New Directions in Fuels Technology

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Panel on New Directions in Engines & Fuels
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Strategy, Integration & Spec. Businesses
Transportation Fuels Bottom Line

- All fuels have real economic and social costs and benefits; scale matters

- Liquid fuels compatible with current powertrains & energy infrastructure are near term answer

- Energy efficient vehicles are needed regardless of fuel

- Real commitment to improving energy security precludes taking any energy option off the table

- Long term, electricity offers primary energy diversification to transportation beyond oil & liquid biofuels

- Technology & innovation will drive the fuels of the future
All Fuels Have Pros & Cons
They Become Evident at Large Scale

<table>
<thead>
<tr>
<th>Selected Criteria</th>
<th>Petroleum-Derived Fuels</th>
<th>Bio-Derived Liquid Fuels</th>
<th>Electricity (Coal)</th>
<th>Hydrogen (Natural Gas)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Security</td>
<td>![Concern]</td>
<td>![Potential Concern]</td>
<td>![Minimal Concern]</td>
<td>![Minimal Concern]</td>
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<tr>
<td>Weather Vulnerability</td>
<td>![Potential Concern]</td>
<td>![Concern]</td>
<td>![Minimal Concern]</td>
<td>![Potential Concern]</td>
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<tr>
<td>In Use Fleet Compatibility</td>
<td>![Minimal Concern]</td>
<td>![Concern]</td>
<td>![Concern]</td>
<td>![Potential Concern]</td>
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<tr>
<td>Infrastructure Readiness</td>
<td>![Potential Concern]</td>
<td>![Potential Concern]</td>
<td>![Concern]</td>
<td>![Minimal Concern]</td>
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<tr>
<td>CO2 Intensity</td>
<td>![Potential Concern]</td>
<td>![Potential Concern]</td>
<td>![Concern]</td>
<td>![Concern]</td>
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<tr>
<td>Land Use Effects</td>
<td>![Minimal Concern]</td>
<td>![Concern]</td>
<td>![Concern]</td>
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</tr>
</tbody>
</table>

- **Concern**: High potential for concern.
- **Potential Concern**: Moderate potential for concern.
- **Minimal Concern**: Low potential for concern.

*Source: ConocoPhillips*
Moving Toward Energy Security Precludes Taking Energy Options Off the Table

U.S. Primary Energy Demand, Barrels/Day Oil Equivalent, Millions

Economic Development Enables Personal Vehicle Ownership

Vehicles In Operation per 1,000 population, 2007

54 Countries Over 20 MM population

W Europe, Australia, Japan, Canada

Developing countries including China & India

GDP Per Capita, ‘000s UD, 2007

Sources: United Nations statistics & WardsAuto.com
## Technology Focus Areas Within COP

<table>
<thead>
<tr>
<th>Coal/CTL &amp; Gasification</th>
<th>Challenged Resources</th>
<th>Core Upstream</th>
<th>Core Downstream</th>
<th>Biofuels</th>
<th>Alternative Energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Coal</td>
<td>• Shale</td>
<td>• Reliability &amp; Integrity</td>
<td>• Advanced Hydrocarbon Fuels</td>
<td>• 1&lt;sup&gt;st&lt;/sup&gt; Gen</td>
<td>• Batteries</td>
</tr>
<tr>
<td>• E-Gas</td>
<td>• Hydrates</td>
<td>• Exploration Improvements</td>
<td>• Refinery Processing</td>
<td>• 2&lt;sup&gt;nd&lt;/sup&gt; Gen</td>
<td>• Geothermal</td>
</tr>
<tr>
<td>• Syn Gas</td>
<td>• Arctic</td>
<td>• Production Opt</td>
<td>• Catalyst Evaluation</td>
<td></td>
<td>• Solar</td>
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<tr>
<td>• CTL</td>
<td>• LNG</td>
<td>• Integrated Surveillance &amp; Performance</td>
<td>• Sulfur Removal Technology</td>
<td></td>
<td>• Wind</td>
</tr>
<tr>
<td></td>
<td>• Challenged gas (tight, stranded, sour)</td>
<td>• Improved Recovery</td>
<td>• Process H&lt;sub&gt;2&lt;/sub&gt;</td>
<td></td>
<td>• Ocean</td>
</tr>
</tbody>
</table>

### Core Upstream
- Reliability & Integrity
- Exploration Improvements
- Production Opt
- Integrated Surveillance & Performance
- Improved Recovery

### Core Downstream
- Advanced Hydrocarbon Fuels
- Refinery Processing
- Catalyst Evaluation
- Sulfur Removal Technology
- Process H<sub>2</sub>
- Enhanced Reliability

### Biofuels
- 1<sup>st</sup> Gen
- 2<sup>nd</sup> Gen

### Alternative Energy
- Batteries
- Geothermal
- Solar
- Wind
- Ocean
- Fuel Cells
- Novel H<sub>2</sub>
- Nuclear

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### Environmental Technology
- CO<sub>2</sub>
- Water
- Environment – License to Operate
Biofuels are a critical part of the energy future, but are not the only solution.
Quantity Challenges of Biomass

- 19 Bushels Corn
- 42 Bushels of Soybeans
- 2 Cows
- 14 Pigs
- 900 Chickens
- 900 lb of biomass

= 1 Barrel of Fuel
COP Funded Research Areas

- **Renewable Diesel**
  - Commercialized refinery co-processing of oils/fats with distillates in 2007

- **Biocrude Development Program**
  - Developing technology to produce transportation fuels from biomass
  - ADM-COP joint program to commercialize technology by 2013

- **COP Biofuels Algae program**
  - Conducting research necessary for development of a long term position on algae as a renewable fuel feedstock
  - Leveraging internal expertise on oil extraction & oil conversion with externally sponsored algae research
  - Member of Colorado Center for Biorefining & Biofuels (C2B2) consortium

- **Biomass Gasification R&D**
  - Member of NREL-ISU-COP collaboration
  - Conducting multiple programs at Iowa State University through 2014
  - Plan to demonstrate integrated BTL pilot plant (0.5 TPD)

- **CRC (Coordinating Research Council) Participation**
  - AVFL Committee: Gasoline HCCI, diesel HCCI, E20, & biofuels research
  - FACE: Develop and characterize fuels for advanced combustion engines
Renewable Diesel Process

Crude Distillation

- Straight Run Gasoline
- Straight Run Diesel
- Renewable Fats/Oils

Hydrogen

Diesel Hydrotreater

- ULSD
- Renewable Diesel Blend

Note: Over 100 million gallons of fats and oils have been processed into renewable diesel worldwide by COP & others.
## Relative CO₂ Life Cycle Emissions

<table>
<thead>
<tr>
<th></th>
<th>Petroleum Diesel</th>
<th>Biodiesel B100</th>
<th>Renewable Diesel R100</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>COP</strong> (substitution, soy)</td>
<td>100%</td>
<td>59%</td>
<td>44%</td>
</tr>
<tr>
<td><strong>UOP</strong> (mass allocation, soy)</td>
<td>100%</td>
<td>43%</td>
<td>26%</td>
</tr>
<tr>
<td><strong>NExBTL®</strong> (substitution, rapeseed)</td>
<td>100%</td>
<td>60%</td>
<td>31%</td>
</tr>
<tr>
<td><strong>GREET Model</strong> (energy allocation, soy)</td>
<td>100%</td>
<td>32%</td>
<td>26%</td>
</tr>
</tbody>
</table>
COP Algae Program

**External Collaborations**
- Strain Characterization and modification
- Algae Production

**Internal Efforts**
- Algae Oil Characterization
- Oil Extraction
- Algae Oil Upgrading
- Fuel Blending & Characterization

**Modeling & Systems Analysis**
Biomass Gasification (BTL)

- **Biomass**
- **Gasifier**
- **Gas Cleaning**
- **Synthesis Gas** $(H_2, CO)$
- **Fuel Synthesis** (FT, MTG)
- **Upgrading**
- **Transportation Fuel**

- **O$_2$**
Closing Thoughts
How do we meet the challenges?

- **Diversify supply**
  - Oil, Gas, Coal will still provide most energy
  - Biofuels and Renewables are a vital part of the mix

- **Improve Energy Efficiency**
  - Transport, Residential and Industrial
  - Within our industry

- **Develop new technologies**
  - Improve conventional oil and gas
  - Recover unconventional from oil sands to shale to hydrates
  - Focus new technology to convert biomass to fuel

- **Protect the environment**
  - Lower the footprint of our operations
  - Address climate change issues
Backup Slides
Coordinating Research Council is Developing Test Fuels for advanced combustion in their FACE (Fuels for Advanced Combustion Engines) Work Group

- Fuel design & individual species information.
- Info on grouping and visualization of chemical families by boiling point or carbon number.
- Data reduced to tabular form for use in correlations to combustion data.
- Example: FACE Diesel No. 9 shown here.
CRC AVFL (Advanced Vehicle/Fuel/Lubricants) Committee is testing gasoline & diesel HCCI fuels and developing new diesel surrogates

<table>
<thead>
<tr>
<th>Carbon type</th>
<th>Content (mole%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aromatic</td>
<td>Calculated 25</td>
</tr>
<tr>
<td></td>
<td>Measured 23</td>
</tr>
<tr>
<td>Cycloparaffinic</td>
<td>Calculated 21</td>
</tr>
<tr>
<td></td>
<td>Measured 25</td>
</tr>
<tr>
<td>Branched Paraffin</td>
<td>Calculated 15</td>
</tr>
<tr>
<td></td>
<td>Measured 17</td>
</tr>
<tr>
<td>Paraffin Chain (C1+)</td>
<td>Calculated 40</td>
</tr>
<tr>
<td></td>
<td>Measured 36</td>
</tr>
<tr>
<td>Olefin</td>
<td>Calculated 0</td>
</tr>
<tr>
<td></td>
<td>Measured 0</td>
</tr>
<tr>
<td>C=O*</td>
<td>Calculated 0</td>
</tr>
<tr>
<td></td>
<td>Measured 0</td>
</tr>
<tr>
<td>Total</td>
<td>Calculated 100</td>
</tr>
<tr>
<td></td>
<td>Measured 100</td>
</tr>
</tbody>
</table>

Example of branch chain characterization that can be used to replicate a fuel with a limited number of surrogate compounds

- **Useful in visualizing relative importance of carbon structures to the bulk makeup of the fuel; example here is for 16 carbon chain.**
- **May be useful in formulating kinetic surrogate fuels.**