Lecture 15

Overview
World Marketed Energy Use by Fuel Type 1980-2030

US Department of Energy; Energy Information Administration 2007
OIL AND GAS LIQUIDS
2004 Scenario

A Future: ~ 3.5 Trillion bbls  Oil Resources

S. Koonin, Chief Scientist BP, 2008
nrg.caltech.edu

Source: Modified from Cambridge Energy Research Associates, Inc. (CERA). "The use of this graphic was authorized in accordance by CERA. No other use or redistribution of this information is permitted without written permission by CERA."
Net Primary Resource Consumption ~103 Exajoules

Power ~3.3TW

Rejected Energy 61%

Lawrence Livermore National Lab., http://eed.llnl.gov/flow
Electric Potential of Wind

- Significant potential in US Great Plains, inner Mongolia and northwest China

- U.S.:
  Use 6% of land suitable for wind energy development; practical electrical generation potential of $\approx 0.5$ TW

- Globally:
  Theoretical: 27% of earth’s land is class $>3$ $\Rightarrow$ 50 TW
  Practical: 2 TW potential (4% utilization)

Off-shore potential is larger but must be close to grid to be interesting; (no installation $> 20$ km offshore now)

Nate Lewis, Caltech
Turbine Sizes

Airbus A380
wing span 80m

50 kW
Ø 15 m
1980

100 kW
Ø 20 m
1985

500 kW
Ø 40 m
1990

600 kW
Ø 50 m
1995

2.000 kW
Ø 80 m
2000

4.500 kW
Ø 120 m
2005

10,000 kW
Ø 180 m
2010

Trend toward bigger turbine sizes

Helge Aagaard Madsen, DTU Risø
Source: Berkeley Lab database (some data points suppressed to protect confidentiality)

http://www.eere.energy.gov/

2008 Wind Technologies Market Report
Geothermal energy

- The only form of renewable energy that is independent of the sun.
- One or more boreholes are drilled into the reservoir, the hot fluid flows or is pumped to surface and is then used in conventional steam turbines or heating equipment.
Geothermal Energy Potential

- Mean terrestrial geothermal flux at earth’s surface: 0.057 W/m²
- Total continental geothermal energy potential: 11.6 TW
- Oceanic geothermal energy potential: 30 TW

- Wells “run out of steam” in 5 years
- Power from a good geothermal well (pair): 5 MW
- Power from typical Saudi oil well: 500 MW
- Needs drilling technology breakthrough
  (from exponential $/m to linear $/m) to become economical

Nate Lewis, Caltech
Energy from the Oceans?

Currents

Tides

Thermal Differences

Waves

Ken Pedrotti, UCSC
Biomass Energy Potential

Global: Top Down

- Requires Large Areas Because Inefficient (0.3%)
- 3 TW requires ≈ 600 million hectares = 6 \times 10^{12} \text{ m}^2
- 20 TW requires ≈ 4 \times 10^{13} \text{ m}^2
- Total land area of earth: 1.3 \times 10^{14} \text{ m}^2
- Hence requires 4/13 = 31\% of total land area
# Biofuels

<table>
<thead>
<tr>
<th>CROP</th>
<th>Harvestable Biomass (tons/acre)</th>
<th>Ethanol (gal/t)</th>
<th>Million acres needed for 35 billion gallons of ethanol</th>
<th>% 2006 harvested US cropland needed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn grain</td>
<td>4</td>
<td>500</td>
<td>70</td>
<td>25.3</td>
</tr>
<tr>
<td>Corn stover</td>
<td>3</td>
<td>300</td>
<td>105</td>
<td>38.5</td>
</tr>
<tr>
<td>Corn Total</td>
<td>7</td>
<td>800</td>
<td>40</td>
<td>15.3</td>
</tr>
<tr>
<td>Prairie</td>
<td>2</td>
<td>200</td>
<td>210</td>
<td>75.1</td>
</tr>
<tr>
<td>Sorghum</td>
<td>2</td>
<td>200</td>
<td>210</td>
<td>75.1</td>
</tr>
<tr>
<td>Switchgrass</td>
<td>6</td>
<td>600</td>
<td>60</td>
<td>20.7</td>
</tr>
<tr>
<td>Miscanthus</td>
<td>17</td>
<td>1700</td>
<td>18</td>
<td>5.8</td>
</tr>
<tr>
<td>Tank Algae*</td>
<td>80+</td>
<td>600+</td>
<td>&lt; 10</td>
<td>&lt; 2</td>
</tr>
</tbody>
</table>

*assumes CO₂ input
Solar Energy Potential

- Theoretical: $1.2 \times 10^5$ TW solar energy potential
- Practical: $\approx 600$ TW solar energy potential
- Onshore electricity generation potential of $\approx 60$ TW (10% conversion efficiency):
  - *Photosynthesis*: 90 TW

- Generating 12 TW (1998 Global Primary Power) requires
  $0.1\%$ of Globe = $5 \times 10^{11}$ m$^2$ (i.e., 5.5% of U.S.A.)
### Solar Source

<table>
<thead>
<tr>
<th>Energy Content</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solar Radiation on Earth</td>
<td>5,500,000 EJ</td>
</tr>
<tr>
<td>Solar Radiation on lower regions on Earth</td>
<td>3,800,000 EJ</td>
</tr>
<tr>
<td>Global Coal Resources</td>
<td>200,000 EJ</td>
</tr>
<tr>
<td>Global Plant Mass</td>
<td>10,000 EJ</td>
</tr>
<tr>
<td>Global Fossil Fuel Production</td>
<td>300,000 EJ</td>
</tr>
<tr>
<td>Typical Caribbean Hurricane</td>
<td>40 EJ</td>
</tr>
<tr>
<td>Hiroshima Bomb (1945)</td>
<td>0.0000084 EJ</td>
</tr>
</tbody>
</table>
World Insolation
In class discussion

- Myths
  - The greenhouse effect and global warming is bad.
  - There is enough fossil fuel in the ground to last for hundreds of years.
  - Two dollars a gallon is too much to pay for gasoline.
  - Oil is produced by oil companies.
  - When we do run out of oil, the marketplace will ensure that it’s replaced by something else.
  - Nuclear energy is bad.
  - We can help by conserving energy; otherwise, there will be an energy crisis.
7 hands-on laboratory experiments (6 are required)
Final Review

- Lectures (Oxana Pantchenko)
- Guest Lectures (Ali Shakouri)
- Labs
- Discussion Topics (Out of Gas)
- Midterm
- Quizzes