2008 Energy Use = 505 Quads

World Energy Inputs:
- Liquids: 34%
- Natural Gas: 28%
- Coal: 23%
- Nuclear: 10%
- Renewables: 5%
Oil and Gas Liquids
Oil and Gas Liquids

**Blessings**
- Mostly used to for transportation, cars, trucks, aircraft, rail, etc.
- Also used to make petrochemicals, asphalt, lubricants, electricity, etc.
- Enables international trade
- Is closely tied to world economies
- Very easy to transport to refine and as final product
- Burning has low acute hazards
- Easily stored at distribution points
- Exceedingly high energy density
  - 1 barrel = $84,000 of manual labor
  - allows for long range transport
  - only fuel that enables air travel
- Has established an infrastructure for other liquid fuels

**Curses**
- Oil drilling & refining is hazardous
  - to workers, fire, explosion, etc.
  - spills into the environment
- Transporting oil is not without risk
  - pollution
  - theft and terrorism
- Burning oil is not clean
  - pollution
  - greenhouse gas (CO₂) emissions
- Large reserves are in politically unstable countries
- Human rights violations track with high oil prices
- Easy half of oil has been pumped
- Future oil will be more difficult to extract \( \therefore \) more expensive
- Price instability
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Also used to make petrochemicals, asphalt, lubricants, electricity, etc.

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Price instability

Oil and Gas Liquids

Blessings

Curses
Coal
Coal

**Blessings**
- Mostly used to make electricity
- Abundant domestically & world-wide (US has the most)
- Abundance = affordable
- Available from politically stable countries
- Relatively easy to transport
- Burning has low acute hazards
- Easily stored at power plant
- Operation independent of
  - weather
  - seasons
  - time of day
- Can be converted into a liquid fuel

**Curses**
- Coal mining is very dangerous
  - fires and explosions
  - black lung
- Transportation can be hazardous
- Burning coal is not clean
  - high chronic hazards
  - pollution (gases, heavy metals, radioactivity, etc.)
    - greenhouse gas (CO₂) emissions
    - sequestered products still hazardous
- Centralized electric power generation
  - security risk
  - copious quantities of cooling water
  - most energy is lost to heat (>60%)
- Environmental impacts
  - mining
  - emissions
  - tailings
- Liquefaction losses of >50% before internal combustion losses of > 75%
Coal

Blessings

• Mostly used to make electricity
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Natural Gas

**Blessings**

- Very diverse fuel source
  - space and water heating
  - electricity generation
  - chemical production (e.g., fertilizer)
  - industrial manufacturing
  - cooking and clothes drying
  - dehumidifying and incineration
- Can be piped directly to buildings for multiple uses
- Somewhat easy to transport
- Available from many countries, including politically stable ones
- Burning has low acute hazards
- Can be stored for future use
- For electricity generation vs. coal
  - spins up turbines faster
  - burns cleaner
  - smaller plant footprint (no trains)

**Curses**

- Gas drilling is hazardous
  - to workers, fire, explosion, etc.
  - pumping fluids reaching groundwater
  - leaks from fractured bed rock
  - number of wells rapidly increasing
- Transportation can be hazardous
  - pipeline explosions (old infrastructure)
  - liquefied natural gas is highly volatile
- Greenhouse gas issues
  - burning produces CO$_2$ emissions
  - leaked CH$_4$ traps 72x the heat of CO$_2$
- Centralized electric power generation
  - security risk
  - copious quantities of cooling water
  - most energy is lost to heat (>60%)
- Not a good transportation fuel
  - not a liquid :: different infrastructure
  - resource size doesn’t match the transportation sector’s size/demand
  - energy density is lower than gasoline
Natural Gas

Curses

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Nuclear (existing fission)
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**Blessings**
- Existing fission reactors use a simple nuclear ($\text{U}^{238}$) reaction
- Used to make electricity
- $\text{U}$ available from many countries, including politically stabile ones
- Recycling can extend reserves
- Electricity generation does not emit greenhouse gases
- Normal operation is much cleaner than burning coal (or anything)
- Relatively small amount of nuclear fuel to make a lot of energy
- Fuel easily stored at power plant
- Operation independent of
  - weather
  - seasons
  - time of day
- Breeder reactors (future) extend reserves by 1000x

**Curses**
- Uranium mining and refining has potential exposure hazards
- Recycling is very expensive and only increases reserves by 20-30%
- Centralized electric power generation
  - security risk
  - copious quantities of cooling water
  - waste issue not resolved
- Environmental and public health risk in the “100-year event” scenario (and it has happened in Japan)
- Nuclear power is more expensive than that from coal or natural gas
- Major security risk at all stages of fuel handling and waste disposal
- Breeder reactors (future) make copious quantities of weapons grade waste, presenting a security risk and obligation for future generations
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Legend:
- Liquids
- Natural Gas
- Coal
- Nuclear
- Renewables
Consumable Energy Reserves
>36,000 Quads

- Coal: 19,100
- Gas: 6,200
- Light Oils: 8,500
- U238: 2,200
- Heavy Oils: ????
Energy Use Always Increases

World commercial energy use

Billion toe

18
15
12
9
6
3
0
1870 1910 1950 1990 2030

Renewables*
Nuclear
Hydro
Gas
Oil
Coal

Does “Current Consumption” Exist?
Are reserves infinite?
In 1956 M. King Hubbert predicted that if we don’t supplement US production with foreign oil, we’d be in trouble.
What Happened?

His production prediction was correct within 5%. We filled the gap with foreign oil (increasingly). Consumption continues to grow.

"Our ignorance is not so vast as our failure to use what we know."

M. King Hubbert
Importance of “Peak Oil”

1) Resource in the ground is fixed (area under curve)
2) Extraction past the peak dictates transition time
3) It takes decades to transition to new technologies

The World is here with crude oil.
Fuels: from *Hell* to *Heaven*
How Far can Renewables Go?

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How Far can Renewables Go?

World Energy Inputs

- Liquids
- Natural Gas
- Coal
- Nuclear
- Renewables

- 34%
- 23%
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- 10%
Ocean Power: 8-80 Quads

Ocean Thermal Energy Conversion

Tidal Power

Wave Power

Geothermal: 15-60 Quads
Hydropower: 50-120 Quads

http://ga.water.usgs.gov/edu/hyhowworks.html
BioEnergy: 60-240 Quads

• Bio-Liquid Fuels
  – Ethanol
  – Biodiesel

• BioPower
  – Direct-fired
  – Co-fired
  – Gasification
  – Modular systems

• BioHeat

• BioProducts
Wind: 400-2,200 Quads
Solar: 3,000-30,000 Quads

- **Heat**
  - Passive
  - Active (fluid or air)

- **Electricity**
  - Direct (PV)
  - Turbines (CSP)
Concentrating Solar Power

Linear Trough CSP

Power Tower CSP

Dish/Engine CSP
Think of PV as a solar battery.
How Does it Add Up/Compare?

Annual Consumption ~ 500 Quads

Coal 19,100

U$^{238}$ 2,200

Light Oils 8,500

Gas 6,200

Heavy Oils ????
How Does it Add Up/Compare?

Annual Consumption ~ 500 Quads

- Coal: 19,100
- Light Oils: 8,500
- Heavy Oils: ???
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- U^{238}: 2,200
How Does it Add Up/Compare?

Everything left in the ground = ALL future

Available Each & Every Year

Solar
3,000-30,000

Gas
6,200

Light Oils
8,500

Coal
19,100

Heavy Oils
????

U\textsuperscript{238}
2,200

2008
Use

Geothermal: 15-60
Oceans: 8-80
Hydro: 50-120
Bio: 60-240
Wind: 400-2,200

Everything left in the ground = ALL future
Solar = HUGE Potential
The Sun Warms the World

Everything left in the ground = ALL future

Available Each & Every Year

Solar 3,000-30,000

- Light Oils: 8,500
- Gas: 6,200
- Heavy Oils: ???
- Coal: 19,100
- U^{238}: 2,200

2008 World Energy Use

- Geothermal: 15-60
- Oceans: 8-80
- Hydro: 50-120
- Bio: 60-240
- Wind: 400-2,200
The Sun Warms the World

Solar On Land Every Year

2008 Use

One hour of sunlight reaching the earth

- Geothermal
- Oceans
- Hydro
- Bio
- Wind
GHGs Keep Us Warm at Night

- Reflected Solar Radiation: 107 Wm⁻²
- Absorbed by Surface: 168
- Evapotranspiration: 78
- Thermals: 24
- Latent Heat: 78
- Absorbed by Atmosphere: 67
- Reflected by Clouds, Aerosol and Atmosphere: 77
- Incoming Solar Radiation: 342 Wm⁻²
- Outgoing Longwave Radiation: 235 Wm⁻²

Greenhouse Gases (GHGs)
### Human Activity Affect on GHCs

#### Radiative Forcing Components

<table>
<thead>
<tr>
<th>RF Terms</th>
<th>RF values (W m⁻²)</th>
<th>Spatial scale</th>
<th>LOSU</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long-lived greenhouse gases</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>1.66 [1.49 to 1.83]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>N₂O</td>
<td>0.48 [0.43 to 0.53]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.16 [0.14 to 0.18]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>Halocarbons</td>
<td>0.34 [0.31 to 0.37]</td>
<td>Global</td>
<td>High</td>
</tr>
<tr>
<td>Ozone</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stratospheric</td>
<td>-0.05 [-0.15 to 0.05]</td>
<td>Continental to global</td>
<td>Med</td>
</tr>
<tr>
<td>Tropospheric</td>
<td>0.35 [0.25 to 0.65]</td>
<td>Global</td>
<td>Med</td>
</tr>
<tr>
<td>Stratospheric water vapour from CH₄</td>
<td>0.07 [0.02 to 0.12]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td>Surface albedo</td>
<td>-0.2 [-0.4 to 0.0]</td>
<td>Local to continental</td>
<td>Med - Low</td>
</tr>
<tr>
<td>Land use</td>
<td>0.1 [0.0 to 0.2]</td>
<td>Local to continental</td>
<td>Med - Low</td>
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<tr>
<td>Black carbon on snow</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Aerosol</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct effect</td>
<td>-0.5 [-0.9 to -0.1]</td>
<td>Continental to global</td>
<td>Med - Low</td>
</tr>
<tr>
<td>Cloud albedo effect</td>
<td>-0.7 [-1.8 to -0.3]</td>
<td>Continental to global</td>
<td>Low</td>
</tr>
<tr>
<td>Linear contrails</td>
<td>0.01 [0.003 to 0.03]</td>
<td>Continental</td>
<td>Low</td>
</tr>
<tr>
<td>Natural</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solar irradiance</td>
<td>0.12 [0.06 to 0.30]</td>
<td>Global</td>
<td>Low</td>
</tr>
<tr>
<td>Total net anthropogenic</td>
<td>1.6 [0.6 to 2.4]</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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Energy Has the Biggest Impact
Conclusions

• The longer we wait, the more difficult the transition. The cost of waiting includes:
  - Potential wars, resource constraints, increased health costs, degraded environment, accelerated global warming, etc.
  - Impacts will be most felt by the poor and disenfranchised!!

• Renewables are our Energy Future!!!
  - Maintains the advantages of modern society
  - Minimizes negative costs listed above
  - Reduces impacts of climate change

• Does the end justify the means?
Questions?