WyINL Coal Gasification Project Evaluation Codes

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Idaho National Laboratory
Outline

- Energy Security – The Grand Challenge
- Wyoming Coal – Energy Supply Security
- Converting Wyoming Coal to Clean Energy Products
- WyINL Coal Gasification Project Evaluation Tools
  - Process Simulations
  - Economic Assessments
  - Life Cycle Analysis
- CTL Case study results
Energy: Our Grand Challenge

• Global population marches on
  – Over 8 billion by 2030; 9 billion by 2050
  – Globalization of economies continues
  – 3 to 5 fold increase in economic activity

• Access to stable, affordable energy is key to peace and prosperity
  – 40% increase in demand by 2030 (IEA estimate)
  – 2-3 fold increase in demand by 2050 (WBCSD estimate)

• Greatest energy consumption growth in non-OECD countries
  – China, India and Middle East account for over 90% of the increase

Sources: United Nations Population Division
And United States Energy Information Agency
Attaining Energy Security

Energy Security

- Economic Stability
  - Energy cost affordability and stability
  - Least external costs
  - Domestic job creation and maintenance
  - Balance foreign trade, raise tax revenues

- Supply Security
  - Resource security (availability and accessibility)
  - Reduce foreign dependence
  - Maximize benefit of both fossil fuels and biomass energy crops
  - Conservation of energy resources

- Environmental Sustainability
  - Maximize available work from renewable wind, solar, geothermal
  - Stabilize climate
  - Reduce air and water pollutant discharges
  - Water resource conservation
World-Class Energy Resources
Wyoming Coal Deposits

Strippable Coal (million of short tons)*

Powder River Basin 570,000
Greater Green River 2,700
Hanna-Carbon 7,200

* USGS, 1999 Resource Assessment
Significance of Coal Gasification

- Cost competitive for clean coal power generation with carbon capture & sequestration

- Produce transportation fuels
  - Fischer-Tropsch Liquids (F-T)
  - Methanol to “motor” gasoline (MTG)

- Produce feedstock for chemical plants
  - hydrogen generation
  - ammonia $\rightarrow$ ammonium nitrate $\rightarrow$ explosives or fertilizer
  - polymers, pharmaceuticals

- Polygeneration of power, fuels, hydrogen, etc.
**Notional Coal-to-Liquids Plant**

- **Coal**
  - 14,600 tons/day

- **Gasifier**
  - CO + H₂O → CO₂ + H₂

- **Water-Gas Shift**

- **Fischer-Tropsch Synthesis**

- **Product Upgrade**
  - Synfuel 25,000 barrels/day

- **Gas Cleanup**
  - CO₂ (25,000 tpd)

- **Vent or Sequester**

- **Sulfur Product**
  - H₂S
Barriers to Build-up of Gasification for Synfuels

- Process integration
  - gasification, power generation, refinery, multi-energy inputs and products

- Technical risks
  - first-of-kind plant, plant complexity, limited pilot plant operations

- Economical risks
  - high capital, product market volatility

- Greenhouse gas emissions

- Water consumption

- Manufacture and construction
  - experience, shipping, work force

- Plant operating experience
  - start-up, monitoring & control, maintenance
Purpose of Project

• Develop process simulation tools
  – Project technical/business case studies
  – Conceptual design (preliminary equipment selection and sizing)
  – Product optimization

• Economics models
  – Per forma calculations
  – Financial sensitivity (capital, operating, revenue, debt/equity, IRR, LCOE, etc.)

• Life cycle analysis
  – Greenhouse gas emissions
  – Water use, cost benefit tradeoffs

• Provide project roadmap
  – Permitting
  – Construction logistics

• Operator training simulator
General Case Studies

Legend
- Orange: Subbituminous
- Purple: Bituminous
- Green: Mineable Deposits

Gillette

Green River
Reference Plant Studies

Gillette

- Mine-mouth coal mine
- Coal HHV as fed = 8,425 Btu/lbm
- Coal moisture as fed = 28.09 %
- Coal ash as fed = 8.8%
- Water from coal and well
- Liquid products pipeline to Billings, Montana
- CO$_2$ by-product for EOR (50 mile radius)
- 10 miles to electrical grid
- 5 miles to rail spur

Rock Springs

- Mine-mouth coal mine
- Coal HHV as fed = 9,500 Btu/lbm
- Coal moisture as fed = 19.95%
- Coal ash as fed = 11.2%
- Green River
- Liquid products pipeline to Salt Lake City, Utah
- CO$_2$ by-product for Sequestration (Rock Springs Uplift)
- 10 miles to electrical grid
- 5 miles to rail spur
Reference Plants

- IGCC (500 MWe)
- F-T CTL (50,000 bbl/day)
- C/MTG (60,000 bbl/day)
- SNG (150 MMSCF/day)
- Ammonia (2,750 ton/day)
Configurable Process Model with Code Modules

- Coal milling & drying
- Air separation unit
- Gasification (entrained flow)
  - Slurry or dry-fed
  - Syngas coolers
- Syngas cleanup
  - Scrubber
  - Mercury removal
  - Sulfur guard
- CO shift
- Sulfur pollutants & CO2 capture
  - ammine (MEA or MDEA)
  - selective Rectisol ™ and Selexol™
- CO₂ compression
- Sulfur recovery
  - Claus / SCOT
- PSA for hydrogen separation
- Waste water treatment
- F-T synthesis
  - Co or Fe catalyst reactors
- Product refinery
  - hydrocracking/hydrotreatment
  - Distillation
- Methanol to gas
  - Methanol, DME, Gasoline catalyst beds
- SNG methanation reactors
- H₂ Steam methane reforming
- Ammonia
  - urea
  - ammonium nitrate
- Power generation
  - tuned gas turbines
  - saturated and condensing turbines
- Heat recovery / Steam generation
- Cooling tower
- Air coolers
### Total Liquids
- **49,999 bbl/day**

### Diesel
- **35,244 bbl/day**

### Naphtha
- **12,747 bbl/day**

### LPG
- **2,008 bbl/day**
# Economics Model

## 50,000 bbl/day CTL Plant

### Project Inputs

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Startup Year</td>
<td>2012</td>
</tr>
<tr>
<td>Initial Construction Year</td>
<td>2009</td>
</tr>
<tr>
<td>Construction Period Fossil</td>
<td>3 yr</td>
</tr>
<tr>
<td>% Capital Fossil</td>
<td>33%</td>
</tr>
<tr>
<td>Startup Time</td>
<td>1 yr</td>
</tr>
<tr>
<td>% Operating Cost</td>
<td>85%</td>
</tr>
<tr>
<td>% Revenues</td>
<td>60%</td>
</tr>
<tr>
<td>Analysis Period</td>
<td>35 yr</td>
</tr>
<tr>
<td>Plant Life</td>
<td>30 yr</td>
</tr>
<tr>
<td>Inflation Rate</td>
<td>2.5%</td>
</tr>
<tr>
<td>Debt Financing</td>
<td>55%</td>
</tr>
<tr>
<td>Equity Financing</td>
<td>45%</td>
</tr>
<tr>
<td>Interest Rate on Debt</td>
<td>8%</td>
</tr>
<tr>
<td>Repayment Term</td>
<td>15 yr</td>
</tr>
<tr>
<td>State Tax</td>
<td>6%</td>
</tr>
<tr>
<td>Federal Tax</td>
<td>35%</td>
</tr>
<tr>
<td>Total Tax Rate</td>
<td>38.9%</td>
</tr>
<tr>
<td>IRR</td>
<td>12%</td>
</tr>
<tr>
<td>CTL Availability</td>
<td>88%</td>
</tr>
<tr>
<td>CEPCI</td>
<td>512</td>
</tr>
</tbody>
</table>

### CTL Commodity Prices

<table>
<thead>
<tr>
<th>Commodity</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal Cost ($/ton)</td>
<td>10.00</td>
</tr>
<tr>
<td>Ash disposal ($/ton)</td>
<td>33.20</td>
</tr>
<tr>
<td>Slag ($/ton)</td>
<td>25.63</td>
</tr>
<tr>
<td>Sulfur ($/ton)</td>
<td>38.13</td>
</tr>
<tr>
<td>Naphtha ($/gal) low</td>
<td>1.34</td>
</tr>
<tr>
<td>Low Sulfur Diesel ($/gal) low</td>
<td>1.41</td>
</tr>
<tr>
<td>Naphtha ($/gal) high</td>
<td>3.86</td>
</tr>
<tr>
<td>Low Sulfur Diesel ($/gal) high</td>
<td>4.04</td>
</tr>
<tr>
<td>Naphtha ($/gal) avg</td>
<td>2.60</td>
</tr>
<tr>
<td>Low Sulfur Diesel ($/gal) avg</td>
<td>2.72</td>
</tr>
<tr>
<td>LPG ($/ton)</td>
<td>351.96</td>
</tr>
<tr>
<td>Oxygen ($/ton)</td>
<td>41.60</td>
</tr>
<tr>
<td>Electricity Purchase ($/kW-day)</td>
<td>1.67</td>
</tr>
<tr>
<td>Electricity Sell ($/kW-day)</td>
<td>2.39</td>
</tr>
<tr>
<td>Water Use ($/1000 gal)</td>
<td>1.67</td>
</tr>
<tr>
<td>Wastewater Treatment ($/1000 gal)</td>
<td>1.31</td>
</tr>
</tbody>
</table>
Capital Breakdown

50,000 bbl/day CTL Plant

- Gasification: 23%
- Gas Cleaning: 20%
- ASU: 10%
- Coal Preparation: 7%
- Electrical Systems: 6%
- Buildings and Structures: 7%
- Piping: 5%
- Water Systems: 5%
- Cooling Towers: 0%
- Steam Turbines: 3%
- Gas Turbines: 2%
- FT Reactors and Refining: 9%
# Economics Model

## 50,000 bbl/day CTL Plant

<table>
<thead>
<tr>
<th>80% Debt 20% Equity</th>
<th>TCI -30%</th>
<th>TCI</th>
<th>TCI +30%</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTL</td>
<td>IRR</td>
<td>$/gal</td>
<td>IRR</td>
</tr>
<tr>
<td>low fuel price</td>
<td>14.41</td>
<td>$1.41</td>
<td>8.20</td>
</tr>
<tr>
<td>average fuel price</td>
<td>31.42</td>
<td>$2.72</td>
<td>22.44</td>
</tr>
<tr>
<td>high fuel price</td>
<td>44.50</td>
<td>$4.04</td>
<td>33.34</td>
</tr>
<tr>
<td>IRR=12%</td>
<td>12.00</td>
<td>$1.01</td>
<td>12.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>55% Debt 45% Equity</th>
<th>CTL No Sequestration</th>
<th>CTL With Sequestration</th>
</tr>
</thead>
<tbody>
<tr>
<td>CTL</td>
<td>IRR $/gal</td>
<td>IRR $/gal</td>
</tr>
<tr>
<td>low fuel price</td>
<td>18.18</td>
<td>11.43</td>
</tr>
<tr>
<td>average fuel price</td>
<td>34.24</td>
<td>24.74</td>
</tr>
<tr>
<td>high fuel price</td>
<td>46.84</td>
<td>35.27</td>
</tr>
<tr>
<td>IRR=12%</td>
<td>12.00</td>
<td>$1.45</td>
</tr>
</tbody>
</table>

##CTL No Sequestration
- **80% Debt 20% Equity**
- **12% IRR**
- **$1.35/gal**

##CTL With Sequestration
- **55% Debt 45% Equity**
- **$1.60/gal**

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**50,000 bbl/day CTL Plant**

*Note: TCI refers to Total Capital Investment.*
Life-Cycle GHG Emissions
**PRB: F-T CTL Carbon Balance Summary**

50,000 bbl/day CTL Plant

**Carbon Balance Summary:**

<table>
<thead>
<tr>
<th>Description</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>% Carbon to Liquid Fuel</td>
<td>29.1%</td>
</tr>
<tr>
<td>% Carbon to Slag &amp; Flyash</td>
<td>0.4%</td>
</tr>
<tr>
<td>% Carbon to CO2 Sequestration</td>
<td>47.3%</td>
</tr>
<tr>
<td>% Carbon to HRSG Tailgas</td>
<td>15.4%</td>
</tr>
<tr>
<td>% Carbon to Vent</td>
<td>7.6%</td>
</tr>
<tr>
<td>% Unaccounted Carbon</td>
<td>0.2%</td>
</tr>
</tbody>
</table>

**CO₂ Captured (SEQ or EOR):**

- CO₂ Captured (SEQ or EOR) = 30780 TON/DY
- CO₂ Captured (SEQ or EOR) = 539 MMscf/d
- CO₂ Purity = 97.9%

**CO₂ Captured / Liq Prod:**

- CO₂ Captured / Liq Prod = 4.97 LB/LB
- CO₂ Captured / Liq Prod = 0.01 MMscf/BBL
- CO₂ Captured / Coal Fed = 0.85 LB/LB

**CO₂ Emitted:**

- CO₂ Emitted = 14983 TON/DY
- CO₂ Emitted = 262 MMscf/d
- From HRSG = 10058 TON/DY
- From Vent = 4925 TON/DY

**CO₂ Emitted / Liq Prod:**

- CO₂ Emitted / Liq Prod = 2.42 LB/LB
- CO₂ Emitted / Coal Fed = 0.41 LB/LB

**CO₂ for EOR or Seq:**

- 539 MMscf/d
- 97.9% pure
**PRB: Life Cycle Carbon Analysis**

50,000 bbl/day CTL Plant

- **Biomass**
- **Sequestration**

**Conventional Diesel from Crude**

**Natural gas reforming for H₂ with sequestration**
## PRB: F-T CTL Water Balance Summary

50,000 bbl/day CTL Plant

### WATER BALANCE:

#### PROCESS WATER SUMMARY:

- **CMD WATER NOT RECOVERED =** 8030.2 GPM
- **WATER CONSUMED:**
  - GASIFIER ISLAND = 1124.0 GPM
  - BOILER FEED WATER = 3440.2 GPM
  - TOTAL WATER CONSUMED = 4564.2 GPM
- **WATER GENERATED:**
  - ASU = 121.6 GPM
  - SOUR WATER = 871.9 GPM
  - GAS CLEANING WATER = 22.4 GPM
  - FISCHER TROPSCH WATER = 1631.4 GPM
  - REFINING WATER = 2.0 GPM
  - TOTAL WATER GENERATED = 2649.3 GPM
- **NET PROCESS WATER (+ GEN, - CONS) =** -1914.9 GPM
- **WATER (+ GEN, - CONS) / LIQ PROD =** -1.86 LB/LB
- **WATER (+ GEN, - CONS) / LIQ PROD =** -1.31 BBL/BBL
- **WATER (+ GEN, - CONS) / COAL FED =** -0.32 LB/LB

#### COOLING WATER OPTION:

- **COOLING CIRCUIT FLOW RATE =** 709805.7 GPM
- **MAKEUP WATER FLOW RATE =** 26907.2 GPM
- **EVAPORATION LOSS RATE =** 217906.6 GPM
- **BLOWDOWN RATE =** 5110.6 GPM
- **NET COOLING WATER CONSUMED =** 217906.6 GPM
- **NET WATER CONSUMED =** 23711.4 GPM
- **WATER CONSUMED / LIQ PRODUCED =** 22.98 LB/LB
- **WATER CONSUMED / LIQ PRODUCED =** 16.26 BBL/BBL
- **WATER CONSUMED / COAL FED =** 3.93 LB/LB

**Process Water**
1.31 bbl water/bbl Fuel

**Cooling Tower**
14.9 bbl water/bbl Fuel

**Net Water Required**
16.3 bbl water/bbl Fuel
## PRB: F-T CTL Power Summary

50,000 bbl/day CTL Plant

### Power Calculations:

#### Power Generators:
- Gas Turbine Power Output = 290.2 MW
- Condensing Turbine Power Output = 155.4 MW
- Saturated Turbine Power Output = 439.6 MW
- Total Power Generated = 885.2 MW

#### Power Consumers:
- Coal Processing Power Consumption = 57.0 MW
- ASU Power Consumption = 364.3 MW
- Gasifier Power Consumption = 5.9 MW
- Gas Cleaning Power Consumption = 160.1 MW
- SCOT Process Power Consumption = 3.0 MW
- Claus Power Consumption = 0.1 MW
- CO₂ Liquef. Power Consumption = 125.1 MW
- Fisher Tropsch Power Consumption = 8.3 MW
- Refinery Power Consumption = 10.4 MW
- Power Block Power Consumption = 5.8 MW
- Refrigeration Power Consumption = 24.3 MW
- Total Power Consumed = 764.3 MW

#### Cooling Water Option:
- Cooling Tower Power Consumption = 17.5 MW
- Net Plant Power (+ Gen, - Cons) = 103.4 MW

#### Air Cooling Option:
- Air Cooling Power Consumption = 57.9 MW
- Net Plant Power (+ Gen, - Cons) = 63.0 MW

**Total Power Generated**

885 MWₑ

**Power Consumed**

764.3 MWₑ

**Net Power Generated**

103 MWₑ Cooling Tower Option

63.0 MWₑ Air Coolers
Summary

• **WyINL Aspen™ modules and pre-configured reference plant models available for license through Wyoming Business Council**
  – Projects that use Wyoming coal

• **Plant capital and variable cost assessment models available for reference cases**

• **Code uses-**
  – Conceptual design / Optimization
  – Resource planning
  – Technology evaluation
  – Economic and LCA assessments
  – Operator training
  – Permit application support