



Coal Conversion – Pathway to Alternate Fuels

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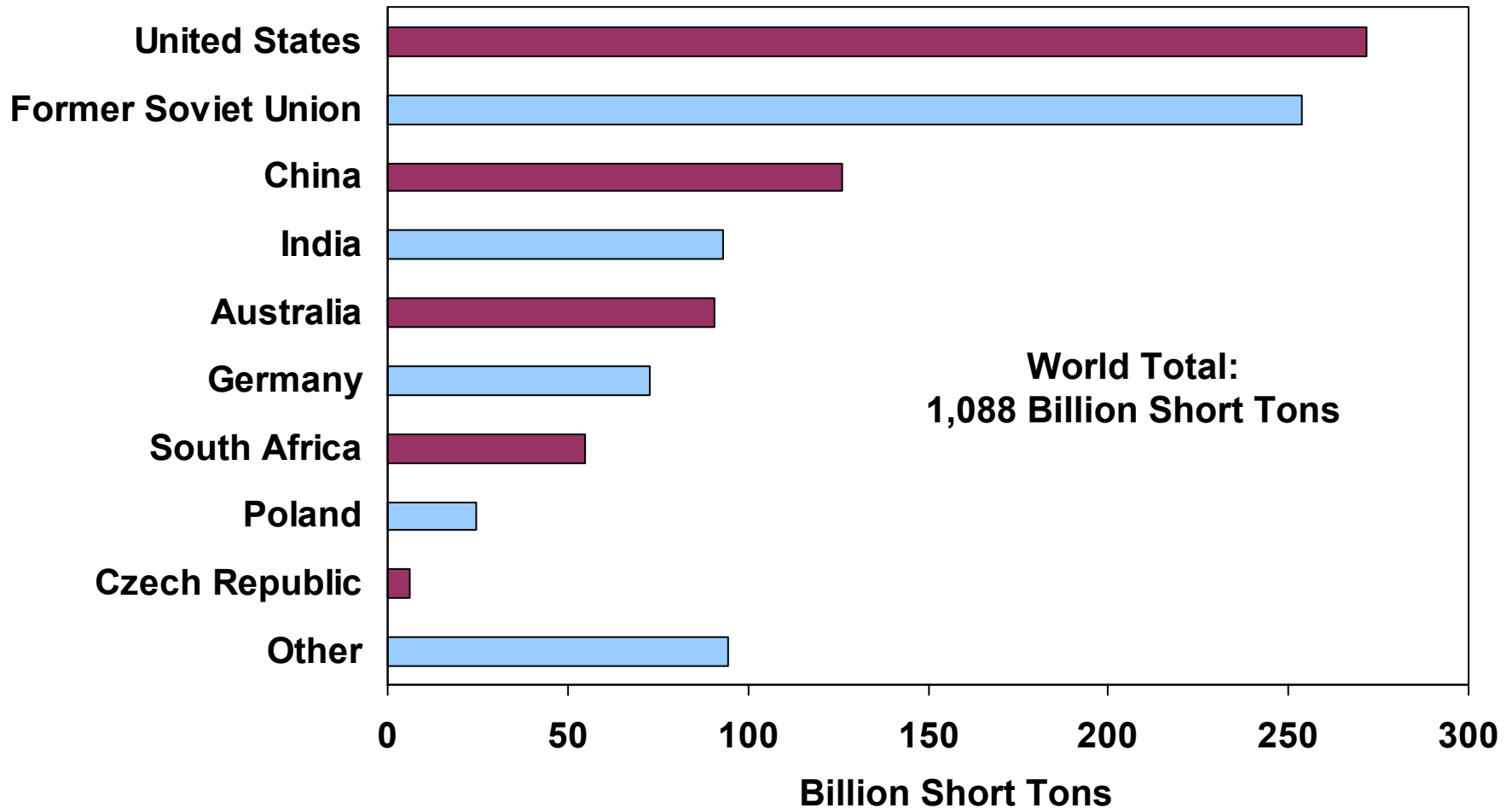
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Overview

- Coal A Major Energy Resource
- Why Coal-to-Alternative Fuels and Chemicals
- Coal Liquefaction – Background
- Direct Liquefaction
- Indirect Liquefaction
- Coal to Liquids – Current Status
- Conclusions

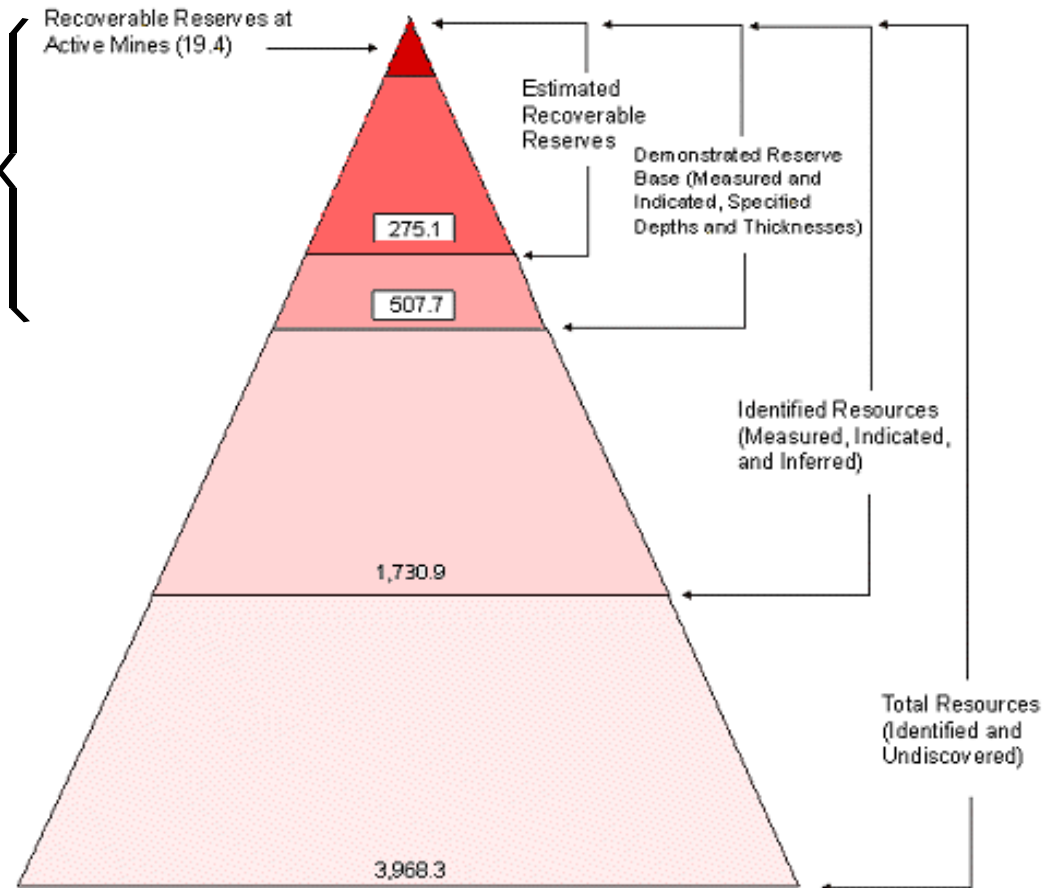
The U.S. Leads in Coal Reserves



Source: Energy Information Administration, World Recoverable Coal Reserves; *International Energy Annual 2002*

Delineation of U.S. Coal Resources and Reserves

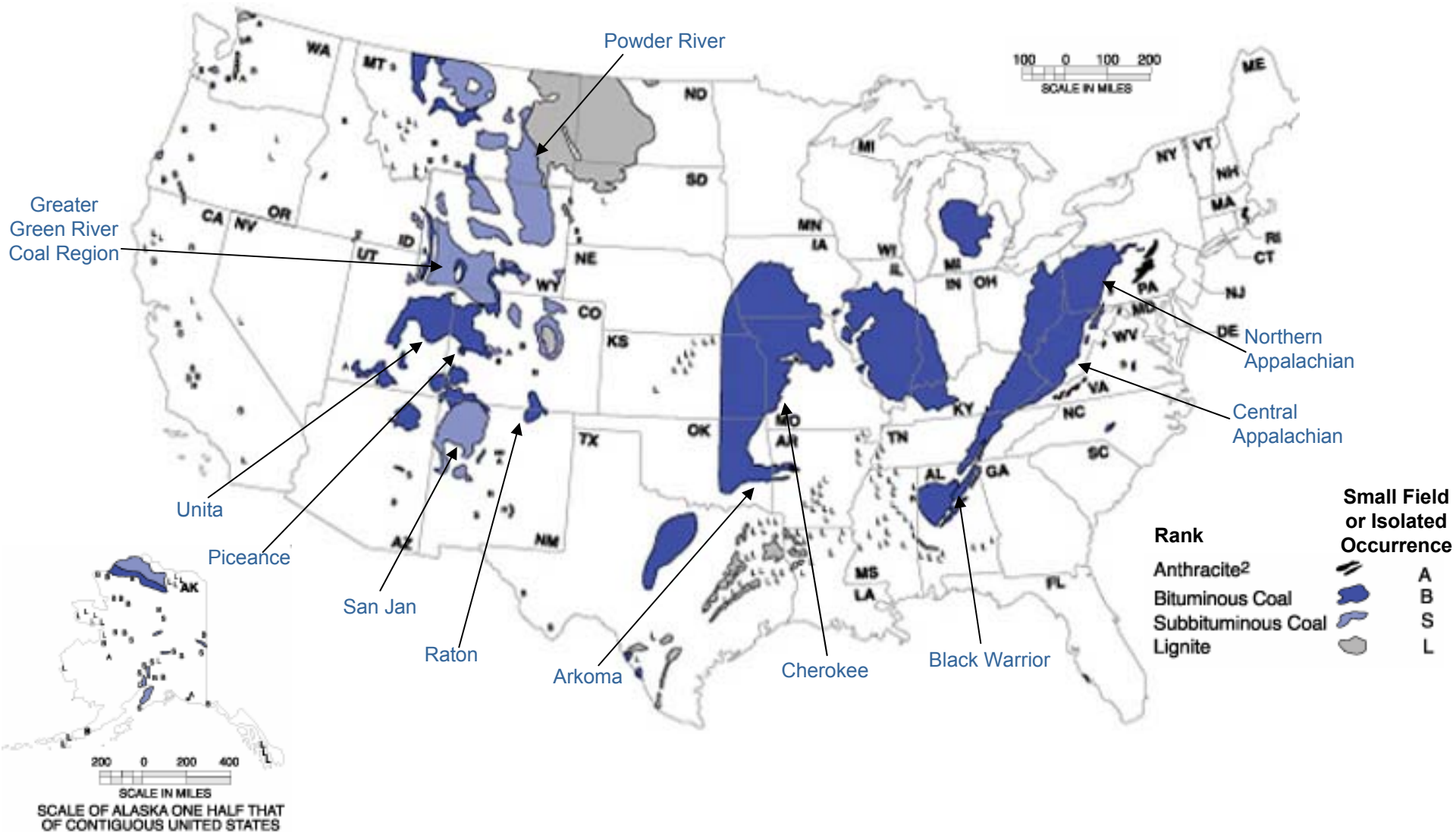
Sufficient reserve to meet projected demand for electricity and up to 4MM bpd CTL industry for over 100 years



Source: EIA Coal Reserves Data 1997

<http://www.eia.doe.gov/cneaf/coal/reserves/chapter1.html#chapter1a.html>

U.S. Coal Reserves Distribution



Why Coal-To-Liquids?

- 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

Coal Liquefaction

Introduction:

The production of coal-derived liquids as a by-product of coke making commenced in Germany and the UK in the 1840s. These by-product liquids had a variety of uses including solvents, wood preservatives, fuels, and from the 1850s, as the basis of the coal-tar dyes still in current use. They formed the feedstocks for the developing petrochemical industry, where coal-derived aromatics were used in significant quantities until recently.

In these early stages of development, two distinct technical approaches were pursued. The earliest process route involved high temperature and high pressure dissolution of coal in a solvent to produce high boiling point liquids. No hydrogen or catalyst was used at this time. This approach was known as direct liquefaction, and was patented in 1913 and commercialized in the early 1920s. This approach also became known as either the Pott-Broche or I.G. Farben Process.

A patent was granted to Fischer and Tropsch in 1925 for an alternative process, known as indirect liquefaction. This involved the gasification of coal to produce a synthesis gas containing hydrogen and carbon monoxide. The synthesis gas was reacted over a cobalt catalyst to produce liquids. The process was commercialized by Ruhrchemie in the mid-1930s.

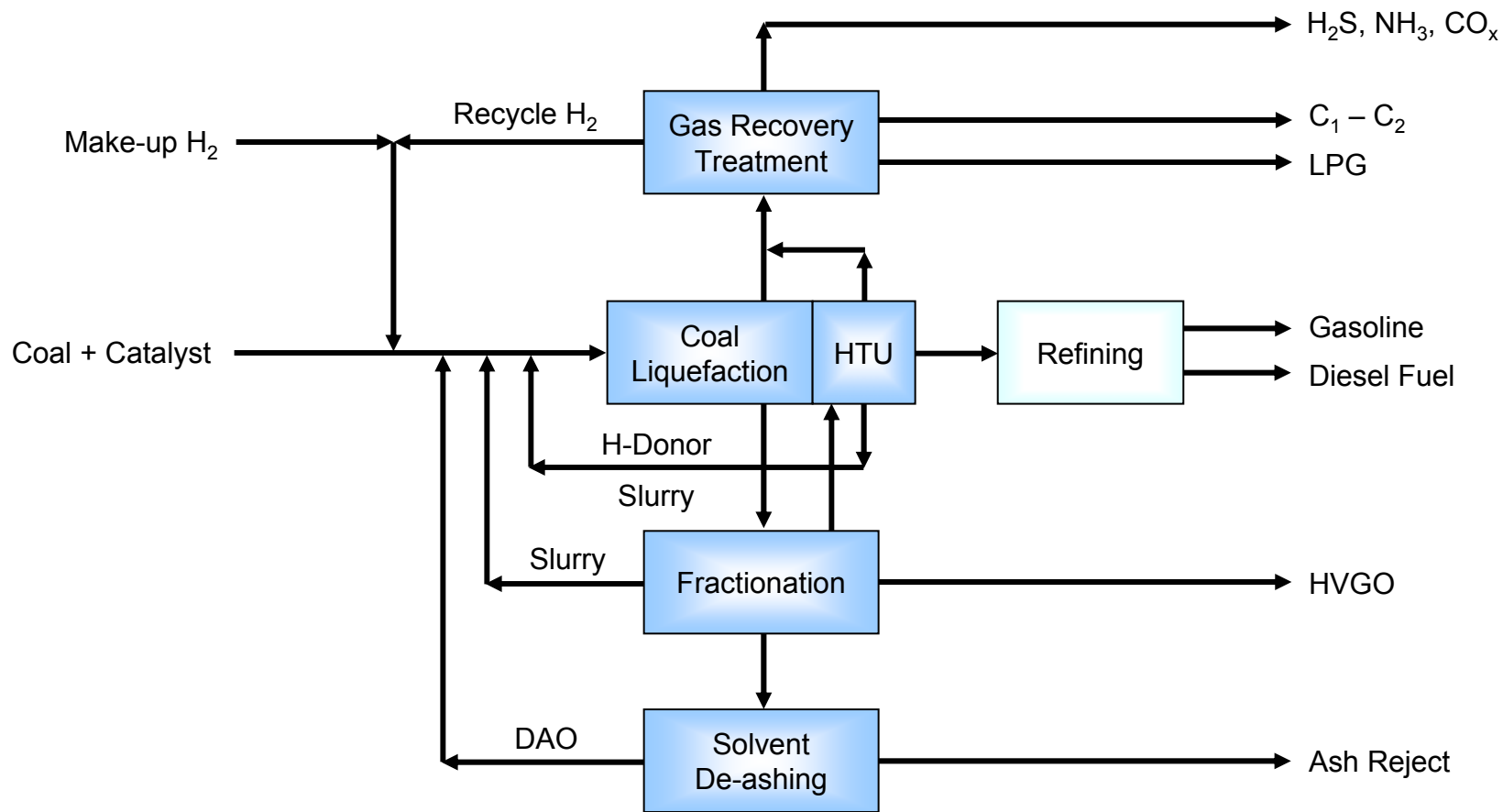
Coal Conversion Processes

- 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

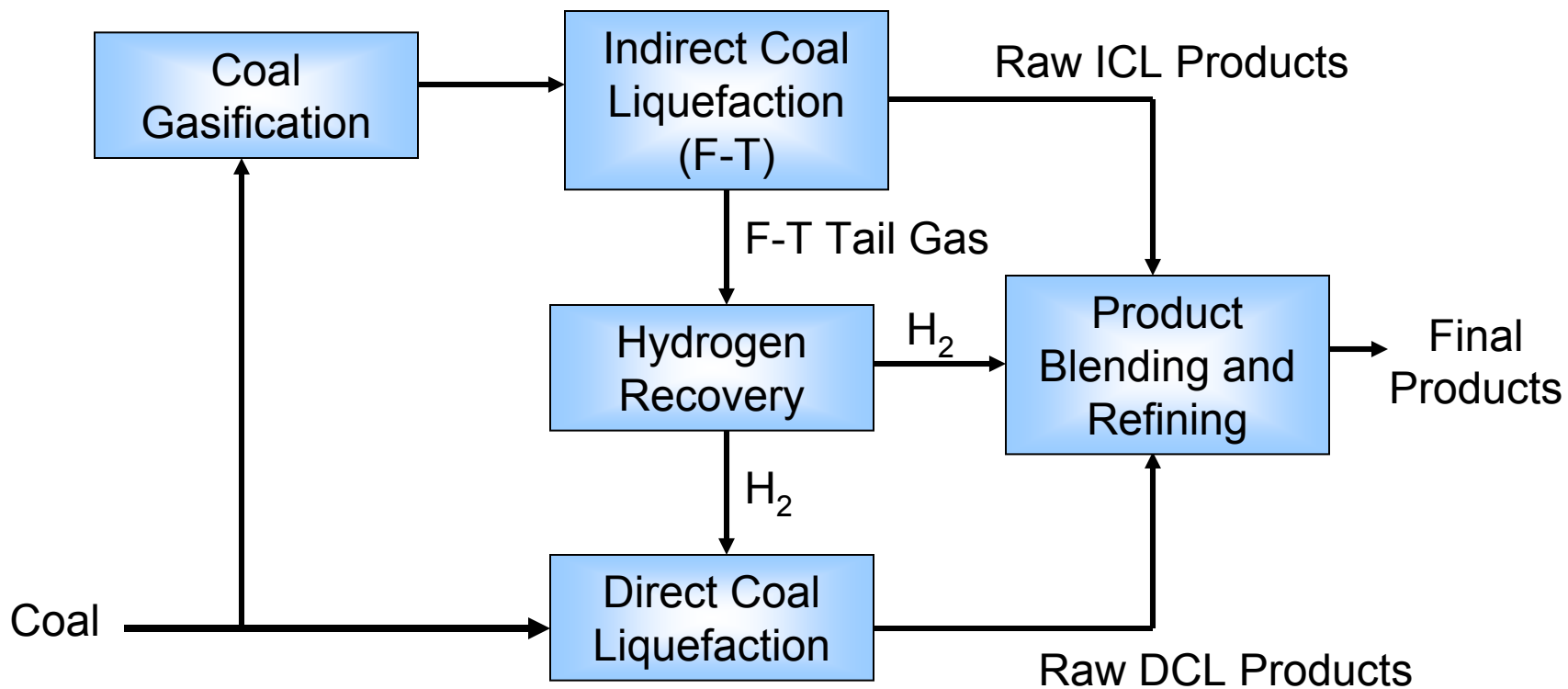
Direct Liquefaction

In order to generate liquids directly from coal, the macromolecular structure of the coal must be broken down to a size that makes it suitable for further treatment. This is generally achieved by reacting the coal as a slurry in a process-derived solvent. Different processes may use hydrogen along with the solvent, and may operate with or without a reaction catalyst. The process conditions used for this step vary considerably, with temperatures in the range of 370–470 °C, and pressures of 50–300 bar (735–4,400 psig). Processes that do not use hydrogen at this point tend to operate at low pressures. The more severe conditions are generally associated with processes that carry out both the dissolution of the coal and the hydro-cracking of the dissolved products in a single reactor. Liquid yields in excess of 70% by weight of the dry, mineral matter free coal feed, have been demonstrated for some processes. The extent to which coal can be broken down and dissolved depends upon many factors, including its origin, rank, and petrographic composition. Most processes are capable of converting at least 90% of the organic part of suitable coals. The mineral matter contained in the coal is largely unaffected by the dissolution reaction, and must be removed with the un-dissolved coal at some stage in the process. The way that this removal is accomplished is a key distinguishing feature of some processes.

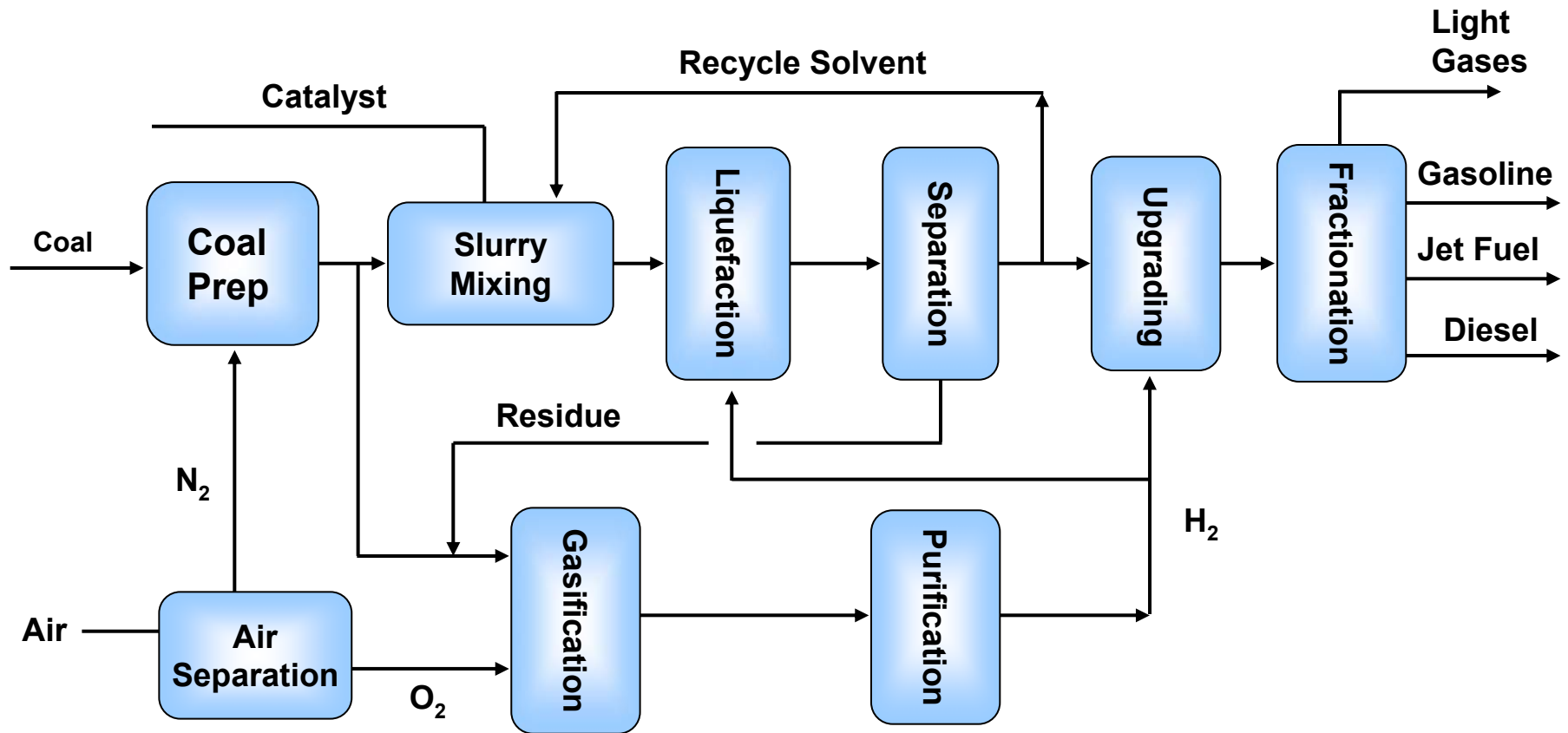
Direct Coal Liquefaction Process



Hybrid DCL/ICL Plant Concept



Shenhua DCL Project



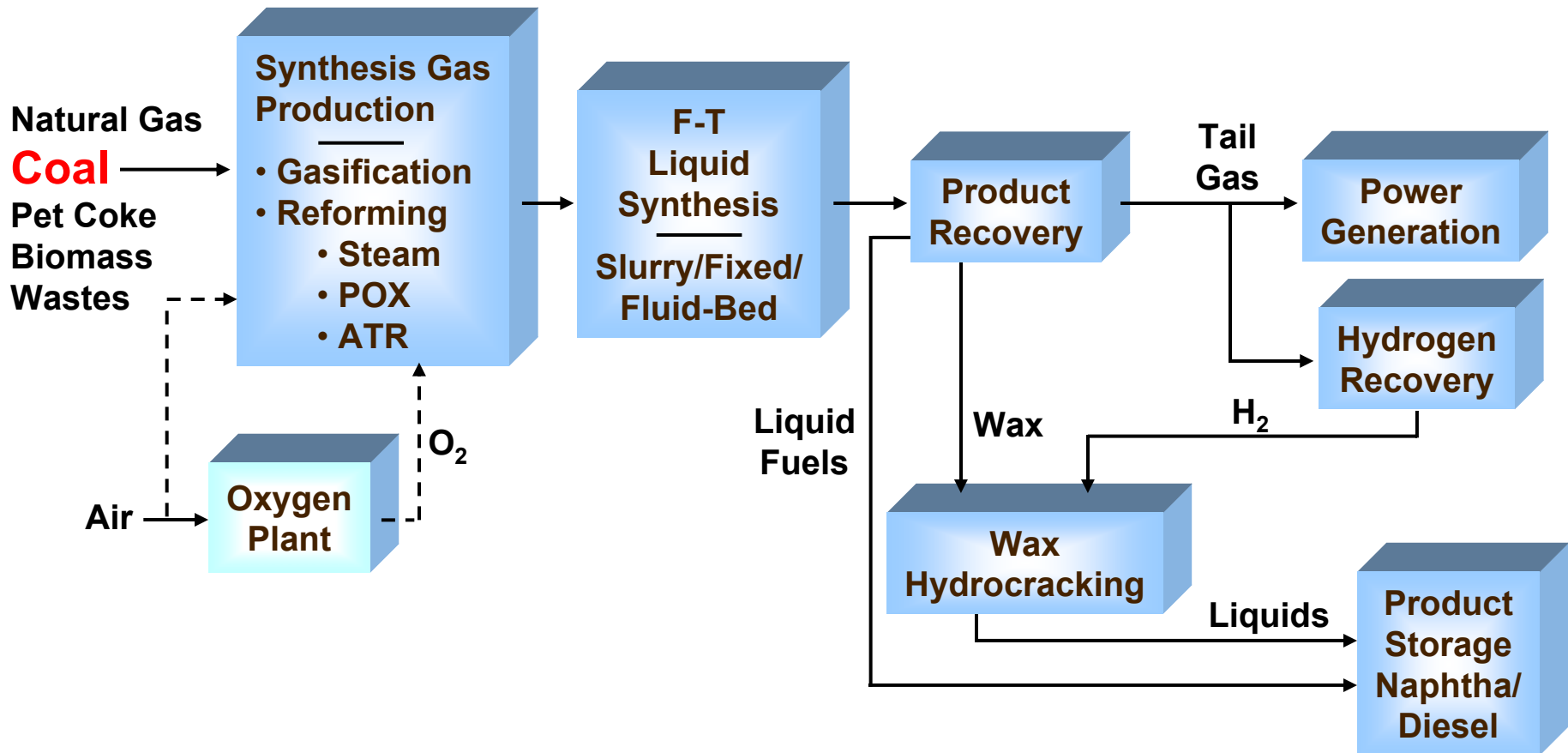
➤ Shenhua Direct Coal Liquefaction Process

➤ First Train: 1 MT/a Liquefaction Oil

Indirect Liquefaction

Indirect liquefaction involves, as a first step, the complete breakdown of the coal structure by gasification with steam and oxygen. The composition of the gasification products is then adjusted to give the required mixture of hydrogen and carbon monoxide, and cleaned to remove impurities, principally sulfur-containing catalyst poisons. The resulting synthesis gas is reacted over a catalyst at relatively low pressure and temperature. In the synthesis step, operating temperatures are in the range of 200–350 °C, with operating pressures in the range of 20–30 bar (300–450 psig). Both fixed-bed and fluidized-bed systems have been used. Fixed beds operate at the lower end of the temperature range and yield predominantly paraffinic products, a high proportion of which is heavy oils and waxes. Fluidized beds operate at higher temperatures, give a lighter and more olefinic product, and offer engineering advantages for large-scale installations. More recently, several processes have been developed with the intention of producing middle distillates. Following partial oxidation, the synthesis gas is reacted over what are described as cobalt-based or metallocene catalysts. A diesel fuel of exceptionally high quality, with a cetane number greater than 70, is 70–80% of the product slate with naphtha being the other 20–30%. The naphtha is an excellent refinery cracker feed stock for olefin production or other chemicals, and may be a valuable fuel for advanced engines.

Indirect Coal Liquefaction Overview



Coal-To-Liquids: Current Status

- Costs – Many systems analyses ongoing – for 50,000 bpd plant:
 - Capital costs estimated as \$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 support 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 Liquefaction Technologies

Mild Pyrolysis	Single-Stage Direct Liquefaction	Two-Stage Direct Liquefaction	Co-Processing and Dry Hydrogenation	Indirect Liquefaction
<ul style="list-style-type: none"> Liquids from Coal (LFC) Process – Encoal Coal Technology Corporation Univ. of North Dakota Energy and Environmental Centre (EERC)/AMAX R&D Process Institute of Gas Technology Char, Oil Energy Development (COED) 	<ul style="list-style-type: none"> Solvent Refined Coal Processes (SRC-I and SRC-II) – Gulf Oil Exxon Donor Solvent (EDS) Process H-Coal Process – HRI Imhausen High-Pressure Process Conoco Zinc Chloride Process Kohleoel Process – Ruhrkohle NEDO Process 	<ul style="list-style-type: none"> Consol Synthetic Fuel (CSF) Process Lummus ITSL Process Chevron Coal Liquefaction Process (CCLP) Kerr-McGee ITSL Work Mitsubishi Solvolysis Process Pyrosol Process – Saarbergwerke Catalytic Two-Stage Liquefaction Process – DOE and HRI Liquid Solvent Extraction (LSE) Process – British Coal Brown Coal Liquefaction (BCL) Process – NEDO Amoco CC-TSL Process Supercritical Gas Extraction (SGE) Process – British Coal 	<ul style="list-style-type: none"> MITI Mark I and Mark II Co-Processing Cherry P Process – Osaka Gas Co. Solvolysis Co-Processing – Mitsubishi Mobil Co-Processing Pyrosol Co-Processing – Saarbergwerke Chevron Co-Processing Lummus Crest Co-Processing Alberta Research Council Co-Processing CANMET Co-Processing Rheinbraun Co-Processing TUC Co-Processing UOP Slurry-Catalysed Co-Processing HTI Co-Processing 	<ul style="list-style-type: none"> Sasol Rentech Syntroleum Mobil Methanol-to-Gasoline (MTG) Process Mobil Methanol-to-Olefins (MTO) Process Shell Middle Distillate Synthesis (SMOS)

Source: Paper – 23rd Int'l Pittsburgh Coal Conference, September 25-28, 2006.

Paper Title: Coal Conversion – A Rising Star

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

Current and Potential Future CTL Worldwide

- GTL Qatar: 800,000 BPD (Shell, Sasol, ConocoPhillips, ExxonMobil, Marathon)
- Other GTL Worldwide: 480,000 BPD (includes existing plants and proposed plants in Iran, Russia, Australia, and Nigeria)
- CTL Sasol South Africa 150,000 BPD
- CTL Sasol Potential Plants in China 160,000 BPD
- Bench & pilot facilities at Rentech, Syntroleum, and ConocoPhillips

Conclusions

- Many complex energy challenges face America over the next several decades
- Coal can play key role in ways that go beyond power generation
- Technologies exist to use coal as feedstock for production of liquid fuels, chemicals, and hydrogen
- Successful demonstrations of advanced technologies could lead to a new generation of coal plants that co-produce power, liquid fuels, chemicals, and/or hydrogen while capturing and sequestering carbon dioxide