COMPARATIVE ANALYSIS OF ICL AS AN ALTERNATIVE TO CRUDE OIL

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When the US can no longer rely on our current sources of crude oil, how will a domestic indirect coal to syncrude plant compare to other US crude oil alternatives for the transportation sector?
Project Scope

ICL plant location and feedstock selection

Technology selection

Aspen Simulation

Economic analysis

Environmental analysis

Energy/Exergy analysis

Alternative Fuel Comparison
Aspen Plus simulation of designed CTL plant
Final CTL plant simulation

Gasifier

Fischer Tropsch

Gas cooling and cleanup
Aspen - Gasifier

- 90 t/hr
- 32 bar and 1600°C
- 95% Oxygen 85.9 t/hr
- Steam at 250°C 25.5 t/hr
- 191 t/hr
- 39.8MW
Aspen – Gas cleanup

Reaction:
\[ \text{COS} + \text{H}_2\text{O} = \text{CO}_2 + \text{H}_2\text{S} \]
Conditions: 150°C, 30bar

Selexol (ideal)

166.8 t/hr

Reaction:
\[ \text{H}_2\text{S} + 1.5 \text{ O}_2 = \text{SO}_2 + \text{H}_2\text{O} \]
Conditions: 1200°C, 1bar

1.44 t/hr S

22.0 t/hr

2.6 t/hr

0.36 t/hr COS

191 t/hr
Aspen – F.T. Synthesis

- Kinetic model from Fernandes

\[ R_{FTS} = \frac{k_{FTS}P_{CO}P_{H_2}}{P_{CO} + aP_{H_2O}} \]

\[ R_{WGS} = \frac{k_{WGS}\left(P_{CO}P_{H_2O} - \frac{P_{CO_2}P_{H_2}}{K_1}\right)}{(P_{CO} + K_2P_{H_2O})^2} \]

- Assuming steady-state operation and isothermal conditions

- Valid for multi-tubular fixed bed

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## XTL simulations

<table>
<thead>
<tr>
<th></th>
<th><strong>CTL</strong></th>
<th></th>
<th><strong>CBTL</strong></th>
<th></th>
<th><strong>BTL</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Feed</strong></td>
<td>100% Coal</td>
<td><strong>Feed</strong></td>
<td>25% BM</td>
<td>75% Coal</td>
<td>100% Switchgrass</td>
</tr>
<tr>
<td><strong>Syngas</strong></td>
<td>CO: 59.5%</td>
<td><strong>Syngas</strong></td>
<td>CO: 53.3%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>composition</strong></td>
<td>H₂: 30.7%</td>
<td><strong>composition</strong></td>
<td>H₂: 33.1%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>FT product</strong></td>
<td>29.6 t/hr</td>
<td><strong>FT product</strong></td>
<td>29.2 t/hr</td>
<td></td>
<td>17.8 t/hr</td>
</tr>
<tr>
<td><strong>Efficiency</strong></td>
<td>51.2%</td>
<td><strong>Efficiency</strong></td>
<td>51.3%</td>
<td></td>
<td>50.8%</td>
</tr>
</tbody>
</table>
### Sensitivity Analysis - Aspen

#### Gasifier

#### Sensitivity OXIDANT Results Summary

<table>
<thead>
<tr>
<th>Oxygen flow rate (KG/SEC)</th>
<th>Mole Fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>15.0</td>
<td>0.2</td>
</tr>
<tr>
<td>16.0</td>
<td>0.4</td>
</tr>
<tr>
<td>17.0</td>
<td>0.6</td>
</tr>
<tr>
<td>18.0</td>
<td>0.8</td>
</tr>
<tr>
<td>19.0</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Graph showing mole fractions of different gases as a function of oxygen flow rate (KG/SEC):
- **GH2O**
- **GCO**
- **GH2**
- **GCO2**
Sensitivity Analysis - Aspen

Fischer Tropsch

Sensitivity OXIDANT Results Summary

Oxygen KG/SEC
Mole Fraction
14.0 16.5 19.0 21.5 24.0 26.5 29.0 31.5 34.0 36.5 39.0
0.2 0.4 0.6 0.8
FTH2O
FTCO
FTCO2
FTUND
Energy and Exergy Analysis of designed CTL plant
Main Sections of the Aspen Simulation

- Gasifier
- Ash Cooling
- FT synthesis
- Gas Cooling and Cleaning
Mass flow diagram
Energy Flow Diagram
Exergy Flow Diagram

- **$T_0 = 25^\circ C$**
- **$p_0 = 1$ bar**
- Ideal gas
- $B = B_{chem} + B_{phys} + \Delta G_{mix}$
Energy Analysis

Energy Input: 51%

Energy Losses:
- FT: 44%
- electricity: 5%
- Gasifier: 17%
- Syngas cleaning: 6%
- Ash cooling: 2%
- FTprocess: 1%
- ASU: 4%
Gasifier Sensitivity Analysis

An example, oxygen:

- Energy Efficiencies for well insulated gasifiers are very high ~1 [1]
- Rational Efficiencies lower than Energy ones ~ 0.8 [1]
- \( \text{O}_2 \) sensitivity shows a decreasing trend of the chemical and rational efficiencies.

\[
\text{energy\_efficiency} = \frac{\text{energy\_input}}{\text{energy\_output}}
\]

\[
\text{chemical\_efficiency} = \frac{\text{chemical\_energy\_input}}{\text{chemical\_energy\_output}}
\]

\[
\text{exergy\_efficiency} = \frac{\text{exergy\_input}}{\text{exergy\_output}}
\]

\[
\text{exergy\_efficiency} = \frac{\text{exergy\_input}}{\text{exergy\_output}}
\]

Environmental Analysis of designed CTL plant
CO₂ Emissions

Considerations

- Purity of captured CO₂ streams is quite good
- 90% of the impurities in FT Synthesis ‘Fluegas’ is nitrogen

<table>
<thead>
<tr>
<th>Source</th>
<th>Purity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasifier – post Selexol</td>
<td>99</td>
</tr>
<tr>
<td>FT Synthesis</td>
<td>95.28</td>
</tr>
</tbody>
</table>

Table. Summary of CO₂ emissions from CTL plant

<table>
<thead>
<tr>
<th>CO₂</th>
<th>TOTAL PRODUCED</th>
<th>TOTAL CAPTURE READY</th>
<th>TOTAL PRODUCED (Kreutz et al, 2008)</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg CO₂ eq/GJ fuel (HHV)</td>
<td>102.9</td>
<td>85.0</td>
<td>99.0</td>
</tr>
</tbody>
</table>

~28,000 tonnes/day
Effect of Feedstock in Overall CO$_2$ Emissions: CTL, BTL, Co-firing

Figure. CO$_2$ emissions from various feedstock configurations

Assuming a biomass storage capacity = 17.2 kg Ceq/GJ HHV.
Water Usage

Figure. Allocation of water usage in CTL plant

Net consumption = Make-up water (3% total) + consumed process water

Table. Summary of water usage & distribution in CTL plant

<table>
<thead>
<tr>
<th></th>
<th>gal water/gal FT liq</th>
<th>Literature gal water/gal Ftliq</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water recycled in plant</td>
<td>7.70</td>
<td>-</td>
<td>[1]</td>
</tr>
<tr>
<td>Water replaced/consumed</td>
<td>0.85</td>
<td>1.03</td>
<td>[1]</td>
</tr>
<tr>
<td>Water usage in the plant</td>
<td>8.55</td>
<td>7.30, 8-10</td>
<td>[4], [5]</td>
</tr>
</tbody>
</table>
Waste Management

- Bulk mass of waste comes as
  - Ash slag
  - Fly ash

- Concerns
  - Water leaching: hazardous to groundwater resources
  - Slag is less susceptible to leaching than bottom ash

Table. Solid waste production from CTL plant

<table>
<thead>
<tr>
<th>Solid waste lines</th>
<th>Content</th>
<th>From Equipment</th>
<th>Tonnes/day</th>
<th>kg ash-slag/bbl FT_{liq}</th>
</tr>
</thead>
<tbody>
<tr>
<td>COOLASH</td>
<td>ash slag</td>
<td>Slagging Gasifier</td>
<td>1808.0</td>
<td>36.71</td>
</tr>
<tr>
<td>FILTSOL</td>
<td>fly ash</td>
<td>Particulate filter</td>
<td>9.4</td>
<td>0.19</td>
</tr>
</tbody>
</table>

- Management
  - Landfill disposal, ash-ponds (trouble)
  - Recycling of ash (cement industry)

Source: http://www.charah.com/
Policy Prospects for CTL

Possible barriers for CTL

- Remaining Uncertainties
  - Production costs
  - Management of GHG Emissions (CCS development)
  - Crude oil prices (competitiveness with conventional fuels)

- Lack of effective policies to reduce GHG emissions will likely hold back government support

Future government policies & environmental regulations may promote or discourage early investment from the private sector for CTL projects.
Policy Prospects for CTL (cont.)

- **Policy Incentives for CTL**
  - **Subsidies**
    - Investment-tax credits (financial help from the beginning of the project at government’s expense)
    - Production subsidies (favoring alternative vs conventional fuels)
    - Petroleum taxes
  - **Price Floors**
    - Encourages private investment for CTL by removing the financial constrains at times of low crude oil prices
  - **Income Sharing**
    - Beneficial for the government at times of high crude-oil prices to recover public funds from promoting CTL
Economic Analysis of designed CTL plant
Economic Model Considerations

Input categories

- Financing
- Escalation factors
- Technical design criteria
- General facility parameters
- Contingency factors
- 12% discount rate

Major Outputs

- Net Present Value (NPV)
- Return on Investment (ROI)
- Payback Period
- Year to year “At Hand” and “Discounted” Cash Flows
## Model Input Parameters

Design Parameters of a 50,000 Barrel / Day Coal to Liquids Grassroots Facility / 15 yr depreciation

<table>
<thead>
<tr>
<th>General Facility Parameters</th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Expected Plant Lifetime (yrs)</strong></td>
<td>30</td>
<td></td>
</tr>
<tr>
<td><strong>Local Industrial Electrical Costs ($/MWhr)</strong></td>
<td>$0.060</td>
<td></td>
</tr>
<tr>
<td><strong>Capacity Utilization Factor</strong></td>
<td>65%</td>
<td></td>
</tr>
<tr>
<td><strong>Overall Contingency Factor</strong></td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td><strong>Additional FT Contingency Factor</strong></td>
<td>25%</td>
<td></td>
</tr>
<tr>
<td><strong>Total O&amp;M Costs</strong></td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>**Facility Electrical Capacity (MWₚ)</td>
<td>620</td>
<td></td>
</tr>
<tr>
<td>**Facility Electrical Needs (MWₑ)</td>
<td>330</td>
<td></td>
</tr>
<tr>
<td>**Typical Output to Grid (MWₑ)</td>
<td>290</td>
<td></td>
</tr>
</tbody>
</table>

### F-T Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Petro-Oil Market Value ($/bbl)</td>
<td>$97</td>
</tr>
<tr>
<td>Diesel / Naphtha ratio (% diesel)</td>
<td>65%</td>
</tr>
<tr>
<td>ULSD Premium vs. petro crude (multiplier)</td>
<td>1.25</td>
</tr>
<tr>
<td>Naphtha value of diesel</td>
<td>77%</td>
</tr>
<tr>
<td>F-T HHV (BTU/gallon)</td>
<td>126,500</td>
</tr>
<tr>
<td>Capital Investment per bbl capacity (thousand $)</td>
<td>$105</td>
</tr>
</tbody>
</table>

### Economics, Interest, and Projections

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tax Rate</td>
<td>40%</td>
</tr>
<tr>
<td>Financing Fee</td>
<td>3.0%</td>
</tr>
<tr>
<td>Debt to Equity Ratio (% Equity)</td>
<td>55%</td>
</tr>
<tr>
<td>General Inflation</td>
<td>2.0%</td>
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</table>

### Base Year Values (MM$/YR)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Expected Plant Cost (+ contingency)</td>
<td>$5,232</td>
</tr>
<tr>
<td>Annual Fixed and Variable O&amp;M (not including electricity &amp; feed)</td>
<td>$262</td>
</tr>
<tr>
<td>Annual Feedstock Costs</td>
<td>$319</td>
</tr>
<tr>
<td>Annual Electrical Sale to Grid</td>
<td>$130</td>
</tr>
<tr>
<td>Annual F-T Revenue (pre-tax)</td>
<td>$1,628</td>
</tr>
</tbody>
</table>

| Total Expenses | $581 |
| Total Revenue | $1,758 |
| Gross Income (pre-tax) | $1,177 |
| Net Income (post-tax) | $706 |

### NPV (MM$) :

<table>
<thead>
<tr>
<th>Value</th>
</tr>
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<tbody>
<tr>
<td>$1,036</td>
</tr>
</tbody>
</table>

### ROI :

<table>
<thead>
<tr>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>19.8%</td>
</tr>
</tbody>
</table>

### Payback Period :

<table>
<thead>
<tr>
<th>Years</th>
</tr>
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<tbody>
<tr>
<td>10</td>
</tr>
</tbody>
</table>
Sources

- Aspen simulation and exergy analysis
  - Thermal efficiency
  - Coal and oxygen requirements
  - Fisher Tropsch product quality and distribution

- DOE and NETL reports
  - Coal, electricity, and crude oil escalation,
  - Generally accepted debt to equity ratios

- DOE reports
  - Facility lifetimes
  - Scaling and contingency factors
  - Capacity utilization factors
  - Fixed maintenance and start up costs

- IRS 15 year Modified Accelerated Cost Recovery System (MACRS) depreciation schedule for gasification facilities
# Year-to-Year Cash Flows

<table>
<thead>
<tr>
<th>Year</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
<th>12</th>
<th>13</th>
<th>14</th>
<th>15</th>
<th>16</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVW Factor (from discount rate)</td>
<td>0.567</td>
<td>0.507</td>
<td>0.452</td>
<td>0.404</td>
<td>0.361</td>
<td>0.322</td>
<td>0.287</td>
<td>0.257</td>
<td>0.229</td>
<td>0.205</td>
<td>0.183</td>
<td>0.163</td>
</tr>
<tr>
<td>Cumulative Inflation Factor</td>
<td>1.082</td>
<td>1.104</td>
<td>1.126</td>
<td>1.149</td>
<td>1.173</td>
<td>1.198</td>
<td>1.224</td>
<td>1.250</td>
<td>1.277</td>
<td>1.304</td>
<td>1.331</td>
<td>1.358</td>
</tr>
<tr>
<td>Depreciation Schedule</td>
<td>0.0693</td>
<td>0.0623</td>
<td>0.059</td>
<td>0.069</td>
<td>0.070</td>
<td>0.072</td>
<td>0.073</td>
<td>0.075</td>
<td>0.076</td>
<td>0.078</td>
<td>0.079</td>
<td>0.081</td>
</tr>
<tr>
<td>Crude Oil Projection</td>
<td>109</td>
<td>112</td>
<td>116</td>
<td>119</td>
<td>123</td>
<td>127</td>
<td>132</td>
<td>137</td>
<td>142</td>
<td>147</td>
<td>151</td>
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<tr>
<td>Coal Projection</td>
<td>45</td>
<td>46</td>
<td>47</td>
<td>48</td>
<td>49</td>
<td>50</td>
<td>51</td>
<td>52</td>
<td>53</td>
<td>54</td>
<td>55</td>
<td>57</td>
</tr>
<tr>
<td>Electricity Projection</td>
<td>0.065</td>
<td>0.066</td>
<td>0.068</td>
<td>0.069</td>
<td>0.070</td>
<td>0.072</td>
<td>0.073</td>
<td>0.075</td>
<td>0.076</td>
<td>0.078</td>
<td>0.079</td>
<td>0.081</td>
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<tr>
<td>Capital Costs</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Feedstock Costs</td>
<td>346</td>
<td>352</td>
<td>360</td>
<td>367</td>
<td>374</td>
<td>381</td>
<td>388</td>
<td>395</td>
<td>402</td>
<td>409</td>
<td>416</td>
<td>423</td>
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<tr>
<td>O&amp;M Costs</td>
<td>283</td>
<td>289</td>
<td>295</td>
<td>301</td>
<td>307</td>
<td>313</td>
<td>319</td>
<td>325</td>
<td>331</td>
<td>337</td>
<td>343</td>
<td>349</td>
</tr>
<tr>
<td>Operational Expenses</td>
<td>629</td>
<td>641</td>
<td>654</td>
<td>667</td>
<td>681</td>
<td>694</td>
<td>708</td>
<td>722</td>
<td>737</td>
<td>751</td>
<td>766</td>
<td>782</td>
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<tr>
<td>F-T Sales Revenue</td>
<td>1,832</td>
<td>1,887</td>
<td>1,944</td>
<td>2,002</td>
<td>2,061</td>
<td>2,121</td>
<td>2,182</td>
<td>2,245</td>
<td>2,311</td>
<td>2,391</td>
<td>2,463</td>
<td>2,537</td>
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<tr>
<td>Electricity Sales Revenue</td>
<td>140</td>
<td>143</td>
<td>146</td>
<td>149</td>
<td>152</td>
<td>155</td>
<td>158</td>
<td>161</td>
<td>164</td>
<td>168</td>
<td>172</td>
<td>176</td>
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<tr>
<td>Total Sales Revenue</td>
<td>1,973</td>
<td>2,030</td>
<td>2,090</td>
<td>2,151</td>
<td>2,214</td>
<td>2,279</td>
<td>2,346</td>
<td>2,415</td>
<td>2,486</td>
<td>2,559</td>
<td>2,634</td>
<td>2,711</td>
</tr>
<tr>
<td>Gross Income (pre-tax)</td>
<td>1,344</td>
<td>1,389</td>
<td>1,436</td>
<td>1,484</td>
<td>1,534</td>
<td>1,585</td>
<td>1,638</td>
<td>1,693</td>
<td>1,749</td>
<td>1,807</td>
<td>1,867</td>
<td>1,929</td>
</tr>
<tr>
<td>Depreciation</td>
<td>363</td>
<td>326</td>
<td>309</td>
<td>305</td>
<td>301</td>
<td>297</td>
<td>293</td>
<td>289</td>
<td>285</td>
<td>281</td>
<td>277</td>
<td>273</td>
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<tr>
<td>Gross Income - Depreciation (pre-tax)</td>
<td>981</td>
<td>1,063</td>
<td>1,127</td>
<td>1,191</td>
<td>1,255</td>
<td>1,319</td>
<td>1,383</td>
<td>1,447</td>
<td>1,512</td>
<td>1,576</td>
<td>1,640</td>
<td>1,704</td>
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<tr>
<td>Income Tax</td>
<td>393</td>
<td>425</td>
<td>451</td>
<td>470</td>
<td>490</td>
<td>510</td>
<td>531</td>
<td>554</td>
<td>576</td>
<td>599</td>
<td>623</td>
<td>646</td>
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<tr>
<td>Interest Payment</td>
<td>112</td>
<td>105</td>
<td>97</td>
<td>89</td>
<td>82</td>
<td>75</td>
<td>68</td>
<td>61</td>
<td>54</td>
<td>47</td>
<td>40</td>
<td>33</td>
</tr>
<tr>
<td>Principal Payment</td>
<td>125</td>
<td>132</td>
<td>140</td>
<td>148</td>
<td>155</td>
<td>163</td>
<td>171</td>
<td>179</td>
<td>187</td>
<td>195</td>
<td>203</td>
<td>211</td>
</tr>
<tr>
<td>At Hand Cash (post-tax)</td>
<td>714</td>
<td>727</td>
<td>748</td>
<td>777</td>
<td>807</td>
<td>837</td>
<td>867</td>
<td>902</td>
<td>936</td>
<td>971</td>
<td>1,007</td>
<td>1,043</td>
</tr>
<tr>
<td>Present Worth</td>
<td>405</td>
<td>368</td>
<td>331</td>
<td>296</td>
<td>264</td>
<td>234</td>
<td>206</td>
<td>180</td>
<td>156</td>
<td>134</td>
<td>114</td>
<td>95</td>
</tr>
</tbody>
</table>
Sensitivity Analysis

Change in ROI (percentage points)
Economic Scenarios

Scenarios not run

- Less than a three percentage effect on ROI
  - Loan interest
  - coal and electricity escalation
  - base year electricity costs
  - general inflation

- Lesser degree of uncertainty
  - Capacity factor
  - ULSD premiums
  - tax rates
  - ratio of diesel to naphtha product
  - O&M costs
  - Delivered price of coal.
Economic Scenarios (cont.)

- **Scenario 1**: Base Case Scenario representing the required market value of crude oil to achieve 20% ROI. The payback period was calculated from this scenario.

- **Scenario 2**: The effect of plant lifetime on required market value and ROI

- **Scenario 3**: The effect of contingency factor

- **Scenario 4**: CCS
Base Case (Scenario 1)

March, 2010 Crude Oil Price
$82 / bbl

Required Crude Oil Price
~$97 / bbl

20% ROI
Payback Period

Payback Period: 10 yrs (Base Scenario)
Plant Lifetime (Scenario 2)

-20%  -10%   0%      10%      20%      30%      40%
$80 $85 $90 $95 $100 $105 $110 $115 $120
Market Crude Value
Return on Investment
30 yr lifetime
(~$97 / bbl)
20% ROI
24 yr lifetime
(~$103 / bbl)
36 yr lifetime
(~$94 / bbl)
Contingency Factors (Scenario 3)

Considers uncertainties of pioneer plants vs. a plant of n\textsuperscript{th} design (3rd or 4th of its kind).
CCS (Scenario 4)

Assumes $7 / ton to compress and transport CO$_2$ (2200psi & 200 miles)
Alternative Fuel Comparisons
ICL Plant Comparisons

- Compared on an energy, economic and environmental basis

- Two methods
  1. Literature sources
  2. GREET - Greenhouse gases, Regulated Emissions, and Energy use in Transportation – Free software from Argonne National Laboratories
Comparison nomenclatures

- **Our plant:**
  - Indirect coal liquefaction diesel (ICL diesel)
  - Indirect biomass liquefaction diesel (IBL diesel)

- **To other transportation fuels**
  - Petroleum diesel @ $100/barrel of crude oil (Petro diesel)
  - Petroleum gasoline @ $100/barrel of crude oil (Petro gas)
  - Biodiesel soy and woody biomass (B100)
  - Ethanol from corn (E85)
  - Compresses natural gas, 200bar (CNG)
  - Synthetic natural gas from IGCC, 200bar (SNG)
  - Hydrogen from NG internal combustion at 200bar (H2 NG ICE)
  - Hydrogen from NG in a 80kW fuel cell vehicle, 200bar (H2 NG FCV)
  - Hydrogen from wind energy in 80kW fuel cell vehicle, 200bar (H2 WE FCV)
  - Electricity from fossil fuels in a 80kW electric vehicle (FF BEV)
  - Electricity from photovoltaic energy in a 80kW electric vehicle (PV BEV)
GREET modeling

INPUTS

OUTPUTS
CO$_2$ emissions from GREET modeling
Fuel economies and production efficiencies

ASPENplus Software; GREET Software
http://www.fueleconomy.gov/


David Pimentel and Tad W. Patzek “Ethanol Production Using Corn, Switchgrass, and Wood; Biodiesel Production Using Soybean and Sunflower” Natural Resources Research, Vol. 14, No. 1, March 2005 pages 65-76


Yan, X. Y.; Inderwildi, O. R.; King, D. A., Biofuels and synthetic fuels in the US and China: A review of Well-to-Wheel energy use and greenhouse gas emissions with the impact

![Graph showing fuel economies and production efficiencies](image-url)
Other consideration examples:

- **Environmental** - 1 liter of ethanol - 13 liters of wastewater; B100 - High NOx
- **Energy** - Farming considerations: Corn-9438 kWh/ha; Soy-4357 kWh/ha
- **Economic** – FC vehicles cost an average of $3,600 more with an average fuel cell costing 121$/m²

"Liquid transportation fuels from coal and biomass" America’s Energy Future Panel on Alternative Liquid Transportation Fuels, THE NATIONAL ACADEMIES PRESS Washington, DC www.nap.edu


www.eia.doe.gov/steo; illinoisgasprices.com; cngprices.com; e85prices.com/illinois


Hesterberg T. W., Lapin, C. A.; Bunn, W. B., A Comparison of Emissions from Vehicles Fueled with Diesel, Compressed Natural Gas, Environmental Science & Technology 2008, 42 (17)
Conclusions

An indirect coal liquefaction plant in the US was simulated and results appeared comparable to the literature.

- Efficiency = 50%
- ROI ICL = 20% @ $97/bbl ($102/bbl w CCS)
- Emissions CO\textsubscript{2} = 102.9 kgCO\textsubscript{2}/GJ fuel

ICL appears to be technically and economically sufficient to develop in the US and the main constraint at the moment is the environmental impact from CO\textsubscript{2} emissions compared to other transportation options.
THANK YOU
QUESTIONS?
F.T. model

- Assumptions:
  Steady-state operation; isothermal conditions; large-bubble flow in plug-flow regime due to its velocity; assumption of hydrocarbon products in the gas and liquid phases to be in equilibrium at the reactor outlet; negligible mass and heat transfer resistances between the catalyst and the liquid; location of the gas-liquid mass transfer limitation in the liquid phase; intrinsic kinetics for FT synthesis

- Kinetic parameters

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<th>Parameter</th>
<th>Value</th>
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<tr>
<td>$K_2$</td>
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</table>

* Obtained experimentally\(^2\) at $T = 270$ °C, $P = 0.5–3.0$ MPa, and $H_2$: CO = 0.67–1.7.

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