Sustainable Energy Engineering — The Mix of Fossil Fuels, Nuclear, Wind, Solar, and Renewables

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Purpose of this Presentation:

- The "reality" of sustainable energy is "fossil fuels" (oil, gas, coal) and this will remain so for at least the next 50-100 years. The world will continue to be powered by "stored sunshine" in the form of fossil fuels.
- As an industrial society we are accustomed to "dense" energy sources — oil, gas, coal, uranium. The industrial, residential, and transport sectors all DEPEND on dense energy sources.
- As a society, we will have to adjust to "diffuse" energy sources — wind, solar, and biomass (some would argue that biomass forms a "dense" source, but my logic is that it is derived from diffuse (agricultural) sources).
- Technology breakthroughs will likely come from integration of energy management, distribution, and the ability to use "diffuse" sources on local and grid-scales.
- As orientation, hydrogen is not an energy source — but like electricity, is an energy carrier.
Overview:

- **Topics/Issues:**
  - **Energy Supply and Consumption:**
    - Supply is tight due to demand from emerging economies.
    - Oil, gas, and coal provide ≈ 90 percent of U.S. energy supply.
  - **ExxonMobil Says…:**
    - Predictions from ExxonMobil (we should probably listen…).
  - **Peak Oil:**
    - Don't worry, we know where the oil is (and how to get it).
  - **U.S. Energy Trends:**
    - ACCESS to energy → wealth and prosperity.
  - **Nuclear Energy:**
    - No new nuclear power plants in U.S. since late 1970's.
    - Nuclear energy ≈ 18% of electricity in U.S. — France ≈ 80%!
  - **Solar/Alternatives/Renewables:**
    - Geothermal: Almost limitless geothermal potential (U.S.).
    - Solar: (Some) Very good solar resources (U.S.).
    - Wind: Wind is good (not great), but incentives (TX)?
    - Biomass: Competition with food?
Energy Lecture: Overview

Topics/Issues:

- **Global Warming:**
  - CO2 Effect on Climate Change.
  - Anthropogenic CO2 Issues (*i.e.*, We caused climate change?).

- **The Real Problems:**
  - Water.
  - Energy.
  - Biocapacity.
Energy Supply and Consumption

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Consumption per capita 2007
Tonnes oil equivalent

Message:
Who are the "energy hogs?"

(1 metric ton ≈ 7.33 bbls)
World primary energy consumption slowed in 2007, but growth of 2.4% was still above the 10-year average. Coal remained the fastest-growing fuel, but oil consumption grew slowly. Oil is still the world’s leading fuel, but has lost global market share for six consecutive years, while coal has gained market share for six years.

(1 metric ton ≈ 7.33 bbls)
Energy: *Total Energy Consumed by Region (2007)*

**Message:**
North America and Western Europe are dependent on FOSSIL FUELS for 85-90 percent of their energy!

Oil remains the dominant fuel in all regions except Europe and Eurasia and Asia Pacific. Coal dominates in Asia Pacific, primarily because it meets 70% of China’s energy needs. Gas remains the dominant fuel in Europe and Eurasia even though gas consumption in the region was weak in 2007.
Fossil Energy: Conventional Oil Reserves (2007)

Message:
Guess where all the (conventional) oil is… (Middle East)

(1 metric ton ≈ 7.33 bbls)
Fossil Energy: Conventional *Oil Reserves by Region*

Distribution of proved reserves in 1987, 1997 and 2007

- Middle East
- Europe & Eurasia
- Africa
- S. & Cent. America
- North America
- Asia Pacific

**Message:**

*The location of proved reserves will not change...*

**Note:** Global OIL reserves are INCREASING with time.

(1 metric ton ≈ 7.33 bbls)

Fossil Energy: Country Size by Oil Reserves

Who has the oil?

Tar Sands (1-2 TB)

Oil Shale (1-2 TB)

Heavy Oil (1-3 TB)

Conventional Oil (0.25 TB)
Fossil Energy: *Natural Gas Reserves (2007)*

Message:
Guess where all the (conventional) natural gas is... *(Middle East and Russia)*

(1 cubic meter ≈ 35.315 cubic feet)

**Distribution of proved reserves in 1987, 1997 and 2007**

Percentage

- Middle East
- Europe & Eurasia
- Africa
- Asia Pacific
- North America
- S. & Cent. America

- 1987: Total 106.86 trillion cubic metres
- 1997: Total 146.46 trillion cubic metres
- 2007: Total 177.36 trillion cubic metres

**Note:** Global GAS reserves are INCREASING with time.

(1 cubic meter ≈ 35.315 cubic feet)
Fossil Energy: *US Natural Gas RESOURCES (2008/9)*

2009 Potential Gas Committee Report

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Total Potential Resources*</td>
<td>1836.4/52.0</td>
<td>1320.9/37.4</td>
<td>515.5/14.6</td>
<td>39.0</td>
</tr>
<tr>
<td>Proved reserves (DOE/EIA)</td>
<td>237.7/6.7</td>
<td>211.1/6.0</td>
<td></td>
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<tr>
<td>U.S. Future Gas Supply</td>
<td>2074.1/58.7</td>
<td>1532.0/43.4</td>
<td>542.1/15.4</td>
<td>35.4</td>
</tr>
</tbody>
</table>

* 2009 Potential Gas Committee Report (Colorado School of Mines)

Fossil Energy: Coal Reserves (2007)

Message:
Coal reserves are ENORMOUS, and the extraction/use technologies are well established.

[North America R/P = (250.5 \times 10^9 \text{ tonnes})/(620 \times 10^6 \text{ tonnes/year}) \approx 400 \text{ years}!]
"ExxonMobil Says…"
(all data taken from public sources)

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ExxonMobil Says…: *Economics and Energy*

### Population
- **Billions**
  - 10
  - Average Growth / Yr.
    - 2000 - 2030: 0.9%
- **Average Growth / Yr.**
- **1.1%**
- **0.4%**
- **Non-OECD**
- **OECD**

### GDP
- **Trillion (2000$)**
  - 80
  - 2.8%

### Energy Demand
- **MBDOE**
  - 350
  - 1.6%

- **Energy Demand Growth**
  - 2.4%
  - 0.7%

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http://www.exxonmobil.com/Corporate/energy_outlook.aspx
ExxonMobil Says...: Energy Demand

ExxonMobil Says...: Energy Demand

Message:
Energy demand cannot increase unabated — market and/or political forces will regulate demand...

http://www.exxonmobil.com/Corporate/energy_outlook.aspx
ExxonMobil Says…: *Energy Demand by Fuel*

**Primary Energy**
- **Liquids**: 1.4% growth per year (2000-2030)
- **Gas**: 1.7% growth per year (2000-2030)
- **Coal**: 1.6% growth per year (2000-2030)
- **Other**: 1.5% growth per year (2000-2030)
- **MBDOE**: 350

**Other Energy**
- **Wind & Solar**: 10.5% growth per year (2000-2030)
- **Hydro/Geo**: 2.2% growth per year (2000-2030)
- **Nuclear**: 1.4% growth per year (2000-2030)
- **Biomass/Others**: 1.0% growth per year (2000-2030)
- **MBDOE**: 60

**Wind & Solar**
- **MBDOE**: 3.0
- **Solar**: 8.4% growth per year (2000-2030)
- **Wind**: 12.5% growth per year (2000-2030)
- **MBDOE**: 2.5

[Link to ExxonMobil’s energy outlook](http://www.exxonmobil.com/Corporate/energy_outlook.aspx)
ExxonMobil Says…: Biofuels

Liquids Supply

<table>
<thead>
<tr>
<th></th>
<th>MBDOE</th>
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<tbody>
<tr>
<td>1980</td>
<td>3</td>
</tr>
<tr>
<td>2005</td>
<td>2</td>
</tr>
<tr>
<td>2030</td>
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Biofuels

<table>
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<th>MBDOE</th>
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<tbody>
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<td>1980</td>
<td>3</td>
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<tr>
<td>2005</td>
<td>2</td>
</tr>
<tr>
<td>2030</td>
<td>1</td>
</tr>
</tbody>
</table>

Biofuels

- Total (Volume Basis)

- Crude & Condensate
- Other NGL
- Oil Sands

http://www.exxonmobil.com/Corporate/energy_outlook.aspx
ExxonMobil Says…: Oil Resource Base

Message:
There is PLENTY of oil — it is just difficult to extract, or in politically "challenged" locations, or both…

http://www.exxonmobil.com/Corporate/energy_outlook.aspx
"Peak Oil"

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Peak Oil: When Will It Get Here?

- Coming, we don't know when — and we can delay "peak oil" **indefinitely** (at least at present).
- Oil is critical to transportation, and there is no current suitable (or viable) substitute.
  - Not biofuels ... *(not viable without subsidies)*
  - Not natural gas ... *(source/infrastructure issues)*
  - Not hydrogen ... *(require multi-trillion $ infrastructure)*

- If we want future generations to enjoy the freedom of mobility, **we must find a suitable substitute to oil.** *(hydogen???)*

- Alternative energy sources like nuclear, wind, and solar only apply to electricity, not to transportation (unless transportation infrastructure is electrified).
Peak Oil: Giant Oil Discoveries Versus Time

Agree that most "giant" fields have been discovered — but "so what?"
We have AT LEAST 40 years reserves at current rates of consumption…

Not to mention "unconventional" oil and gas — hundreds of years supply!

"Jack" Discovery in Deepwater Gulf of Mexico US (2006)
"Kashagan" Discovery in Kazakhstan (2000)
"Tupi" Discovery in Deepwater Brazil (late 2007)
Peak Oil: US Oil Production Decline Scenario

US Oil Production (http://www.eia.doe.gov/)

The Stone Age came to an end, not because we had a lack of stones, and the Oil Age will come to an end not because we have a lack of oil...

—Sheikh Zaki Yamani, Oil Minister of Saudi Arabia (1962–86), June 2000

US Oil Production Decline:
- Due to politics (mora-toria, environmental issues, etc.).
- Due to economics (cheaper to produce elsewhere).
- NOT due to technology!
## Peak Oil: US Oil Production Comparison

**Discussion:** *US Oil Production — Comparison*

- An illustration that many processes are Gaussian (*i.e.*, "peak").
- "Peaks" due to many factors — often "disruptive technologies."
- Dimensionless scales used to show similarities in data functions.
U.S. Energy Issues

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U.S. Energy: Fraction of Source Consumption

Oil and Gas Consumption History

- Note that gross energy consumption is ALWAYS on the rise.
- Over the last 30 years — oil, gas, coal, nuclear increasing at ≈ same rate.
- Note the GDP trend on the right-hand y-axis (logarithmic).

Source: US DOE-EIA (http://www.eia.doe.gov)
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**Fractional Energy Consumption History**

- Note that the fractions of energy consumption are \( \approx \) constant since 1980.
- The fraction of nuclear energy has risen since 1970 (capacity utilization).

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**US. Energy: Fraction of Source Consumption**

Energy Consumption History for the United States — Data Given in Fraction of Total Energy Consumed

Data from US DOE-EIA (http://www.eia.doe.gov)

Source: US DOE-EIA (http://www.eia.doe.gov)
Marchetti-Nakicenovic Fractional Energy Consumption History

- The MN fraction shows the natural "peak" of a particular source.
- Oil + gas and coal have been extended beyond their "natural" lives.
- Nuclear energy has not followed its natural path.
Nuclear Energy

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Nuclear Energy: Map of U.S. Nuclear Power Plants
Nuclear Energy: Potential for Low Cost Generation

- Nuclear energy could deliver low cost electricity for the U.S. (and the rest of the world).
- Renewable energy sources do not/cannot compete with the cost of nuclear energy.

From: http://www.oism.org/pproject/
Nuclear Energy: Production by Country

Source: International Atomic Energy Agency
Updated: 11/06

France:
No Oil ...
No Gas ...
No Coal ...
No Choice (→ nuclear energy).

<table>
<thead>
<tr>
<th>Country</th>
<th>Nuclear Energy</th>
</tr>
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<tbody>
<tr>
<td>France</td>
<td>78.5</td>
</tr>
<tr>
<td>Lithuania</td>
<td>69.6</td>
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<tr>
<td>Slovak RP</td>
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<tr>
<td>Belgium</td>
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<td>Ukraine</td>
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<td>Sweden</td>
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<td>Korea Rep.</td>
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<td>Armenia</td>
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<td>Hungary</td>
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<td>Finland</td>
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<td>Switzerland</td>
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<td>Germany</td>
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<td>Czech Rep.</td>
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<td>Japan</td>
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<td>U.K.</td>
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<td>Spain</td>
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<td>U.S.</td>
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<td>Russia</td>
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<td>Canada</td>
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<td>Romania</td>
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<td>Argentina</td>
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<td>South</td>
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<td>Mexico</td>
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<td>Netherlands</td>
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<td>India</td>
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<tr>
<td>Pakistan</td>
<td>2.8</td>
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<tr>
<td>Brazil</td>
<td>2.5</td>
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<tr>
<td>China</td>
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</tbody>
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Alternatives/Renewables

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Alternatives/Renewables: Role of Renewable Energy

From: (2007.01.23)
National Renewable Energy Opportunities
Daniel Arvizu (National Renewable Energy Laboratory)
Alternatives/Renewables: U.S. Energy Resources

Figure 1. U.S. Energy and Geothermal Resources


From: (November 2006)
The Energy Under Our Feet Geothermal Resource Estimates for the United States
Bruce D. Green and R. Gerald Nix, National Renewable Energy Laboratory
Alternatives/Renewables: Energy Resources Costs


*These graphs are reflections of historical cost trends NOT precise annual historical data.
Updated: October 2002

From: (2005.05.12)
Renewable Energy: Strengthening Our Nation's Economy
Daniel Arvizu (National Renewable Energy Laboratory)
Alternatives/Renewables: US Wind Resource

From:
http://rredc.nrel.gov/wind/pubs/atlas/maps/chap2/2-06m.html
http://rredc.nrel.gov/wind/pubs/atlas/maps/chap2/2-16m.html
Alternatives/Renewables: US Solar Resource

From: http://mapserve2.nrel.gov/website/L48NEWPVWATTS/viewer.htm

Units: kWhrs/m2/day
Alternatives/Renewables: Solar Cell Evolution
Alternatives/Renewables: US Geothermal Resource
Renewable Energy: Hydrogen Economy

Discussion: Hydrogen Economy

- Perfect system (no emissions — other than water).
- Cost to convert U.S. to hydrogen for transportation — USD 25-50 trillion.
- But where will we get the hydrogen???
Renewable Energy: Reality Checks...

- We cannot "store" electricity — except on a small scale (batteries). *Electricity is an energy CARRIER, not an energy SOURCE* — we must convert the electricity to another energy form (e.g., kinetic energy (spinning wheel), potential energy (pumped water storage), or something completely different — e.g., hydrogen).

- Geothermal energy is difficult to "cultivate," requires very special conditions for ECONOMIC success.

- Solar and wind energy will evolve — *there is no doubt*. Main issue → these are "dilute" sources.

- Fossil energy is "stored sunshine" and has had the benefit of millions of years to accumulate.
Global Warming
(yes, no, maybe …)

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Global Warming:

Q: Is global warming real?

A: Possible scenarios:

- Yes! (... and it was the oil companies)
- No! (the tooth fairy told me so)
- Maybe … (but I didn't do it)
- So what? (it won't really matter for 100 years)
Global Warming: (Con) \( \text{CO}_2 \) Effects/Climate Change

Petition Project:

- Temperature cycles are a function of solar activity, not the combustion of fossil fuels (i.e., increasing \( \text{CO}_2 \) concentrations in the atmosphere).

- Other studies that argue that recent temperature cycles are the result of cloud activity, cosmic rays, etc.


http://www.petitionproject.org/
Global Warming: (Pro) Anthropogenic CO₂ Issues

http://ipcc-wg1.ucar.edu/wg1/wg1-report.html

Figure SPM.2: Global average radiative forcing (RF) estimates and ranges in 2005 for anthropogenic carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O) and other important agents and mechanisms, together with the typical geographical extent spatial scale of the forcing and the assessed level of scientific understanding (LOSI). The real anthropogenic forcing and its range are also shown. These require summing asymmetric uncertainty estimates from the component terms and cannot be obtained by simple addition. Additional forcing factors not included here are considered to have very low LOSU. Volcanic aerosols contribute an additional natural forcing but are not included in this figure due to their episodic nature. The range for linear controls does not include other possible effects of aviation or clouds. (2.9, Figure 2.30)
Global Warming: Solutions

Q: What can I do to solve global warming?

A: Possible actions:

- Blame others… (... after all, this is America)
- Reduce my "carbon footprint" (i.e., live in a cave)
- Increase my "carbon footprint" (accelerate our demise)
- Nothing… (if I ignore it, it will go away)
The Real Problems
(Energy, Water, Biocapacity)

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Sustainable Development: Mission Statement

"Sustainable development is development that meets the needs of the present, without compromising the ability of future generations to meet their own needs."

— Brundtland Report


"Your yard is starting to mess with my livingroom."
Global Energy Challenge: 2003 Versus 2050

**2003:**
- 14 Terawatts
- 210 M BOE/day

**2050:**
- 30 - 60 Terawatts
- 450 - 900 MBOE/day

The Basis of Prosperity
20th Century = OIL
21st Century = ???

Source: Prof. Richard E. Smalley, Nobel Laureate
The Real Issues: Developing Nations (2007)

- 6.7 billion people currently living on earth.
- 1.1 billion people lack access to clean water.
- 2.6 billion people lack basic sanitation.
- 2.2 billion people have no electricity.

Biocapacity

Biocapacity measures how biologically productive land is. It is measured in “global hectares,” a hectare with the world average biocapacity. Biologically productive land includes cropland, pasture, forests, and fisheries. 16% of the world’s biocapacity is in Brazil.

The biocapacity of a territory is affected by physical conditions and people’s actions. A pertinent example of this is Iraq; the Mesopotamian marshes were once part of the fertile crescent. Much of this marshland has been drained and become desert. Trade sanctions and social upheavals also reduce people’s ability to use land productively. Iraq’s land is now estimated to be the least productive in the world.

Territory size shows the proportion of all biocapacity that is found there.

From: http://www.worldmapper.org/
One Last Thing…

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Opportunity is missed by most people because it is dressed in overalls and looks like work.

—Thomas A. Edison
American Inventor (1847-1931)
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End of Presentation

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