Coal Conversion – Pathway to Alternate Fuels

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Overview

- DOE and Coal Liquefaction RD&D
- Coal – A Significant Source of Energy
- Coal Liquefaction Technology and Status
- Current and Growing Interest in Liquefaction
Components of Earlier DOE RD&D Coal Liquefaction Program

- Technology Screening – Bench and pilot plant projects (1964–1976)
- Component I (1976–1982)
  - Large-scale demos of Phase I processes
  - Thermal and catalytic hydrogenation processes
- Component II (1976–1999)
  - Research program
  - Pursue improvements and alternatives based on better scientific understanding
  - Bench-scale development of Phase II processes
  - Overcome techno-economic limitations of Phase I processes
  - Catalytic hydrogenation processes
Coal Conversion Processes

- Carbonization and Pyrolysis
  - Low severity (mild gasification)
  - High temperature
- Direct Liquefaction
  - One-stage reactor technology
  - Two-stage reactor technology
  - Co-processing
  - Hybrid
- Indirect Liquefaction
  - Gas reactors
  - Slurry reactors
# Coal Liquefaction Technologies

<table>
<thead>
<tr>
<th>Mild Pyrolysis</th>
<th>Single-Stage Direct Liquefaction</th>
<th>Two-Stage Direct Liquefaction</th>
<th>Co-Processing and Dry Hydrogenation</th>
<th>Indirect Liquefaction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Univ. of North Dakota Energy and</td>
<td>H-Coal Process – HRI</td>
<td>Chevron Coal Liquefaction Process</td>
<td>Solvolysis Co-Processing – Mitsubishi</td>
<td>Syntroleum</td>
</tr>
<tr>
<td>Environmental Center (EERC)/AMAX R&amp;D</td>
<td>Imhausen High-Pressure Process</td>
<td>Lummus ITSL Process</td>
<td>Mobil Co-Processing</td>
<td>Mobil Methanol-to-Gasoline (MTG) Process</td>
</tr>
<tr>
<td>Process</td>
<td>Conoco Zinc Chloride Process</td>
<td>Mitsuishi Solvolysis Process</td>
<td>Pyrosol Co-Processing – Saabergwerke</td>
<td>Mobil Methanol-to-Olefins (MTO) Process</td>
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<tr>
<td>Institute of Gas Technology</td>
<td>Kohleol Process – Ruhrkohle</td>
<td>Pyrosol Process – Saabergwerke</td>
<td>Chevron Co-Processing</td>
<td>Shell Middle Distillate Synthesis (SMOS)</td>
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<tr>
<td>Char, Oil Energy Development (COED)</td>
<td>NEDO Process</td>
<td>Catalytic Two-Stage Liquefaction Process – DOE and HRI</td>
<td>Lummus Crest Co-Processing</td>
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<td></td>
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<td>Liquid Solvent Extraction (LSE) Process – British Coal</td>
<td>Alberta Research Council Co-Processing</td>
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<tr>
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<td>Brown Coal Liquefaction (BCL) Process – NEDO</td>
<td>CANMET Co-Processing</td>
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<td>Amoco CC-TSL Process</td>
<td>Rheinbraun Co-Processing</td>
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<td></td>
<td>Supercritical Gas Extraction (SGE) Process – British Coal</td>
<td>TUC Co-Processing</td>
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</tbody>
</table>

Why Coal-To-Liquids (CTL)?

- **Energy Security**
  - Size of coal resources
  - Distribution of resources

- **Environment**
  - Utilization of clean coal technology
  - Sequestration technology expected

- **Flexibility**
  - Advanced technology
  - Co-production capability

- **Economics**
  - Competitive with alternatives
  - World oil price volatility
Global Supplies

- World oil demand will grow by 40% to 50% by 2030
- Coincidentally, crude supplies increasingly concentrated in OPEC/politically unstable geographies
- Coal offers opportunity to diversify worldwide liquid fuel supplies

Comparison of World Oil and Coal Reserves

<table>
<thead>
<tr>
<th>Country</th>
<th>Oil Reserves (BBOE)</th>
<th>Coal Reserves (BBOE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>USA</td>
<td>22 BBOE</td>
<td>535 BBOE</td>
</tr>
<tr>
<td>Others</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>India</td>
<td></td>
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<tr>
<td>China</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Russia</td>
<td></td>
<td></td>
</tr>
<tr>
<td>USA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Middle East</td>
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</tr>
</tbody>
</table>

Billion Barrels Oil Equivalent (BBOE)
Growing consensus on need to diversify transportation fuel sector
- Long term: hydrogen
- Intermediate term: liquids from coal, oil shale, liquids from biomass, increased domestic petroleum production, efficiency

Advantages of Coal and CTL Technology
- U.S. coal reserves amount to 250-year supply at current rates of consumption
- Coal resources are dispersed (proven reserves in 26 states)
- 1 ton of coal can be processed into 2 barrels of high-quality liquid fuels
- Offers opportunity to pre-invest in eventual hydrogen-from-coal production facility
The U.S. Leads in Coal Reserves

Estimated Recoverable Coal
World Total - 997,506 Million Short Tons

Source: Energy Information Administration, World Recoverable Coal Reserves
Delineation of U.S. Coal Reserves and Resources

- **RESERVES** – quantities of coal anticipated to be commercially recoverable from known accumulations from a given date forward under defined conditions.

- **RESOURCES** – quantities of coal estimated, as of a given date, to be potentially recoverable from known accumulations, but which are not currently considered commercially recoverable.

- There is sufficient reserve to meet projected demand for electricity and up to 4MM bpd CTL industry for over 100 years.

Source: EIA Coal Reserves Data 1997
U.S. Coal Reserves Distribution

- Greater Green River Coal Region
- Powder River
- Uinta
- Piceance
- San Juan
- Raton
- Arkoma
- Cherokee
- Black Warrior
- Northern Appalachian
- Central Appalachian
- Small Field or Isolated Occurrence
- Rank
  - Anthracite
  - Bituminous Coal
  - Subbituminous Coal
  - Lignite
  - A
  - B
  - S
  - L
Direct Coal Liquefaction Process

Coal + Catalyst → Coal Liquefaction → HTU → Refining

Gas Recovery Treatment

Make-Up H₂ → Recycle H₂

Slurry → Fractionation

DAO → Solvent De-ashing

H₂S, NH₃, COₓ → H₂S, NH₃, COₓ

C₁ – C₂ → C₁ – C₂

LPG → LPG

Gasoline → Gasoline

Diesel Fuel → Diesel Fuel

HVGO → HVGO

Ash Reject → Ash Reject
Hybrid DCL/ICL Plant Concept

1. Coal Gasification
2. Direct Coal Liquefaction
3. F-T Tail Gas
4. Hydrogen Recovery
5. Indirect Coal Liquefaction (F-T)
6. Product Blending and Refining
7. Raw ICL Products
8. Final Products
9. Raw DCL Products

Coal flow diagram:
- Coal to Coal Gasification
- Coal Gasification to Direct Coal Liquefaction
- Direct Coal Liquefaction to F-T Tail Gas
- F-T Tail Gas to Hydrogen Recovery
- Hydrogen Recovery to Product Blending and Refining
- Raw ICL Products to Final Products
- Raw DCL Products to Final Products

Hybrid DCL/ICL Plant Concept involves the conversion of coal to hydrogen and liquefied products through gasification and liquefaction processes.
Shenhua DCL Process

First Train: 1 MT/a Liquefaction Oil
Indirect Coal Liquefaction Overview

- **Natural Gas**
- **Coal**
- **Pet Coke**
- **Biomass**
- **Wastes**

**Oxygen Plant**

- **Synthesis Gas Production**
  - Gasification
  - Reforming
  - Steam
  - POX
  - ATR

**F-T Liquid Synthesis**

- Slurry/Fixed/Fluid-Bed

**Product Recovery**

- Tail Gas

**Power Generation**

**Hydrogen Recovery**

**Wax Hydrocracking**

- Wax
- H₂

**Product Storage**

- Naphtha/Diesel

**Liquid Fuels**

**Air**

**O₂**
Coal-To-Liquids: Current Status

- Costs – many systems analyses ongoing; for 50,000 bpd plant:
  - Capital costs estimated at $3.5–4.5 billion
  - Product cost at $40/bbl
- Technology considered commercial
  - DOE/industry completed program for development of direct liquefaction technology
  - Sasol producing 150,000 bpd of F-T products
  - Shenhua China Coal Liquefaction Corp. constructing 20,000 bpd plant; additional 180,000 bpd planned
  - Shenhua supports feasibility studies for two 80,000 bpd coal-to-liquid plants
  - Improved processes, catalysts, and slurry reactors available
  - Bench and pilot facilities at Rentech, Headwaters, Syntroleum, and ConocoPhillips
## Coal-to-Liquids Plants Under Consideration in the United States

<table>
<thead>
<tr>
<th>Project Lead</th>
<th>Project Partners</th>
<th>Location</th>
<th>Feedstock</th>
<th>Status</th>
<th>Capacity</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Clean Coal Fuels</td>
<td>None cited</td>
<td>Oakland, IL</td>
<td>Bituminous</td>
<td>Feasibility</td>
<td>25,000</td>
<td>N/A</td>
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<tr>
<td>Synfuels Inc.</td>
<td>GE, Haldor-Topsoe, NACC, ExxonMobil</td>
<td>Ascension Parish, LA</td>
<td>Lignite</td>
<td>Feasibility</td>
<td>N/A</td>
<td>$5 billion</td>
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<tr>
<td>DKRW Advanced Fuels</td>
<td>Rentech, GE</td>
<td>Medicine Bow, WY</td>
<td>Bituminous</td>
<td>Design (2011)</td>
<td>13,000 bpd</td>
<td>$1.4 billion</td>
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<tr>
<td>DKRW Advanced Fuels</td>
<td>Rentech, GE, Bull Mountain Land Company</td>
<td>Roundup, MT</td>
<td>Sub-bituminous/Lignite</td>
<td>Feasibility</td>
<td>22,000 bpd</td>
<td>$1–1.5 billion</td>
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<tr>
<td>AIDEA</td>
<td>ANRTL, CPC</td>
<td>Cook Inlet, AK</td>
<td>Sub-bituminous</td>
<td>Feasibility</td>
<td>80,000 bpd</td>
<td>$5–8 billion</td>
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<tr>
<td>Mingo County</td>
<td>Rentech</td>
<td>WV</td>
<td>Bituminous</td>
<td>Feasibility</td>
<td>20,000 bpd</td>
<td>$2 billion</td>
</tr>
<tr>
<td>WMPI</td>
<td>Sasol, Shell, DOE</td>
<td>Gilberton, PA</td>
<td>Anthracite</td>
<td>Design</td>
<td>5,000 bpd</td>
<td>$612 million</td>
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<tr>
<td>Rentech/Peabody</td>
<td>N/A</td>
<td>MT</td>
<td>Sub-bituminous/lignite</td>
<td>Feasibility</td>
<td>10,000–30,000 bpd</td>
<td>N/A</td>
</tr>
<tr>
<td>Rentech/Peabody</td>
<td>N/A</td>
<td>Southern IL, Southwest IN, Western KY</td>
<td>Bituminous</td>
<td>Feasibility</td>
<td>10,000–30,000 bpd</td>
<td>N/A</td>
</tr>
<tr>
<td>Rentech*</td>
<td>Kiewit Energy Company, WorleyParsons</td>
<td>East Dubuque, IL</td>
<td>Bituminous</td>
<td>Construction (2010)</td>
<td>1,800 bpd*</td>
<td>$800 million</td>
</tr>
<tr>
<td>Rentech</td>
<td>Adams County</td>
<td>Natchez, MS</td>
<td>Coal/Pet coke</td>
<td>Feasibility</td>
<td>10,000 bpd</td>
<td>$650–750 million</td>
</tr>
<tr>
<td>Rentech</td>
<td>Baard Energy</td>
<td>Wellsville, OH</td>
<td>Sub-bituminous</td>
<td>Feasibility</td>
<td>35,000 bpd</td>
<td>$4 billion</td>
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<tr>
<td>Headwaters</td>
<td>Hopi Tribe</td>
<td>AZ</td>
<td>Bituminous</td>
<td>Feasibility</td>
<td>10,000–50,000 bpd</td>
<td>N/A</td>
</tr>
<tr>
<td>Headwaters</td>
<td>NACC, GRE, Falkirk</td>
<td>ND</td>
<td>Lignite</td>
<td>Feasibility</td>
<td>40,000 bpd</td>
<td>$3.6 billion</td>
</tr>
</tbody>
</table>

*Co-producing fertilizer
CTL Projects Worldwide

Key
- Planning
- Engineering
- Construction
- Operational
## International CTL Plants and Projects

<table>
<thead>
<tr>
<th>Country</th>
<th>Owner/Developer</th>
<th>Capacity (bpd)</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>South Africa</td>
<td>Sasol</td>
<td>150,000</td>
<td>Operational</td>
</tr>
<tr>
<td>China</td>
<td>Shenhua</td>
<td>20,000 (initially)</td>
<td>Construction, Operational in 2007–2008</td>
</tr>
<tr>
<td></td>
<td>Lu’an Group</td>
<td>~3,000–4,000</td>
<td>Construction</td>
</tr>
<tr>
<td></td>
<td>Yankuang</td>
<td>40,000 (initially) 180,000 planned</td>
<td>Construction</td>
</tr>
<tr>
<td></td>
<td>Sasol JV (2 studies)</td>
<td>80,000 (each plant)</td>
<td>Planning</td>
</tr>
<tr>
<td></td>
<td>Shell/Shenhua</td>
<td>70,000–80,000</td>
<td>Planning</td>
</tr>
<tr>
<td></td>
<td>Headwaters/UK Race Investment</td>
<td>Two 700-bpd demo plants</td>
<td>Planning</td>
</tr>
<tr>
<td>Indonesia</td>
<td>Pertamina/Accelon</td>
<td>~76,000</td>
<td>Construction</td>
</tr>
<tr>
<td>Australia</td>
<td>Anglo American/Shell</td>
<td>60,000</td>
<td>Planning</td>
</tr>
<tr>
<td>Australia</td>
<td>Altona Resources plc, Jacobs Consultancy, MineConsult</td>
<td>45,000</td>
<td>Planning</td>
</tr>
<tr>
<td>Philippines</td>
<td>Headwaters</td>
<td>50,000</td>
<td>Planning</td>
</tr>
<tr>
<td>New Zealand</td>
<td>L&amp;M Group</td>
<td>50,000</td>
<td>Planning</td>
</tr>
</tbody>
</table>
Congressional Interest in CTL

- **Previous Congress (109th)**
  - H.R. 5965 – Progress Act
  - H.R. 5890 – American-Made Energy Trust Fund Bill
  - S. 1920 – Renewable Diesel Standard Act of 2005
  - S. 2446 – American Fuels Act of 2006
  - S. 3325 – Coal-to-Liquid Fuel Promotion Act of 2006

- **Current Congress (110th)**
  - S. 154
  - S. 155
  - H.R. 370

\[\text{Coal-to-Liquid Fuel Promotion Act of 2007}\]
Reports and Studies – CTL Processes

- Department of Defense
  - OSD Assured Fuels Initiative
  - Flight Test of F-T Jet Fuel Blend
  - Air Force Energy Industry Forum

- Mitretek
  - Techno-Economic Analysis of Wyoming Located CTL Plant
  - Gasification of Kemmerer Coal at the Mine Mouth in Wyoming for Production of Zero Sulfur Liquid Transportation Fuels and Electric Power: A Feasibility Study
  - Clean Transportation Fuels from Domestic Coal

- National Coal Council
  - America’s Energy Future

- Southern States Energy Board
  - American Energy Security Study

- Scully Capital Services, Inc.
  - The Business Case for Coal Gasification with Co-Production
Reports and Studies – CTL Processes (continued)

  - A Development Plan for a Coal-to-Liquid Fuel Program

- Energy Policy Act - 2005, Section 369
  - Commercialization of America’s Strategic Unconventional Fuels: Oil Shale • Tar Sands • Coal Derived Liquids • Heavy Oil • CO₂ Enhanced Recovery and Storage

- Rand Corporation
  - Unconventional Fuels: Strategic and Program Options

- World Coal Institute
  - Coal: Liquid Fuels
CTL Technology – Economics Remain Key Issue

- Conceptual plant designs estimate $3.5–4.5 billion required for initial 50,000-bpd plants (Capital cost = $70–90K/daily barrel)

- Plants may be profitable with crude oil price between $45–60/bbl with carbon storage (carbon storage estimated to account for $4/barrel of the required selling price)

- Higher unit investment costs for pioneer demonstration plants (10,000- to 20,000-bpd plants)

- Difficult to accurately estimate costs since no plants have been built worldwide since the 1980s
Potential Impacts on Cost
Barriers to Coal-To-Liquids

- **Technical**
  - Integrated operations of advanced CTL technologies have never been demonstrated

- **Economic**
  - Uncertainties about future world oil production
  - High capital and operations costs
  - Investment risks
  - Energy price volatility

- **Environmental**
  - CO₂ and criteria pollutant emissions
  - Expansion of coal production and requisite infrastructure (railroads, railcars, etc.)
  - Water use

- **Commercial Deployment**
  - Competition for critical process equipment, engineering, and skilled labor
  - Who would take the lead in commercial deployment? Part power part liquid fuels

- **Social**
  - NIMBY and public resistance to coal use