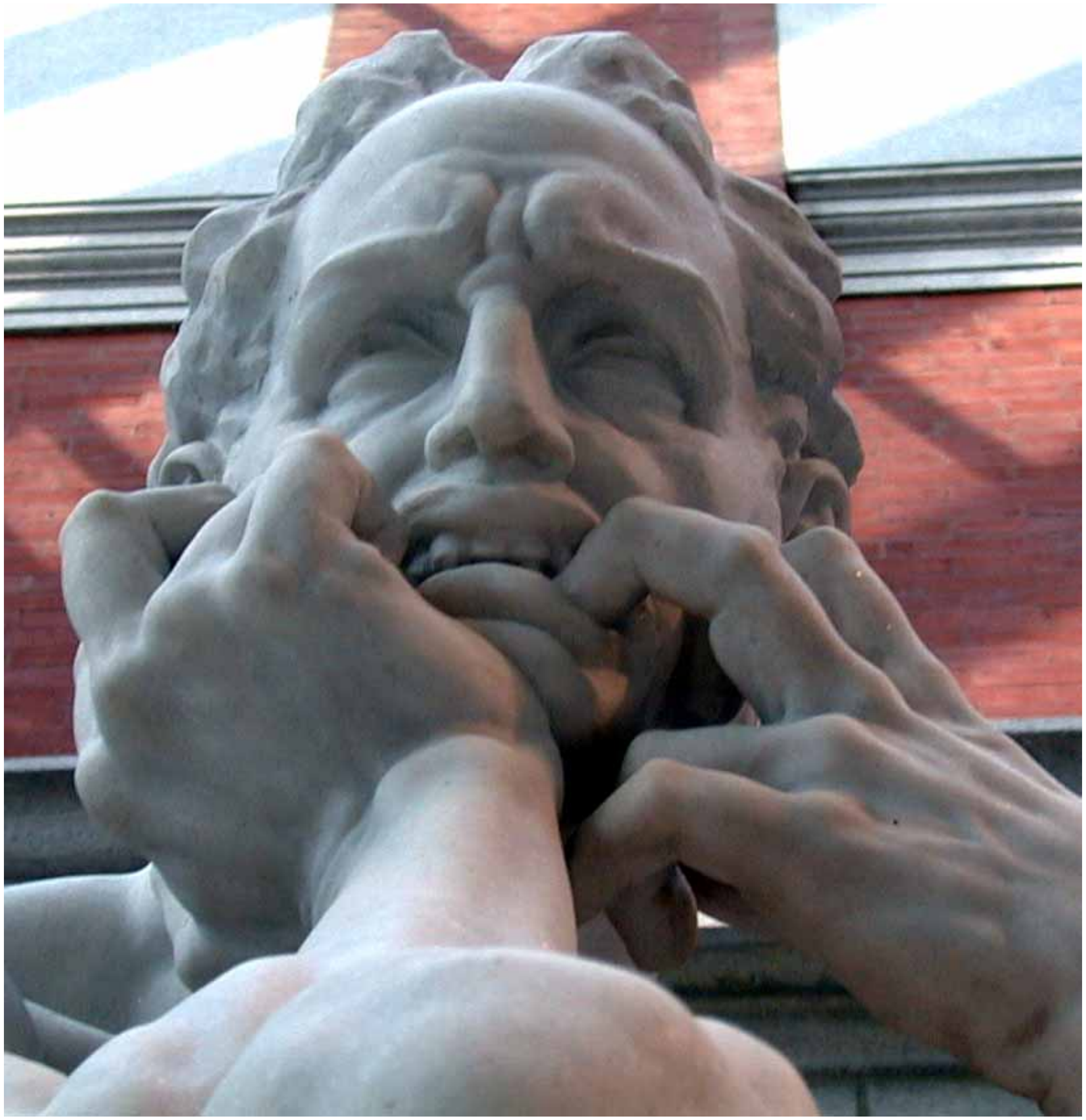


Climate Change Technology/Policy Pathways

- Efficiency
- Low carbon or “carbon-less” technologies/fuels
  - Fuel switching, e.g., coal to natural gas
  - Nuclear power (fission, possibly fusion in long term)
  - Renewables (wind, geothermal, solar,…)
    - Note: scale matters
- Carbon dioxide capture and sequestration

Climate control policy is not new. As early as 1306 Edward I of England prohibited the burning of coal in craftsman’s furnaces. Later Elizabeth I banned burning of coal in London while Parliament was in session.


If It Solved Global Warming, How Much More Would You Be Willing To Pay
on your monthly electricity bill?
Fraction
0
.05
.1
.15
.2
.25
.3
.35
.4
0
$5 or less
$10 or less
$25 or less
$50 or less
$100
willing
Source: 2003 MIT Climate Survey



Uncertainty on a 50-year Time Scale

- Future scenarios highly uncertain on mid-century time scale
  - 50-year time scale characteristic of significant change in energy infrastructure, of greenhouse gas concentrations approaching twice pre-industrial,…
- Multiple uncertainties
  - Resource availability?
    - fossil fuels, land for renewables, effects of renewables at scale…
  - Science and technology advances?
    - technology breakthroughs, climate change impacts
  - Geopolitical considerations?
    - Middle East, climate protocol participation,…
- Broad response pursuing multiple technology and policy options is needed

A Broad Approach Is Needed

- Science and technology for a clean energy future
  - Enabling research to underpin critical breakthroughs
  - Basic research in university environment
  - Shift from hunter-gatherer to farming
- Improving today's energy systems
  - Evolve today's energy systems to higher efficiency, lower cost, less environmental impact,…
  - Closer to marketplace implies strong industry collaboration
- Energy systems for a rapidly developing world
  - Advanced developing countries drive many of the leading energy/environmental challenges
  - Less advanced developing economies offer opportunities for new energy development technologies/models

Where Can Rheologists Contribute?

- The future
  - Biofuels
  - Solar
  - Wind
- How do we get there from here?
  - Drag reduction
  - Enhanced oil recovery
  - Supercritical CO_2 in porous media and oil – sequestration and EOR
  - Flow of waxy crude
  - Viscosity vs. composition, T, p of many hydrocarbons, e.g., kerogen
  - Production from deep wells – slushy flow
  - Drilling muds
  - Efficiency – light weight materials and manufacturing for vehicles
- Global issues
  - Sea ice cover flows – Global Climate Model
  - Glacial flows

Energy Options – Biomass Conversion!

Ad from PBS NewsHour with Jim Lehrer

Opportunity: Biomass as major source of liquid fuels

- Lignin (~25%) → Energy (combustion)

Upon Hydrolysis give sugars:

- Cellulose (45%) → Hexoses (6C sugars)
- Hemicellulose (30%) → Pentoses (5C sugars)

Fermentation → Liquid Fuels (ethanol, alkanes, other oils)

2004: DOE report: 1 B tons biomass/year (actually, 1.38B tons of *sustainable* biomass production/year)

If fully utilized, this biomass can supply ~40% of the US annual liquid fuels demand (~45B gallons/year)

What is different now?
Notable developments in B2B conversion

- 1995-2005: Drastic reduction of biomass hydrolysis cost (from $1/gal of ethanol to ~$0.10/gallon)
  - The prospect of abundant, affordable, fermentable sugars is a distinct possibility
  - A cost-effective B2B conversion process must:
    - Use all sugars (maximize YIELD)
    - Minimize capital cost (maximize PRODUCTIVITY)
    - Use ethanol tolerant organisms
  - Yield, productivity, ethanol tolerance are system properties that depend on many genes
- 1990-2005: Development of Metabolic Engineering as key technology for product synthesis in microorganisms based on a Systems Approach to cell engineering

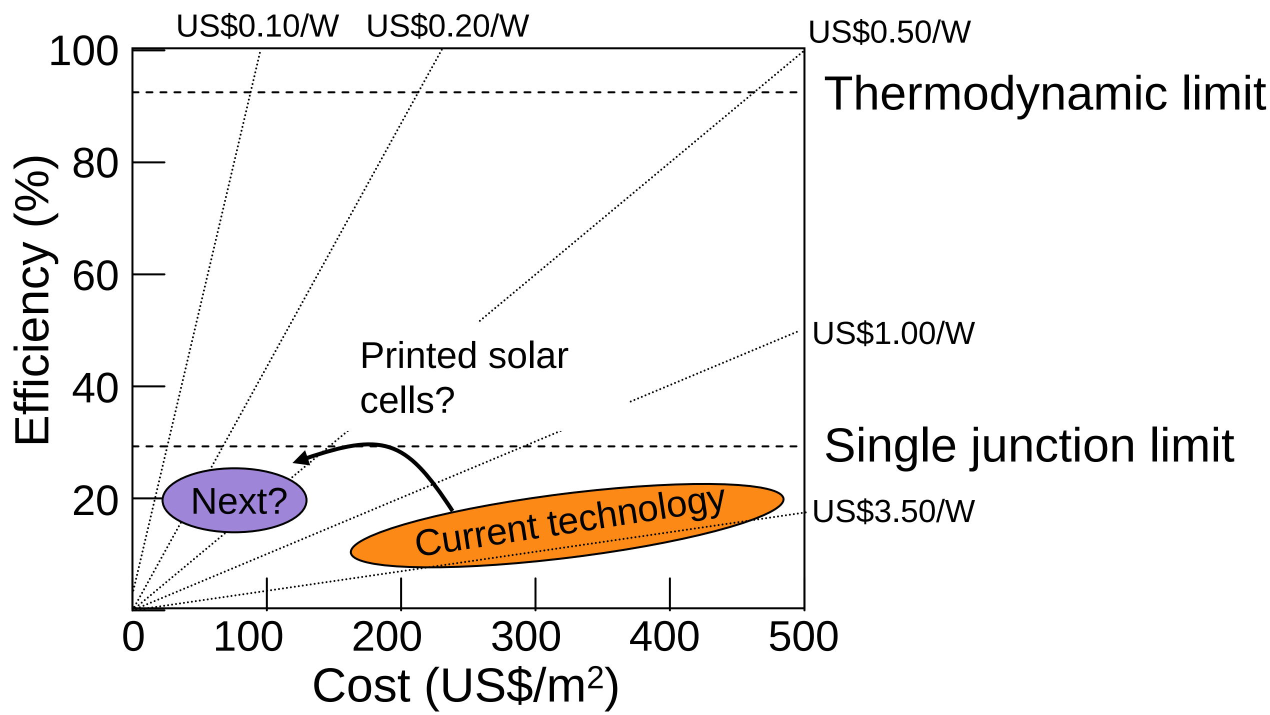
Project feasibility

- Established record of success of Metabolic Engineering
  - Aminoacids, biopolymers, 1,3 propane-diol, AIDS drugs, tamiflu precursor, ethanol, lycopene, artemisinin (malaria),…
- Breakthrough new technology of global Transcriptional Machinery Engineering (gTME)
- Benchmarks: 1,3 propane-diol
  - 5-7 years of development
  - $25-50 M cost
- Engineering strains for the economic full conversion of sugars from biomass hydrolysates is no different or drastically more difficult problem
- Clear benefit (45 B gallons/year) attainable in 5-10 years at a development cost of $50-100 M

The Solar Challenge

- How do we reduce the cost of solar?

Cost and efficiency (*Martin Green UNSW*)

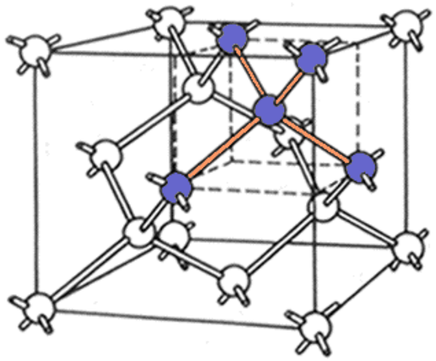


- Fundamentals
  - Low cost manufacturing + need at least 10% power efficiency to compensate for fixed costs (frame, land, inverter, taxes, etc…)

The Opportunity:

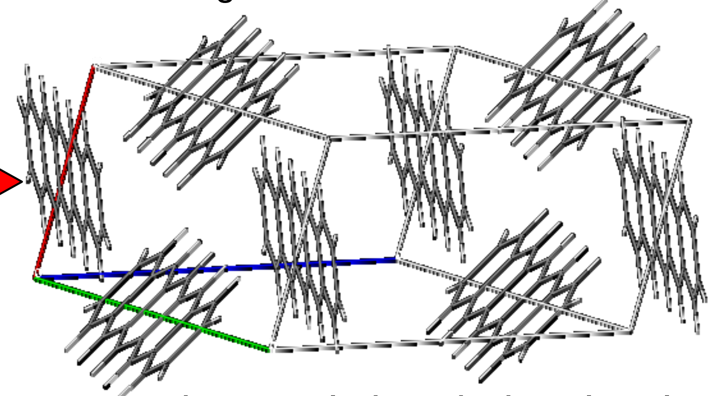
New semiconductors compatible with roll-to-roll processing

Conventional Semiconductor



Lower cost

Organic Semiconductor



Silicon: covalently bonded crystal

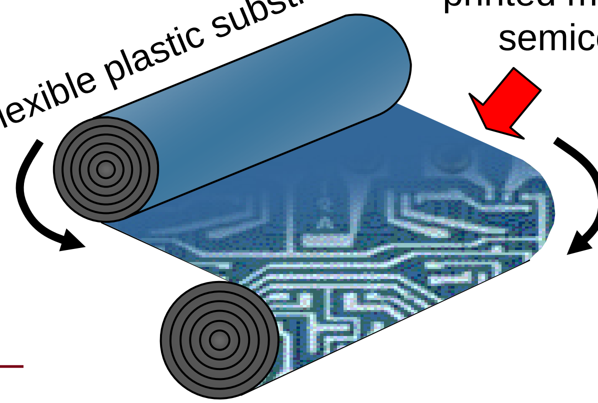
- Deposition requires high temperatures
- Structure is disordered on flexible substrates
- Performance suffers:

Efficiency of amorphous Si on flexible steel ~ 8%
Efficiency of crystalline Si ~ 24%

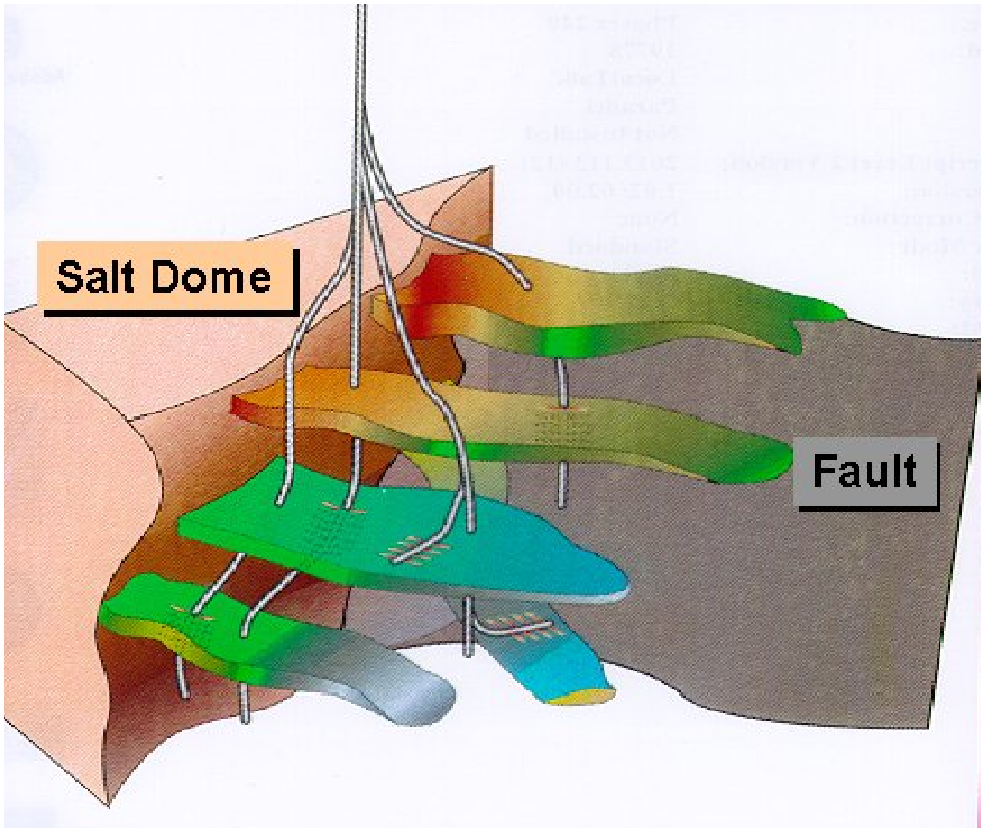
van der Waals bonded molecular crystal or polymer

- Low temperature deposition is OK (compatible with plastic substrates)
- Can be spray coated for high throughput

Wafer processing slows throughput



Increasing the Supply of Fuels

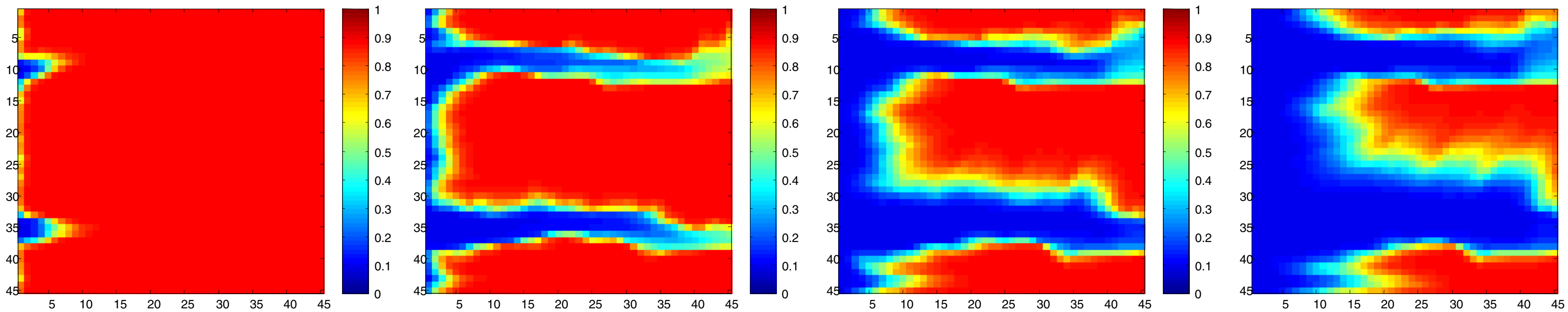


- Current oil recovery factors are ~35%
- At present a 1% increase in oil field recovery factor = 1 year of consumption at current demand

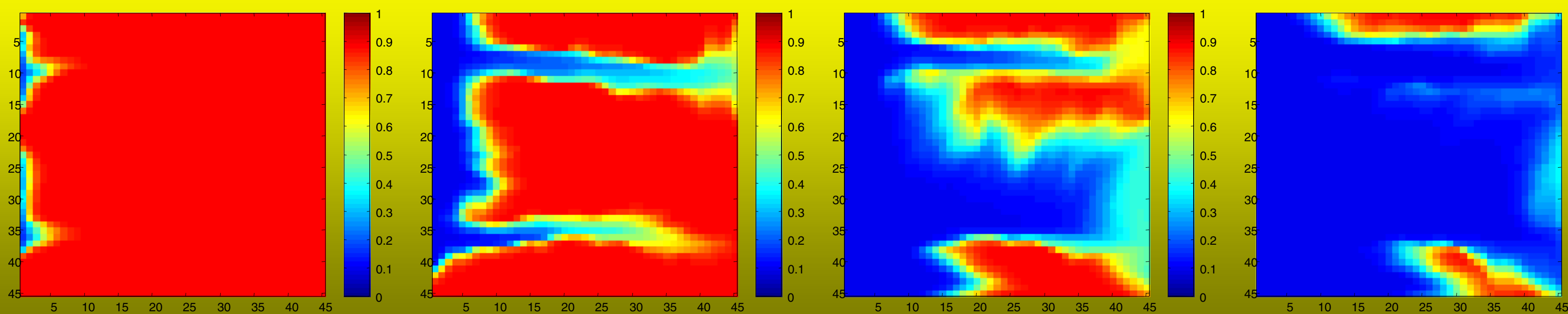
Drill where there are hydrocarbons!!

Importance of Dynamic Reservoir Models

Conventional Water Injection

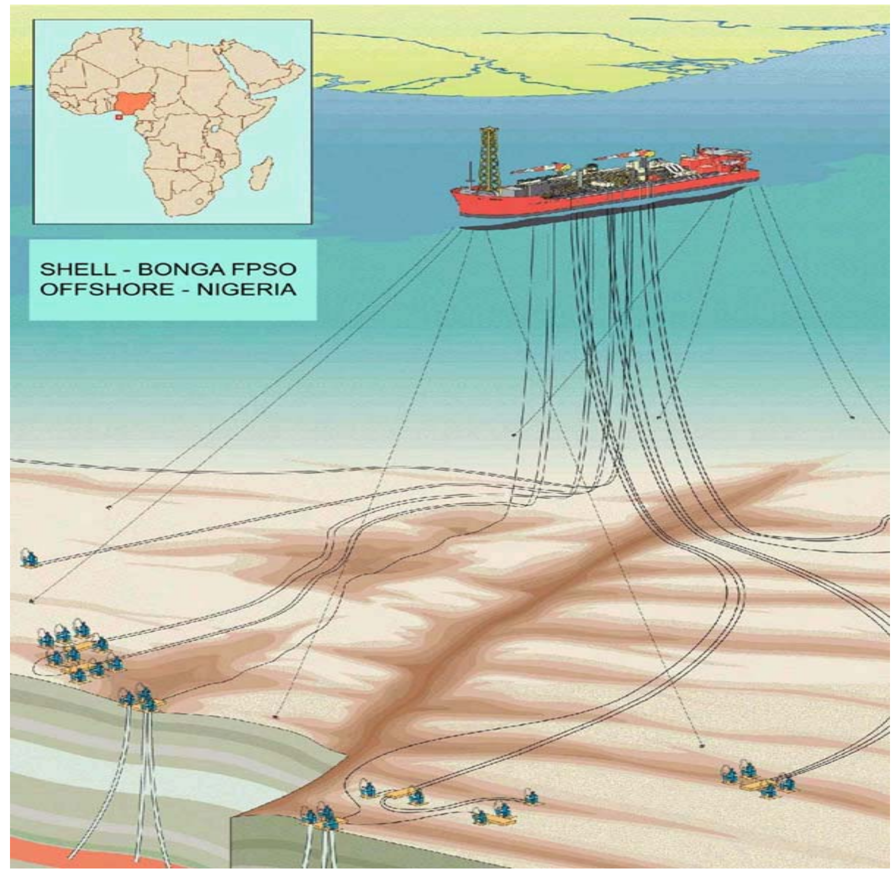


Optimized result (Same production rate, 25% extra recovery)

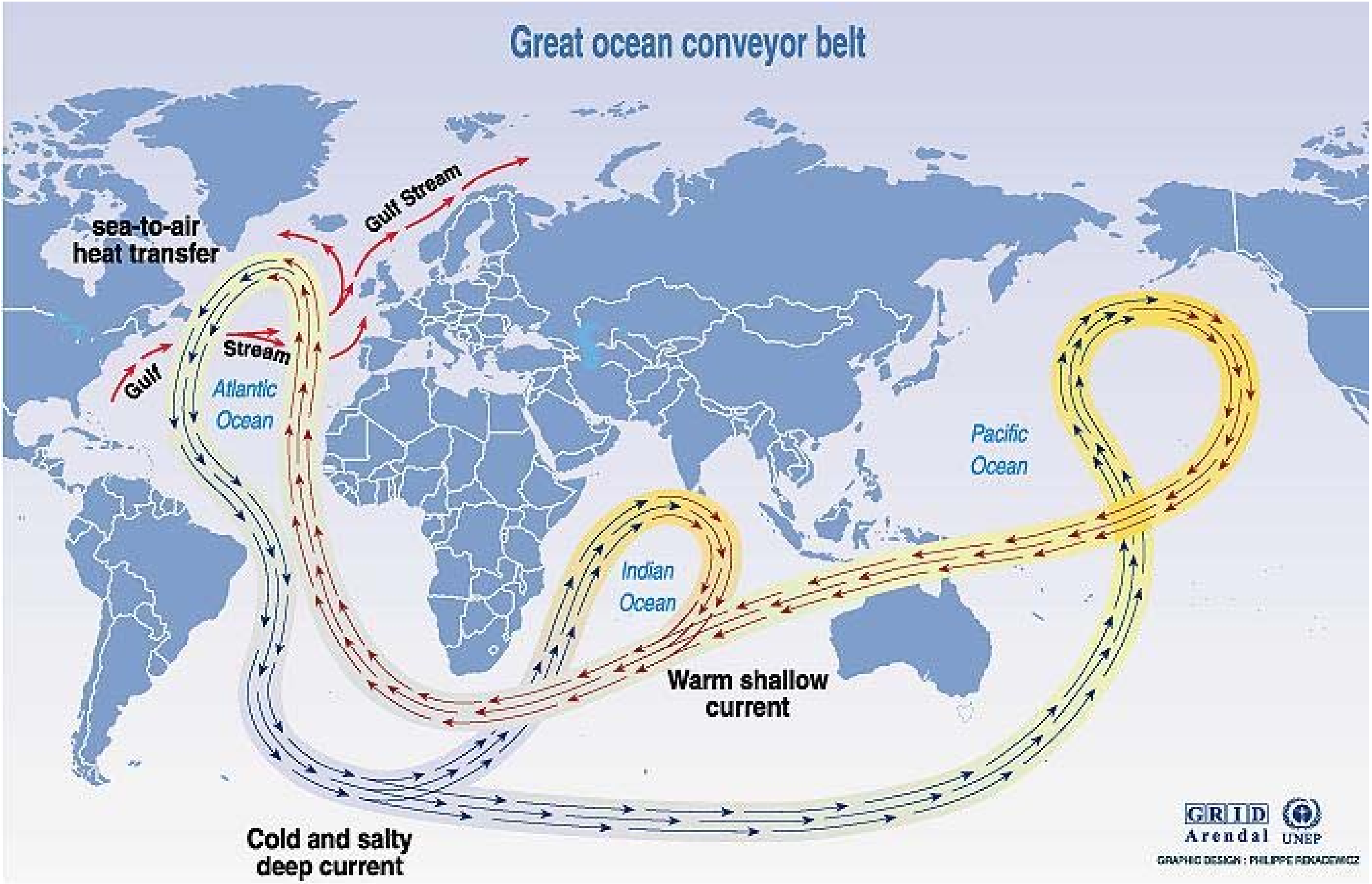


Deep Water Drilling Challenges*

- 4,000 ft of water
- Next few thousand feet are unconsolidated – first oil and gas are found in this region
- Sea water near bottom is near freezing, so T-dependence is important
  - Concern about deposition of asphaltenes, waxy oil, …
- Gas wells might form hydrates – slushy, foamy material that does not flow well



*Richard A. Sears, Shell International Exploration & Production



Source: Broecker, 1991, in Climate change 1995, Impacts, adaptations and mitigation of climate change: scientific-technical analyses, contribution of working group 2 to the second assessment report of the intergovernmental panel on climate change, UNEP and WMO, Cambridge press university, 1996.

Rheology of Sea Ice

- Sea ice cover
  - Layer of sea ice several meters thick can cover up to 8% of the surface of the earth
  - Lateral scale for ice floes is 0.1 to 5 km
  - Long (many floe widths) leads of open water or weaker ice separate these
- Important in global circulation models used for climate predictions
- Stress / deformation model based on ice floe interactions and evolution of ice floe orientation*

*Wilchinsky and Feltham, *JNNFM*, **138**, 22-32 (2006)

Closing Thoughts

- This is an enormous problem both in magnitude and time scale
  - To provide 14 TW of carbon-free power by 2050 from nuclear sources
    - ~ 1 GW power plant needs to be built per day
    - What do we do with the nuclear waste?
  - A variety of technology options are needed
  - We must start now
  - At these magnitudes we must do our best to assess impact on our environment before we commit

Closing Thoughts

- Because of the set of drivers today, this problem will not go away
- There is no single answer – rheological problems abound in
  - Long term
    - Renewables
  - Short term
    - Facilitating fossil fuel supplies
  - Global
    - Climate change
- We all need to contribute towards solving the greatest challenge of the 21st century