A Life Cycle Assessment Comparing Select Gas-to-Liquid Fuels with Conventional Fuels in the Transportation Sector

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Diesel Engines Emission Reduction Conference
Loews Coronado Bay Resort
Coronado, CA

August 29 – September 2, 2004
Study Purpose

- Evaluate GTL energy use and emissions in comparison to alternative fuel production processes and end-uses
- Education and communication with peers and stakeholders
- Assess and improve environmental programs
- DOE’s interest in cleaner fuels for the future led to sponsorship under the DOE Ultra Clean Fuels Initiative
Unique Aspects of this Study

• Used COP process efficiencies
  – Thermal efficiency 67% (2006); 70% (2015)
  – Carbon efficiency 85%
• Followed ISO 14040 and convened Critical Review Panel to verify standards were met
• Developed Co-Product Function Expansion (CFE) methodology to account for co-product contributions to emissions
• Inventory results modeled in LCIA
Life Cycle Analysis

• COP elected to conduct study following procedures established under ISO 14040 standards on Life Cycle Analyses
• Independent Review Panel convened to ensure ISO standards were followed
• Two main phases of LCA’s
  – Life Cycle Inventory (LCI)
  – Life Cycle Impact Analysis (LCIA)
This paper focuses on how FTD and naphtha fuels produced using COP’s GTL technology compare with both conventional and ultra-low sulfur diesel, and FRFG motor fuels.

The UCF LCA develops a set of near-term (2006) and long-term (2015) scenarios to assess impacts associated with likely commercial scenarios for these time frames.
## Near-Term UCF Fuel Scenarios

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Fuel</th>
<th>Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>PADD III FTD20 CIDI</td>
<td>Blend of 20% remotely produced GTL diesel and 80% PADD III LSD</td>
<td>Light duty (LD) passenger vehicle with a compression ignition, direct injection (CIDI) engine</td>
</tr>
<tr>
<td>PADD III conventional diesel CIDI</td>
<td>PADD III conventional diesel</td>
<td>LD vehicle with CIDI engine</td>
</tr>
<tr>
<td>PADD III ULSD CIDI</td>
<td>PADD III ULSD, with CFE</td>
<td>LD vehicle with CIDI engine</td>
</tr>
<tr>
<td>PADD III FRFG</td>
<td>PADD III federal reformulated gasoline with CFE</td>
<td>Light duty passenger vehicle with spark ignition direct injection (SIDI) engine</td>
</tr>
</tbody>
</table>
## Long-Term UCF Fuel Scenarios

<table>
<thead>
<tr>
<th>Scenario Name</th>
<th>Fuel</th>
<th>Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>FTD100 CIDI</td>
<td>100% remotely produced GTL diesel</td>
<td>Light duty passenger, CIDI engine</td>
</tr>
<tr>
<td>PADD III ULSD CIDI</td>
<td>PADD III ULSD with CFE</td>
<td>Light duty passenger, CIDI engine</td>
</tr>
<tr>
<td>PADD III FRFG</td>
<td>PADD III FRFG with CFE</td>
<td>Light duty passenger, SIDI engine</td>
</tr>
<tr>
<td>PADD III FRFG FCV</td>
<td>PADD III federal reformulated gasoline with CFE</td>
<td>FCV, with gasoline reformer</td>
</tr>
<tr>
<td>FT naphtha FCV</td>
<td>100% remotely produced FT naphtha</td>
<td>FCV with FT naphtha reformer</td>
</tr>
</tbody>
</table>
Tools Used in the Analysis

- **DOE’s Greenhouse Gases Regulated Emissions and Energy in Transportation (GREET) Model** - fuel cycle model that inventories energy usage, greenhouse gas and criteria pollutants (NOx, SOx, PM10, VOC’s, CO ) for many fuel pathways.

- **Process Industries Modeling System (PIMS) Model** - simulates the operation of petroleum refineries, considering crude slates, desired product slates, and refinery configuration.

- **Aspen Plus** - a process simulator extensively used to model heat and material balances, thermodynamic equilibriums, and optimization of process design and the operation.

- **U.S. EPA’s Tool for the Reduction and Assessment of Chemical and Other Environmental Impacts (TRACI model)** assesses impacts by taking the emissions data from the LCI.
Dealing with Uncertainty

- Significant uncertainty is inherent in most LCA’s
- LCI – 10% difference chosen for GHG and energy
- LCI – 15% difference chosen for criteria emissions
- LCIA – 100% difference chosen for environmental impact categories
## Comparisons of FTD100 with ULSD and FRFG and FT Naphtha with FRFG in 2015

<table>
<thead>
<tr>
<th>Outputs</th>
<th>FTD100</th>
<th>ULSD CIDI</th>
<th>FRFG SIDI</th>
<th>FT Naphtha FCV</th>
<th>FRFG FCV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total energy</td>
<td></td>
<td>5,188(btu/mi)</td>
<td>25%</td>
<td>4,420</td>
<td>26%</td>
</tr>
<tr>
<td>CO₂</td>
<td>327</td>
<td>-3%</td>
<td>-7%</td>
<td>261</td>
<td>-4%</td>
</tr>
<tr>
<td>CH₄</td>
<td>0.369</td>
<td>0%</td>
<td>-31%</td>
<td>0.318</td>
<td>-16%</td>
</tr>
<tr>
<td>N₂O</td>
<td>0.016</td>
<td>-4%</td>
<td>-44%</td>
<td>0.006</td>
<td>-11%</td>
</tr>
<tr>
<td>GHG emissions</td>
<td>340</td>
<td>-3%</td>
<td>-8%</td>
<td>270</td>
<td>-4%</td>
</tr>
<tr>
<td>VOC</td>
<td>0.071</td>
<td>-11%</td>
<td>-61%</td>
<td>0.034</td>
<td>-68%</td>
</tr>
<tr>
<td>CO</td>
<td>1.198</td>
<td>7%</td>
<td>-58%</td>
<td>0.661</td>
<td>10%</td>
</tr>
<tr>
<td>NOₓ</td>
<td>0.171</td>
<td>-15%</td>
<td>-16%</td>
<td>0.105</td>
<td>-24%</td>
</tr>
<tr>
<td>PM10</td>
<td>0.031</td>
<td>-26%</td>
<td>-34%</td>
<td>0.024</td>
<td>-23%</td>
</tr>
<tr>
<td>SOₓ</td>
<td>0.021</td>
<td>-78%</td>
<td>-87%</td>
<td>0.018</td>
<td>-86%</td>
</tr>
<tr>
<td>VOC: urban</td>
<td>0.051</td>
<td>-11%</td>
<td>-63%</td>
<td>0.018</td>
<td>-75%</td>
</tr>
<tr>
<td>CO: urban</td>
<td>1.071</td>
<td>-1%</td>
<td>-61%</td>
<td>0.552</td>
<td>-2%</td>
</tr>
<tr>
<td>NOₓ: urban</td>
<td>0.056</td>
<td>-35%</td>
<td>-8%</td>
<td>0.009</td>
<td>-65%</td>
</tr>
<tr>
<td>PM10: urban</td>
<td>0.028</td>
<td>-21%</td>
<td>-30%</td>
<td>0.021</td>
<td>-15%</td>
</tr>
<tr>
<td>SOₓ: urban</td>
<td>0.000</td>
<td>-99%</td>
<td>-99%</td>
<td>0.000</td>
<td>-98%</td>
</tr>
</tbody>
</table>
NOx/VOC Comparison
PM10/SOx Comparison

![Graph showing PM10 and SOx emissions comparison]
GHG/Total Energy Comparison
Sensitivity Analyses

- Four Operational Sensitivities Examined:
- Heavy and Light Crude Slates – differences minimal
- From 10 to 3 ppm Ultra-Low Sulfur Diesel - differences minimal
- 100% Middle East Crude Supplies – NOx inventory increased by tanker transportation
- Assuming 10% Flared Gas in GTL Production – GHG and energy consumption improved
Life Cycle Inventory Conclusions

Energy Utilization

- On full life cycle basis based on light duty vehicle miles driven, COP-produced GTL uses ~ 25% more energy than ULSD (GREET model base case showed 44% difference)

Greenhouse Gas Emissions

- GHG emissions (Global Warming Potential) are equivalent between GTL and ULSD

Criteria Pollutant Emissions

- SOx, NOx, VOC, CO and PM10 inventories lower for GTL fuels in both total and urban venues
Environmental Impact Categories with Respective Category Indicators

- Global Warming Potential - gram CO$_2$ equivalents
- Acidification – mole equivalents of H$^+$
- Photochemical Smog – grams NOx equivalents
- Eutrophication – kilograms Nitrogen equivalents
- Ecotoxicity – pounds of dichlorophenoxyacetic acid equivalent
- Human Health Criteria – Disability adjusted life-years (DALY’s)
- Human Health-NonCancer– Human Toxicity Potential (HTP) based on benzene equivalent factor
- Human Health-Cancer – same as HH-NonCancer
Natural Resource Depletion

- Stranded gas utilization extends hydrocarbon reserves significantly
- GTL utilizes very small percentage of stranded gas at current projections
- Crude curve based upon:
  - Crude oil reserves 2000=1.212E+12
  - Undiscovered reserves =6.93E+11
  - Consumption (BOPD)=6.70E+07
Life Cycle Impact Analysis - Conclusions

• Impact categories (acidification, smog, eutrophication, human health, etc.) trend toward favoring GTL fuels compared to ULSD and FRFG
• definitive conclusions unwarranted by data