Energy After Oil

Materials Challenges in Alternative and Renewable Energy Conference
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Global Issues

- Energy
- Water
- Environment
When asked shortly after WWII:

“Prof Einstein, what do you see as the greatest threat to mankind?”

His prompt reply:

“Exponential growth.”
The ENERGY REVOLUTION
(The Terawatt Challenge)

Sources of Energy Supply - Worldwide

Source: International Energy Agency
Setting the Stage: A Global Overview

- Consider in 1900 less than 1 million barrels of oil per day vs. today at ~87 million barrels per day

- “By 2015 we need to find, develop and produce new oil that is equal to 8 out of 10 bbl being produced today.” President Exxon Mobil 2003

Tapped Out, Paul Roberts, National Geographic, June 2008
Crude Oil Production in the Lower 48

M. King Hubbert, 1956
World Proven Oil Reserves

2000

Proven Oil Reserves

Saudi Arabia 26%
UAE 10%
Iraq 11%
Kuwait 9%
Iran 9%
Venezuela 7%
Russia 5%
USA 3%
Libya 3%
Nigeria 2%
Qatar 1%
China 2%
Mexico 3%
Depletion of Oil Reserves

World oil reserves accumulated since 1930 are now being depleted. Industrial growth in Asia will accelerate the depletion

The Coming Oil Crisis, Colin J. Campbell
Alternatives (Renewables & Non-renewables)

Conservation / Efficiency -- not enough

Renewables
- Biomass -- large land mass, cost?, aviation?
- Hydrogen -- cost? safety? Beyond horizon for large scale use
- Wind -- commercial, not enough
- Nuclear Fusion -- technology challenges, cost? Beyond horizon
- Solar terrestrial -- commercial, large land mass, cost?
- Geothermal -- not enough
- Waves / Tides / Currents -- not enough, coastal issues
- Ocean thermal -- confined to tropical / equatorial regions, cost?
- Hydroelectric -- not enough
- Synthetic fuel -- technology challenges

Non-renewables
- Clean Coal / CTL -- sequestration?, cost?
- Nuclear Fission -- radioactive waste?, cost??
- Natural Gas -- not enough / resource limits
- Oil shale -- Technology? Environment? Cost?
- High energy density fuel -- research challenges
- Methane Hydrates -- clean and in abundance

(*) DOE R&D Emphasis
(• Active research at NRL)
Renewables

Biomass: A Potential Renewable Energy
Biomass: A Potential Energy Resource

- The oldest known energy source since the discovery of fire

- World’s 4th largest energy source
  (47 quads/year; $13.6 \times 10^{15}$ watt hr; $47 \times 10^{15}$ BTU)
  - Domestic Biomass Source for Energy
  - Agricultural Waste
  - Forestry Waste
  - Municipal Solid and Industrial Waste
  - Energy Crops (Grown for Fuel)

- US Goals for Energy Contribution from Biomass by 2020 (NREL/DOE)
  - 10% Transportation Fuels
  - 5% Electric Power Production
  - 18% Chemicals and Materials

Robert Armstrong, NDU Report
### Range in Biofuel Production (ethanol & diesel)

<table>
<thead>
<tr>
<th>Feed Stock</th>
<th>Gallons of Oil / Acre / Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn†</td>
<td>~350</td>
</tr>
<tr>
<td>Soybeans</td>
<td>48</td>
</tr>
<tr>
<td>Safflower</td>
<td>83</td>
</tr>
<tr>
<td>Sunflower</td>
<td>102</td>
</tr>
<tr>
<td>Rapeseed</td>
<td>127</td>
</tr>
<tr>
<td>Oil Palm</td>
<td>635</td>
</tr>
<tr>
<td>Algae*</td>
<td>1000-5000**</td>
</tr>
<tr>
<td>Jatropha*</td>
<td>125</td>
</tr>
<tr>
<td>Sugar Cane†</td>
<td>662</td>
</tr>
<tr>
<td>Cassava†</td>
<td>410</td>
</tr>
<tr>
<td>Sweet Sorghum†</td>
<td>374</td>
</tr>
<tr>
<td>Camelina*</td>
<td>75-100</td>
</tr>
<tr>
<td>Switchgrass*</td>
<td>low</td>
</tr>
</tbody>
</table>

† Production of ethanol  
* Non food crops  
** requires massive CO₂ injection for higher gallon number
# Gasoline Gallon Equivalent

<table>
<thead>
<tr>
<th>Fuel Type</th>
<th>BTUs/gal</th>
<th>Gallon Equivalent</th>
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</thead>
<tbody>
<tr>
<td>Gasoline, regular unleaded</td>
<td>114,100</td>
<td>1.00</td>
</tr>
<tr>
<td>Diesel (typical)</td>
<td>129,800</td>
<td>0.88</td>
</tr>
<tr>
<td>Methanol</td>
<td>56,800</td>
<td>2.01</td>
</tr>
<tr>
<td>Ethanol</td>
<td>76,100</td>
<td>1.50</td>
</tr>
</tbody>
</table>
Ethanol from Biomass Controversy (Corn)

- Energy costs for corn production and conversion to one gallon of ethanol are 131,000 BTUs. Energy value of one gallon of ethanol is 76,000 BTUs (~70% more energy is needed than that derived from ethanol).

- Ethanol costs $1.83/gallon compared to $1.00/gallon for gasoline.

- An average car running 10,000 miles/year on ethanol fuel needs 850 gallons, grown on 11 acres of ground.

- $1.5+ Billion/year in subsidies are provided by federal and state governments for ethanol production

David Pimentel, Cornell U. (Encyclopedia of Phy. Sci. & Tech.)
# Alternate renewable fuels (diesels & alcohols)

## Feedstocks
- **Algae**
- **Vegetable Oils**
  - Conoco Philips and Tyson Foods
  - Neste Oil
- **Animal Fat**
  - Conoco Philips and Tyson Foods
  - Neste Oil
- **Multiple Biomass**
  - Neste Oil and Stora Enso
  - Sweden
- **Corn/Sugar Cane**

## Processes
- **Esterification**
  - (methanol, Strong Base)
  - NaOH / KOH
- **Hydro-treating**
  - (Hydrogen)

## Products
- **Biodiesel**
  - Fatty Acid Methyl Ester (FAME)
- **Green diesel**
- **Biomass to Gas**
  - (BTL Gasification)
  - (formation of syngas)
- **Hydrolysis/Fermentation**
- **Fischer-Tropsch (FT)**
  - diesel
- **Ethanol/C2+ Alcohols**

## Problems
- **Stability**
  - (microbial, emulsions, solvation, contaminants)
- **Stability**
  - microbial-induced sulfate → sulfides
- **Need Evaluation**
- **Low Flash Point and Energy Density**
Biodiesel provides carbon source for microbial growth resulting in sulfide production and corrosion.

- Biodiesel
- Natural Persian Gulf Seawater
- Carbon Steel Coupon

No Sulfide Production

Sulfide Production

No Sulfide Production

Sterilized Persian Gulf Seawater + Biodiesel

Natural Persian Gulf Seawater + Biodiesel

Natural Persian Gulf Seawater
Algae to Jet Fuel
(produce $5 \times 10^9$ gal / yr from a yield of 1250 gal / acre / yr)

- **Need high solar flux, abundant water, CO$_2$ and nutrients** and **massive land areas**

- 1250 gallons “oil” / acre / year requires **6000 square miles**

- 233 coal fired power plants in south east US burn about 330 million tons of coal per year and produce about 860 million tons CO$_2$ per year. $5 \times 10^9$ gallons “oil” / yr requires 260 million tons CO$_2$ per year (high CO$_2$ transportation cost if not adjacent)

- Massive **water requirements**
$5 \times 10^9$ gallons “oil” / yr requires **4.5 trillion gallons of water** per year

- **1 % S in coal** will acidify the water to pH from ~ 5 to 3 (killing algae harvest)

- Costs of fuel could **(if the algae ponds and coal fired power plants are adjacent)** be ~ $2 / gallon, excluding capital investment **(if CO$_2$ is transported** the cost will be $35 – 40 / gallon)
Camelina to Jet Fuel
(1.4 Billion gallons / year - Montana project)
(Excluding land acquisition cost)

• Grows on non-arable (non-food) land. (80 – 100 days for harvest)
• Camelina at <100 gal / acre / yr, requires 14 million acres (¼ of pasture land in Montana)
• Fertilizer (~100 x 10^6 lbs / yr), cost - $100 Million / yr
• Planting & harvesting cost at ~$280 Million / yr
• Processing costs to jet fuel ~ $3 Billion / yr
• Processing costs to bio diesel fuel ~ $300 Million / yr
• Market demand will favor FAME over jet fuel
• Crop rotation with dry land wheat is uncertain
Pasture Land: 53% of MT
Crop Land: 19% of MT
Camelina for Navy Fuel: 15% of MT
Switchgrass to Ethanol

- A perennial grass native to the Great Plains
- Grows in marginal land
- Needs seeding once / decade
- Cultivation requires fertilizers (~ 100 lbs N\(_2\) / acre) and irrigation
- 100 gal ethanol / acre / yr
- With higher cost enzymes for bioreactors, cost / gal about that for corn
Jatropha to Biofuel

- Crop grows on marginal land but needs ample water supply
- Claimed to produce more fuel / acre than corn
- Production: a) variable, depending on soil quality, b) highly labor intensive, c) depends on plant life
- Leaves & seeds highly toxic
- Requires tropical climate: (Myanmar, India, China, Philippines, etc.)
Hydrokinetic Energy from Ocean Currents

• Most promising site in North Atlantic - Florida Straits
  • Incident energy flux: ~ 18 GW
  • Extracted energy: 3-4 GW

• Disadvantages:
  • Wake loss
  • Drag on supporting structures
  • Internal turbine and transmission losses
  • High cost
• Usable energy transmitted to the grid: 1-2 GW
Hydrokinetic Energy from Marine Environment

Tides, Waves, Ocean/River Currents, and Ocean/Thermal

**Tidal Energy**
Variations in sea levels (twice daily) due to the gravitational effects of the sun and the moon turn immersed turbines.

**Advantages:**
- Large scale investment (100 MW+)
- Proven technology
- Protection from coastal flooding

**Disadvantages:**
- Specific sites (40 worldwide)
- Intermittent operation (4 flows/day)
- High capital investment ($3-10K/kW)
- Environmental issues
- Navigation limits

**Wave Energy**
Rise and fall of waves moves a cylinder which drives an electric generator.

**Advantages:**
- Single buoy (50 kW)
- Existing technology (tested at New Jersey by OPT)
- No environmental impact

**Disadvantages:**
- Coastal navigation
- High sea states
- Fisheries
- Capital investment
Ocean Thermal Energy Conversion (OTEC)

- First proposed in 1881 - d’Arsonval
- Oceans are the largest solar energy collector on earth
- Stored energy in the equatorial / tropical oceans equals ~ 300 times the world’s energy consumption (best operation for $\Delta T = 40^\circ F$)
- Energy conversion is 24 hours per day. Advantage over tides, solar & wind
- Energy extraction is environmentally neutral (tested in Hawaii: 50 kW in 1979, 1 MW in 1980)
Technology Challenges for Ocean Thermal Energy Conversion

For 100 MW Net Power

- Continental shelf closer to coastline
- Tropical ocean with minimum seastate fluctuation and currents
- Internal tides near islands (Hawaii)
- ~30 feet diameter pipeline extended ~ 3000 feet in ocean column
- Water pumping at a rate of ~ 13,000 cubic feet / sec
- $\Delta T$ equals ~ 40°F for ammonia as a heat exchanging fluid

Power output $\propto (\Delta T)^2$
Depth (m) of 40F isotherm where SST is at least 80F
month 01 from NRL GDEM 4.0
Synthetic Fuel from the Sea
**Objective**

Fuel independence that is cost-effective and CO₂ neutral. Fuel synthesis using H₂ produced by electrolysis of seawater and CO₂ extraction from seawater.

**1. Sea Based Application**

Fuel production plant
Lily Pad
Energy Nuclear/OTEC
Hydrocarbon production

Rest of Battle Group
Cruiser, Destroyer, Frigate, Oiler, Amphibious

**2. Fuel Ship Application**

Fuel production plant

Rest of Battle Group
Cruiser, Destroyer, Frigate, Oiler, Amphibious

CO₂ from seawater:

\[
\begin{align*}
H_2O & \rightarrow H + O_2 \\
H + H_2O + CaHCO_3 & \rightarrow HCO_3^- + CaOH \\
H_2CO_3 & \rightarrow CO_2 + H_2O
\end{align*}
\]

A 100 MW power plant could produce 41,000 gal. of fuel / day
Non Renewables
Petroleum from Domestic Oil Shale
CO, UT & WY

Oil Shale Deposits in the Three-State Area

DOI, 2004
Major World Oil Shale Reserves

Tony Dammer, 2004
Comparison of Principal Factors Influencing the Economics of Producing Refinery Crude Oil

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Athabasca Tar Sands (Canada)</th>
<th>Green River Oil Shale (US)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reserves</td>
<td>More than 1 trillion bbl</td>
<td>More than 1 trillion bbl</td>
</tr>
<tr>
<td>Grade (Richness)</td>
<td>25 gallon bitumen/ton</td>
<td>25 gallon kerogen oil/ton</td>
</tr>
<tr>
<td>Hydrogen Content</td>
<td>10.5%</td>
<td>11.8%</td>
</tr>
<tr>
<td>N and S requiring removal</td>
<td>6.2 Wt%</td>
<td>4.0 Wt%</td>
</tr>
<tr>
<td>Loss to Coke</td>
<td>33 lb/ton-ore</td>
<td>nil (burned for energy)</td>
</tr>
<tr>
<td>Net yield of oil</td>
<td>0.50 bbl/ton mined</td>
<td>0.58 bbl/ton mined</td>
</tr>
<tr>
<td>Quality of oil</td>
<td>34°API</td>
<td>34°API</td>
</tr>
</tbody>
</table>

Tony Dammer, 2004
Petroleum From US Oil Shale

- Maximum deposits estimated at $1.5 \times 10^{12}$ barrels (USGS 1965; DOE 2005; largest in the world)
- Recoverable oil: $1.0$ to $17 \times 10^{10}$ barrels (M. K. Hubbert 1969)
- Extraction technology: (mine and retort (old); in situ extraction (thermal energy, Shell Oil, 2000)
- Advantages
  - Large domestic deposits
  - Excellent finished product (JP-5)
- Issues
  - Disposal of spent shale
  - High levels of arsenic
  - High volumes of water for processing
  - Hydrogen upgrading
  - Meeting regulatory standards CO$_2$ emissions
  - Cost?
    (DoI, BLM estimates)
Abundance of Frozen Clean Energy from the Sea
(Methane Hydrates)
Global Estimate of the Methane Hydrates

Gigatons (10⁹ tons)

- Waste material
- Peat
- Land (animals and plants)
- Dissolved organic matter in water
- Soil
- Total fossil fuels (gas, oil, coal)
- Methane hydrates

Global gas-in-place estimates vary but 700,000 tcf is most widely cited estimate.
One cubic meter of gas hydrate yields 164 m$^3$ of gas and 0.8 m$^3$ of water at STP
World Methane Hydrate Distribution

- Coastal Ocean
- Arctic Permafrost
- NRL Activity
- NRL Plans
US Methane Hydrate Distribution

CH₄ deposit > 300 x 10¹⁵ Cu Ft
US annual consumption ~ 22 x 10¹² Cu Ft

- NRL Sample Sites

Collett, 1995
DTAGS Application on the Cascadia Margin

“Wipe Out” zones related to dissociation of hydrates
Materials Challenges in Alternative and Renewable Energy
(needed for all technologies on alternate energy production)

- Corrosion / stress corrosion and corrosion fatigue resistance
- Materials for deeper ocean drilling
- Advanced catalysts and enzymes
- Environmentally friendly anti-fouling paints and coatings
- New low cost ferrous alloys for hydrogen transport
- Structural materials for OTEC application
- Hybrid plants with improved photosynthetic efficiency
- Genetic engineering to accelerate microbial processes
Energy for the 21st Century

“The crisis facing our nation would make the Depression years look like good times”
- Congressman Bartlett

Thank you

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