Thoughts on Global Energy
Primary Sources of Energy

- Fossil
  - Oil
  - Coal
  - Gas

Non Renewables

- Nuclear
  - Fission
  - Fusion

- Solar
  - Hydropower
  - Biomass
  - Photovoltaic
  - Solar thermal
  - Wind

Renewables

- Geothermal
How much do we consume?

- Worldwide consumption rate (per second)
  - 37,000 gals of oil
  - 150 tons coal
  - 3.2 Mcf gas
- Units must have come from a veritable tower of Babel!
  - Therms (or BTUs), Quads, MWh, Barrels (bbl), Tons, Tcf …
- Lack of uniform units presents a serious impediment to meaningful discussion
- Further confusion caused by the necessity to use millions, billions, trillions, and quadrillions of whatever

Crane and Kinderman, 2000
Idea: Cubic Mile of Oil Equivalent

- A unit that can be visualized
- 1 cmo ≈ 1 trillion gallons of oil
- Also, 1 cmo ≈ current annual worldwide oil consumption

1 cmo is equivalent to:

- 26 Billion \((10^9)\) bbl oil
- 6 Billion \((10^9)\) tons of hard coal
- 49.5 Trillion \((10^{12})\) KWh electricity
- 153 Quadrillion \((10^{15})\) Btu (Quads)
  - 1 Btu ≈ energy from a burning match

Crane and Kinderman, 2000
## Primary Sources of Energy in cmo (2017)

<table>
<thead>
<tr>
<th>Source</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fossil</td>
<td>3.11</td>
</tr>
<tr>
<td>Oil</td>
<td>1.03</td>
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<tr>
<td>Coal</td>
<td>1.22</td>
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<tr>
<td>Gas</td>
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<tr>
<td>Nuclear</td>
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</tr>
<tr>
<td>Fission</td>
<td>0.19</td>
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<tr>
<td>Fusion</td>
<td></td>
</tr>
<tr>
<td>Solar</td>
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</tr>
<tr>
<td>Hydropower</td>
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</tr>
<tr>
<td>Biomass &amp; waste</td>
<td>0.36</td>
</tr>
<tr>
<td>Wind, solar</td>
<td>0.07</td>
</tr>
</tbody>
</table>

**Total** 3.82

3.11 out of 3.82 cmo or 81% from fossil sources

Crane and Kinderman, 2000
World Energy Consumption 2012

- Asia & Oceania: 39%
- North America: 22%
- Europe: 16%
- Eurasia: 9%
- Middle East: 6%
- Central & South America: 5%
- Africa: 3%

- World Energy Consumption 2012
Historic Trend in Energy Use

- Doubling every 27 years
- Increases in population and living standards drive the exponential increase in energy consumption
- By 2050, the world will need between 2 and 7 additional cmo’s!!!
  ⇒ Where will this come from??
Switching to Non-Fossil Energy

What do we do?
- Hydro
- Nuclear
- Wind
- Biomass
- Photovoltaic

Let’s estimate what it would take to get 1 cmo from any of these sources by 2050

Crane and Kinderman, 2000
Hydroelectric – to get 1 CMO

- Three Gorges Dam is 18.2 GWe
  - 9 times size of Aswan Dam
  - $30 billion (US)
  - 15 years (1994 to 2009)
  - Displaced 1 million people from homes
- 18.2 GWe is .003 CMO!
- Need over 300 such dams to get 1 CMO!
  - By 2050, need 1 completed every 2 months
Nuclear – to get 1 CMO

- Diablo Canyon has two reactors of ~1100 MW each
  - Operating for 15 years
  - Studies on earthquake survivability
  - One of two operating nuclear plants in CA
- Provided $1.72 \times 10^7$ MW-hrs of electricity in 2003
- 0.00039 CMO
- Need over 2500 such facilities to get 1 CMO!
  - By 2050, need ~5 facilities completed every month
Wind – to get 1 CMO

* Denmark is putting 2 MW windmill/turbines into the North Sea
  - 64 m high at hub, 74 m rotor diameter (210 ft high at hub, 243 ft diameter)
  - 10 turbines provided $89 \times 10^3$ MW-hrs of electricity for Copenhagen
  - $2 \times 10^{-7}$ CMO per windmill
* Need over 5 million such facilities to get 1 CMO!
  - By 2050, need over 300 such large windmills completed every day!
  - Problems for 2/3 of time wind is not right
Biomass – to get 1 CMO

- Average of 15 tons of biomass per acre per year (in U.S.)
- Average energy content of 7500 Btu/lb
  - Small power plants with low conversion efficiency (~20%)
  - Extra ~75% fossil fuel needed to convert to liquid fuels
- $1.5 \times 10^{-9}$ CMO per acre (not including efficiency of conversion)
- Need over 680 million acres to get 1 CMO!
  - ~1 million square miles, or a square 1000 miles by 1000 miles
  - Impact on food prices (especially meat, wheat, etc.)
Photovoltaic – to get 1 CMO

- Quite expensive to get electricity
- Not bad for hot water
- Average 80 kW-hr/m² of power per year
- $1.8 \times 10^{-12}$ CMO per m²
- Need over 200,000 square miles of photovoltaics to get 1 CMO!
  - A square 450 miles by 450 miles
This analysis was for 1 CMO by 2050!

The world may need 2-7!

We have an enormous task ahead of us…

What about fossil fuel options?
Coal – to get to 1 CMO

- IPP plant near Delta, UT
  - Two 975 MW facilities
  - Each burns ~1 million pounds/hr of coal
  - All converted to DC power and shipped to the LA basin, then reconverted to AC power

- Assume 36% efficiency, 97% uptime
- 16.6 million MW-hrs of power per year
  - .00103 CMO/yr

- Need 968 such facilities by 2050 to get 1 CMO!
  - 19 plants per year for 50 years, or
  - 1.6 plants per month
This is why we use fossil energy!

- Most projections show that the percentage of fossil fuel use will stay relatively constant
  - We still have to build a lot of facilities!
  - Rapid building in China
  - Construction prices have risen 25-30%

- Increased renewables will keep pace with increased energy use and only increase slightly as a percentage of the overall energy use
What Should Be Done?

- Define goals
  - Cost?
  - Environment?
  - National security?
  - Reduce dependence on unstable/unfriendly countries?
- Continue expanding renewable energy using economic judgment
  - How much extra are people willing to pay for fossil fuel alternatives?
- Make fossil fuel use as clean and efficient as possible
  - Rise in natural gas costs -- home heating costs rise
  - Options for cleaner coal – IGCC, oxyfiring, CO\(_2\) sequestration
  - Alternate liquid fuels – biodiesel, (ethanol), coal-to-liquids, biomass-to-liquids
- Nuclear
  - Projected fuel shortage in ~30 years without breeder technology
  - Wastes from breeder technology much smaller
    - handling large quantities of plutonium is a potential terrorist threat
What Else Should We Do?

- Don’t make rash statements or decisions, such as:
  - Eliminate dependence on foreign oil
  - Stop using fossil fuel
  - Require 50% of motor fuel from renewable sources
  - Require H₂ as a fuel for a specified fraction of energy
- Continue to search for economical renewable energy
  - Criteria for use of renewables
    - Must be economic without subsidies
    - Must not increase use of fossil fuels
    - Should not increase prices of other sectors (like food)
    - Must not create additional environmental problems
      - Depleted forest area
      - Oxygen-starved area in Gulf of Mexico at mouth of Mississippi River
- Increase use of unconventional oil
  - Oil sands, oil shale, heavy oil
  - Coal conversion to liquid fuels