Axens
IFP Group Technologies

Direct Coal Liquefaction Synergy with Natural Gas

INTERNATIONAL PITTSBURGH
COAL CONFERENCE
University of Pittsburgh · Swanson School of Engineering

Outline

- Axens Overview
- Direct Coal Liquefaction Process Technology
- The Synergy with Natural Gas
- A Commercial CTL Facility

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- **Axens Overview**
- **Direct Coal Liquefaction Process Technology**
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Who is Axens (Briefly)

5 markets covered

Refining | Petrochemicals | Gases | Alternatives & Renewables | Water

over 2,400 industrial units under license

over 60,000 tons of catalysts & adsorbents produced each year

10 Subsidiaries and Joint Ventures

7 Production Sites

Activities

- Process Licensing
- Catalysts & Adsorbents
- Consulting Services

Axens was created in 2001

Merger of Procatalyse (Catalysts and Adsorbents) and the Technology Licensing & Service Division of IFP Energies Nouvelles

This combination provides a single-source offering of technologies, products and services

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2017 Acquisition of Heurtey Petrochem

To strengthen its offer for the refining, petrochemicals, natural & industrial gases, biofuels & renewable petrochemical intermediates markets **Axens has acquired Heurtey Petrochem,** including its fully owned subsidiary, **Prosernat**

International **Oil & Gas Engineering Group**

Two main business lines/**Technologies** provider

Main businesses are **specialized equipment** & **modular solutions**

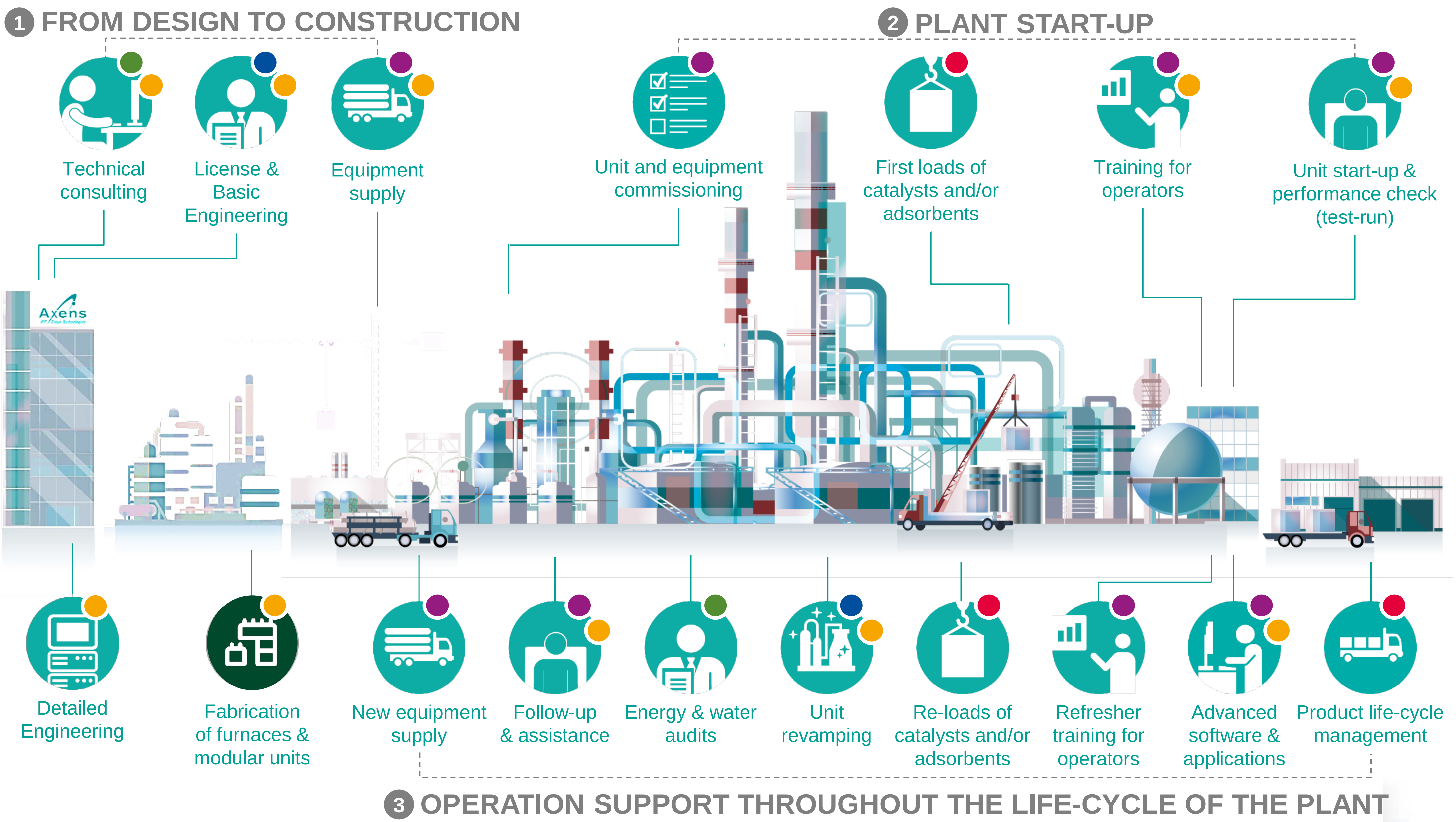
HEURTEY PETROCHEM — DESIGN AND FABRICATION OF PROCESS FURNACES			PROSERNAT — OIL & GAS PROCESSING SOLUTIONS*		
REFINING	PETROCHEMICALS	HYDROGEN / SYNGAS PRODUCTION	NATURAL GAS TREATMENT	DESALTING / SEPARATION	SULFUR RECOVERY






* PROSERNAT: 100% affiliate of HEURTEY PETROCHEM

Axens Group:
A Complete Range of Solutions



Products · Technologies · Consulting services · Operations support · Heurtey Petrochem & Prosernat

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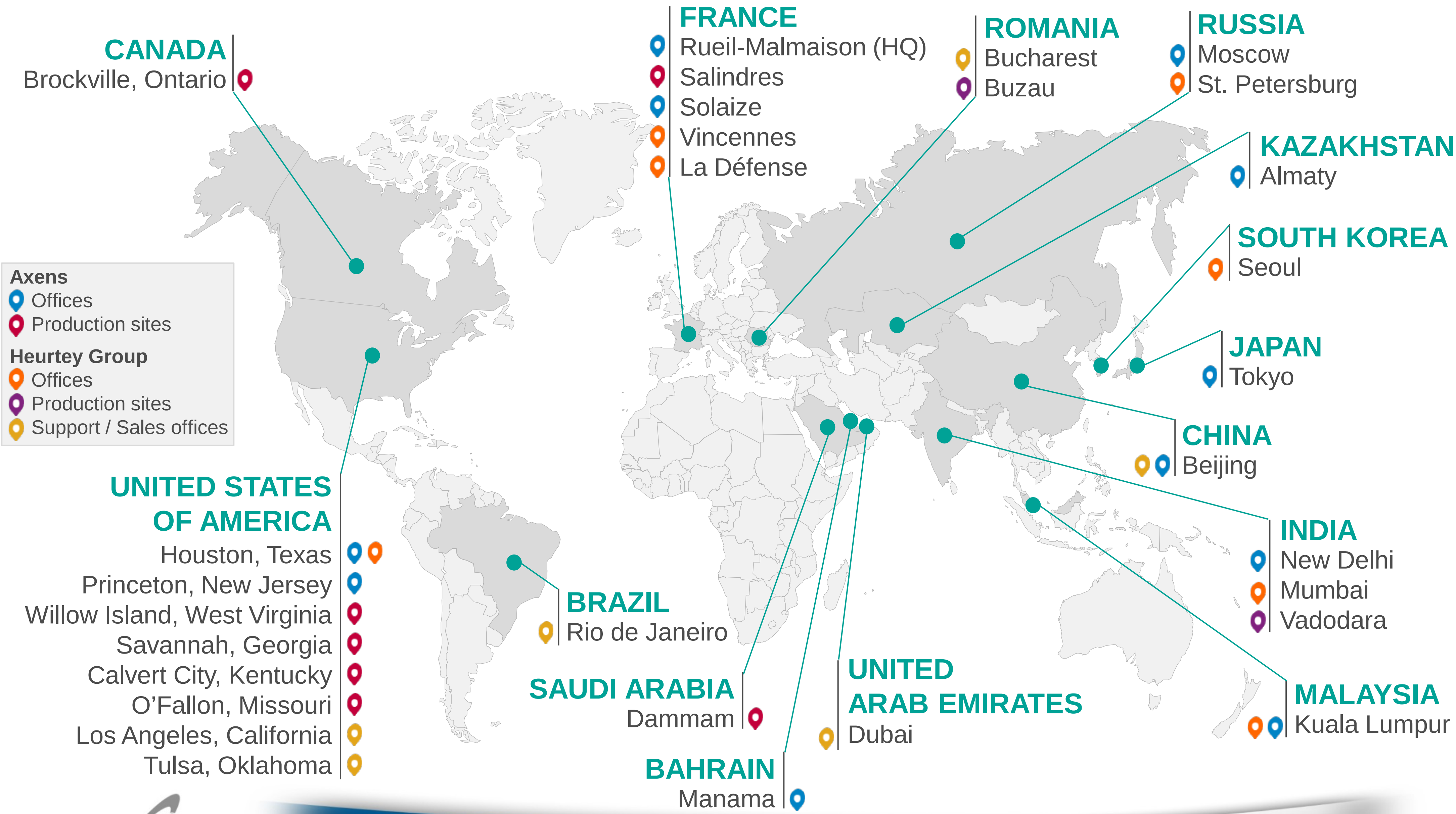
CANADA
Brockville, Ontario
FRANCE
Rueil-Malmaison (HQ)
Salindres
Solaize
Vincennes
La Défense
ROMANIA
Bucharest
Buzau
RUSSIA
Moscow
St. Petersburg
KAZAKHSTAN
Almaty
SOUTH KOREA
Seoul
JAPAN
Tokyo
CHINA
Beijing
INDIA
New Delhi
Mumbai
Vadodara
MALAYSIA
Kuala Lumpur
UNITED ARAB EMIRATES
Dubai
BAHRAIN
Manama
SAUDI ARABIA
Dammam
BRAZIL
Rio de Janeiro
UNITED STATES OF AMERICA
Houston, Texas
Princeton, New Jersey
Willow Island, West Virginia
Savannah, Georgia
Calvert City, Kentucky
O'Fallon, Missouri
Los Angeles, California
Tulsa, Oklahoma
Axens
Offices
Production sites
Heurtey Group
Offices
Production sites
Support / Sales offices

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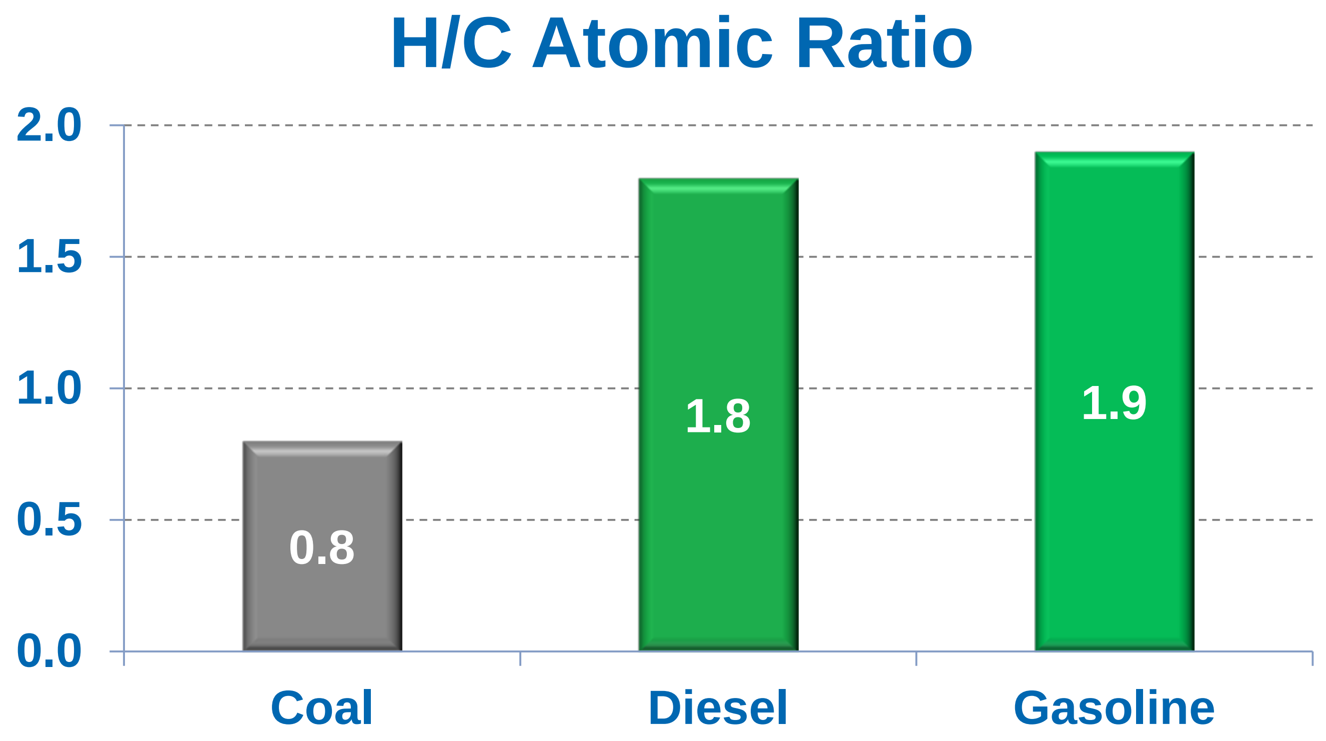
- **Direct Coal Liquefaction Process Technology**
- The Synergy with Natural Gas
- A Commercial CTL Facility

Coal Conversion to Liquid Fuel: Challenge

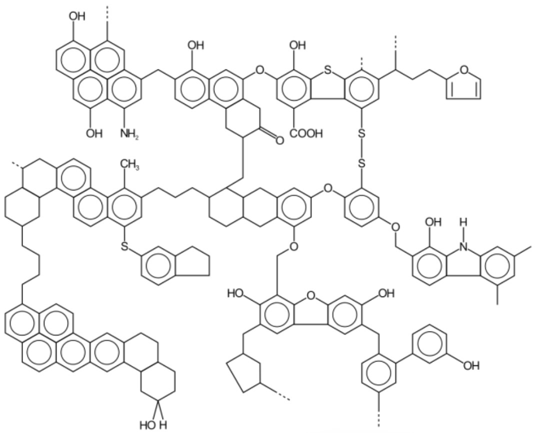


Increase hydrogen-to-carbon ratio to convert coal to liquid fuels

Overview – Indirect Liquefaction of Coal

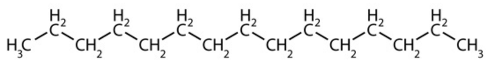
Coal → Gasification → FT Synthesis Conversion → Coal Liquids Refining

$CO + 2\,H2 \rightarrow [-CH2-] + H2O$



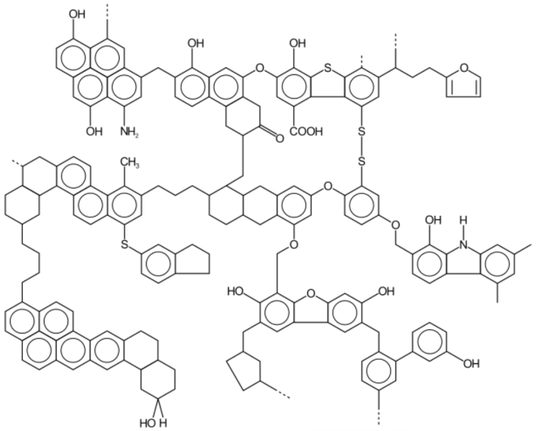
1 MT

2.5 - 3.0 Barrels



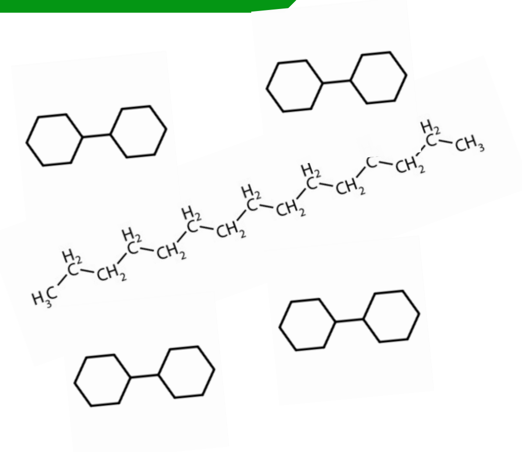
Overview – Direct Coal Liquefaction

Coal → Coal Conversion → Coal Liquids Refining



_1 MT_

3.5 - 4.0 Barrels



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Direct Coal Liquefaction – Friedrich Bergius

Awarded Nobel Prize in 1931

FRIEDRICH BERGIUS

Chemical reactions under high pressure

Nobel Lecture, May 21, 1932

Since the Royal Swedisch Academy of Sciences has considered my work on the development of high pressure methods for chemical reactions, and in particular work on the hydrogenation of heavy hydrocarbons and coal, to be worthy of the Nobel Prize, I wish to combine my gratitude for the high honour bestowed upon me with a report on the development of these systematic investigations and chemical researches to which my academic and industrial activities have been mainly devoted for almost 20 years.

The success of the first experiments with the high-pressure hydrogenation of oil and coal in the years 1912 and 1913 was due to the fact that the laboratory which I directed at that time in Hannover had already developed a method which permitted the conduct of a wide range of reactions in relatively easily operated apparatus at pressures up to about 300 atm and temperatures up to 450°.

In 1908 and 1909 I was given an opportunity in the laboratories of Nernst and Haber to witness the use of the high-pressure methods in investigations into the ammonia equilibrium and ammonia synthesis, and I tried my hand, in these laboratories, at that time, at syntheses by high-pressure techniques, with the then imperfect apparatuses, and with little success.

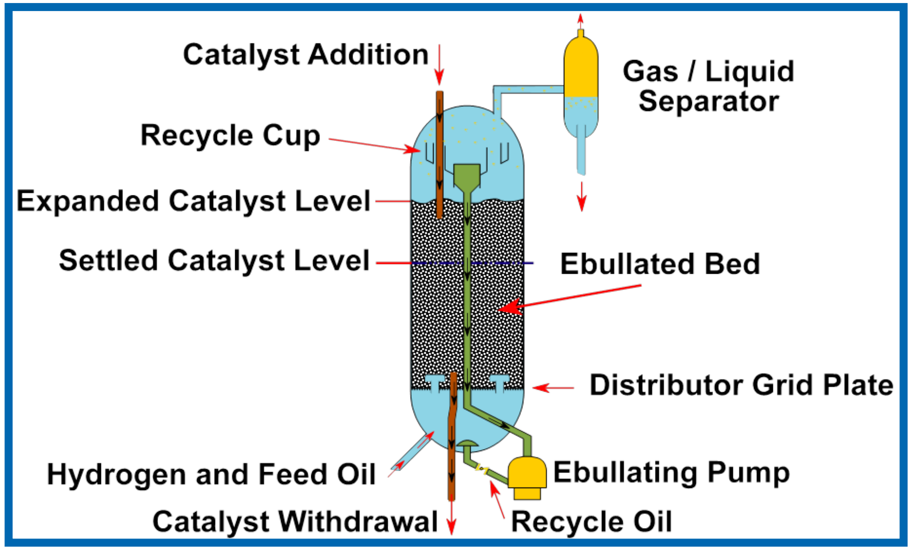
When, in 1909, I joined the physical-chemical laboratory of Hanover Institute of Technology led by Bodenstein, I decided to take up work on this new field which appeared promising to me on a wider scale, and developed, first in the laboratory of the Institute, and then in my own, relatively well-equipped private laboratory, assisted by several colleagues, of whom I would specially mention Hugo Specht, the methods and apparatus for investigating a number of diverse high-pressure reactions in the course of the years.

The problems in most of the investigations were mainly of a technical nature. Purely theoretical research was also done, but, if only for material reasons, to provide an economical justification for the private research laboratory, the principle of practical applicability of the problems studied had to predominate.

In our work, high pressure was used as a means for carrying out chemical

Axens Ebullated-Bed Technology

- **Catalytic Hydrocracking Process for Conversion & Upgrading**
  - Petroleum Feed ⇨ H-Oil®
    - Residue Feed ⇨ H-Oil $_{RC}$
    - VGO/DAO Feed ⇨ H-Oil $_{DC}$
  - Coal Feed ⇨ H-Coal®
- **Ebullated-Bed Reactor**
  - Internal Recycle of Reactor Liquid to Ebullate (Fluidize) Catalyst Bed
  - Operates at High Severity
  - Daily Addition/Withdrawal of Catalyst - Constant Product Quality
- **Reference Units**
  - Used commercially since the 1960's
  - 21 H-Oil Process units awarded with more than 1MMBPSD of combined capacity



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Axens Direct Coal Liquefaction Technology H-Coal® Process

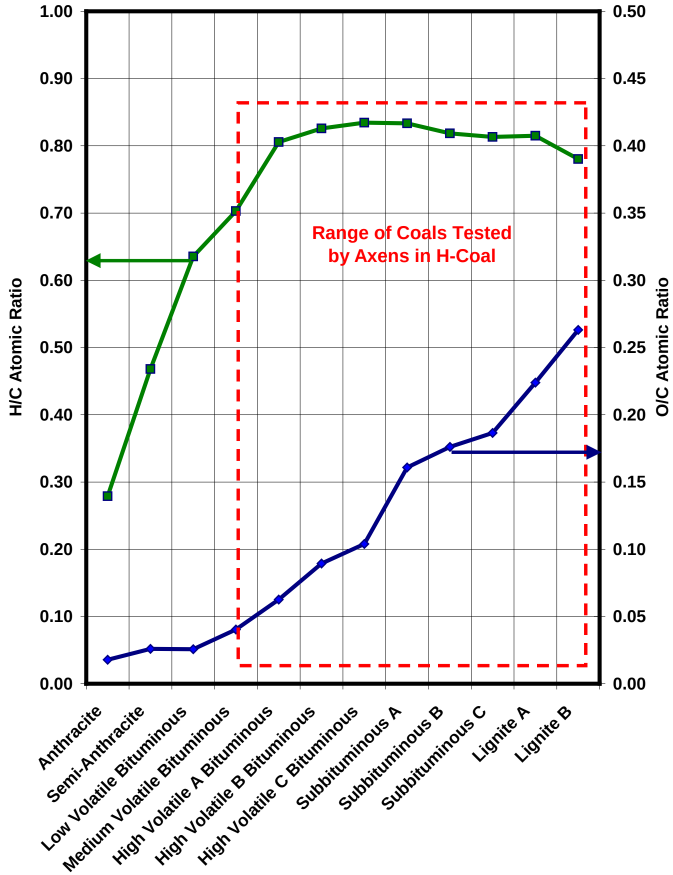
- Based on the H-Oil Process
- H-Coal Development History
  - Same development path/units as H-Oil
  - Pilot plant development started in 1960's
  - Demonstration scale unit (200 TPD) in 1980's
  - Axens prepared basic engineering design and provided start-up support for Shenhua Direct Coal Liquefaction Plant – Start-up in 2008

Technology Options and Feed Flexibility

DCL Technology Options

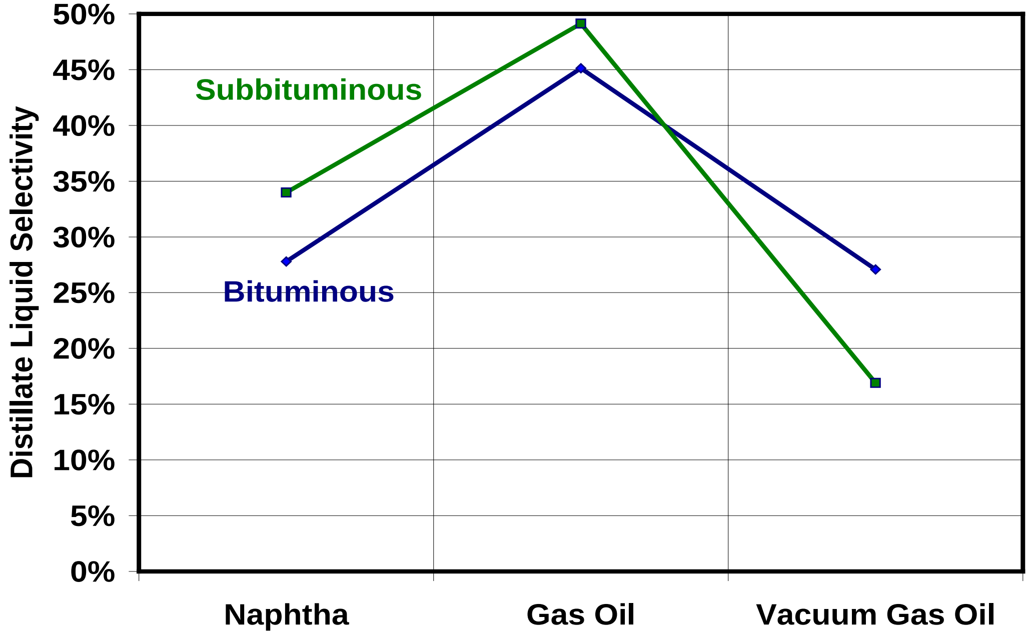
- **H-Coal**
  - **Single reaction stage - H-Coal**
    - Distillate liquid product is 3 barrels per ton of coal
    - successfully demonstrated and scaled to a 200 ton per day pilot plant
  - **Two reaction stages - H-Coal $_{TS}$**
    - Distillate liquid product yield up to 5 barrels per ton
- **Coal/Oil Co-Processing**
  - **Petroleum-derived oil replaces the recycle oil**
    - Reduced capital investment requirements

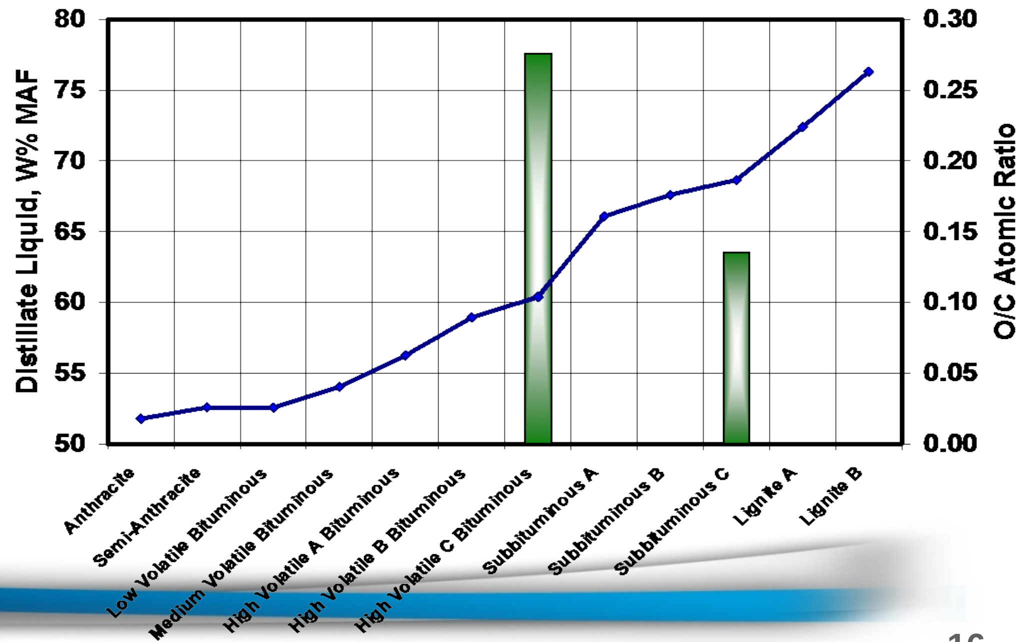
Feedstock Flexibility



H-Coal $_{TS}$ Product Yields and Process Performance

Coal Feed	Bituminous		Deep Cleaned Bituminous	Sub-Bitumninous
Carbon	69.0	69.0	73.9	67.7
Hydrogen	4.5	4.5	4.9	4.5
Nitrogen	1.3	1.3	1.5	1.1
Sulfur	3.5	3.5	2.7	0.5
Ash	11.1	11.1	5.8	6.0
Oxygen	10.6	10.6	11.1	20.2
Total	100.0	100.0	100.0	100.0
H/C	0.8	0.8	0.8	0.8
O/C	0.1	0.1	0.1	0.2
Operating Conditions	1-Stage	2-Stage	2-Stage	2-Stage
Space Velocity/Stage	Base	0.75 * Base	0.50 * Base	0.33 * Base
R1 Temperature, °C	455	400	400	415
R2 Temperature, °C	---	440	440	445
Yields, W% MAF				
H2S/NH3/H2O	12.3	14.7	14.1	22.4
C1-C3	12.0	6.6	8.6	9.4
C4-525 °C	53.2	67.2	78.0	63.6
525 °C+	21.5	12.6	2.7	4.4
Unconverted Coal	6.5	5.2	3.9	8.2
Total (100+ H2 Cons)	105.5	106.3	107.3	108.0
Process Performance				
Coal Conversion, W%	93.5	94.8	96.1	91.8
Liquid Yield, Bbl/MT	3.4	4.1	5.0	4.2
Distillate Selectivity	4.4	10.2	9.1	6.8
Hydrogen Efficiency	9.6	10.7	10.7	8.0





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Assessment of Development Status

DOE/PC 93054-94

**SUMMARY REPORT OF THE
DOE DIRECT LIQUEFACTION PROCESS DEVELOPMENT
CAMPAIGN OF THE LATE TWENTIETH CENTURY:
TOPICAL REPORT**

July 2001

DOE Contract DE-AC22-94PC93054

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CONCLUSIONS

The DOE direct liquefaction program produced a surprisingly mature technology. The intensive effort between 1976 and 1982 (Phase I), when 90% of the program funds were expended, resulted in a demonstration of the technical feasibility of the major process components. The Phase I processes, however, were deficient in terms of product yield and quality. This stimulated further research and development work between 1983 and 1999 (Phase II). The Phase II work was significantly less costly than the earlier demonstration projects, but resulted in substantial improvements in process performance and economics. It now is possible to produce liquids of high quality at yields that approach the theoretical maximum. At the same time, the cost for a barrel of product dropped by 50%, because of

The current technology is well defined in terms of cost and performance. It represents a technically available option for the production of liquid fuels. It can be used domestically in the United States to limit our exposure to oil price increases in the international market or to offset supply reductions. It also can be used by other nations who choose to use domestic coal to meet their transportation fuel needs, thus reducing demands on conventional petroleum sources. It can be used with coal alone, or to co-process a variety of lower value feedstocks. The results of the DOE program allow direct coal liquefaction to be accurately assessed in context to the costs and risks associated with other options for securing liquid fuel supplies should the need arise.

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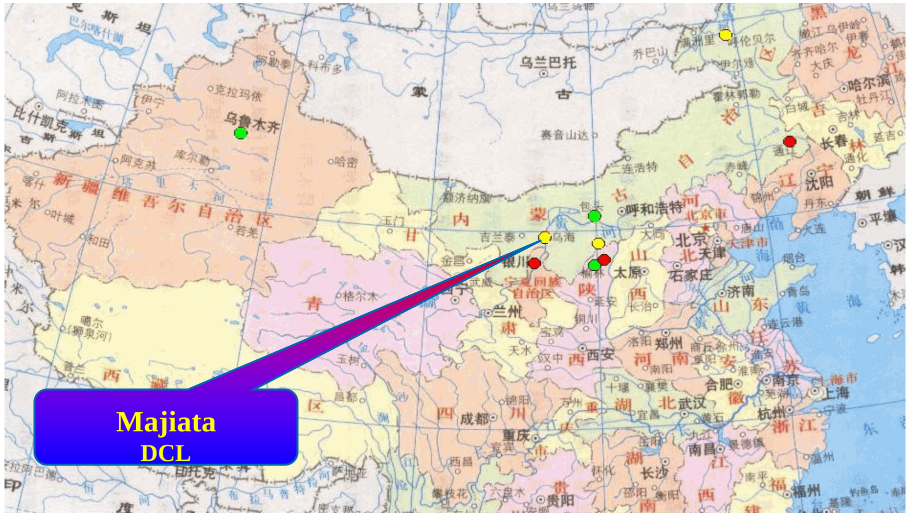
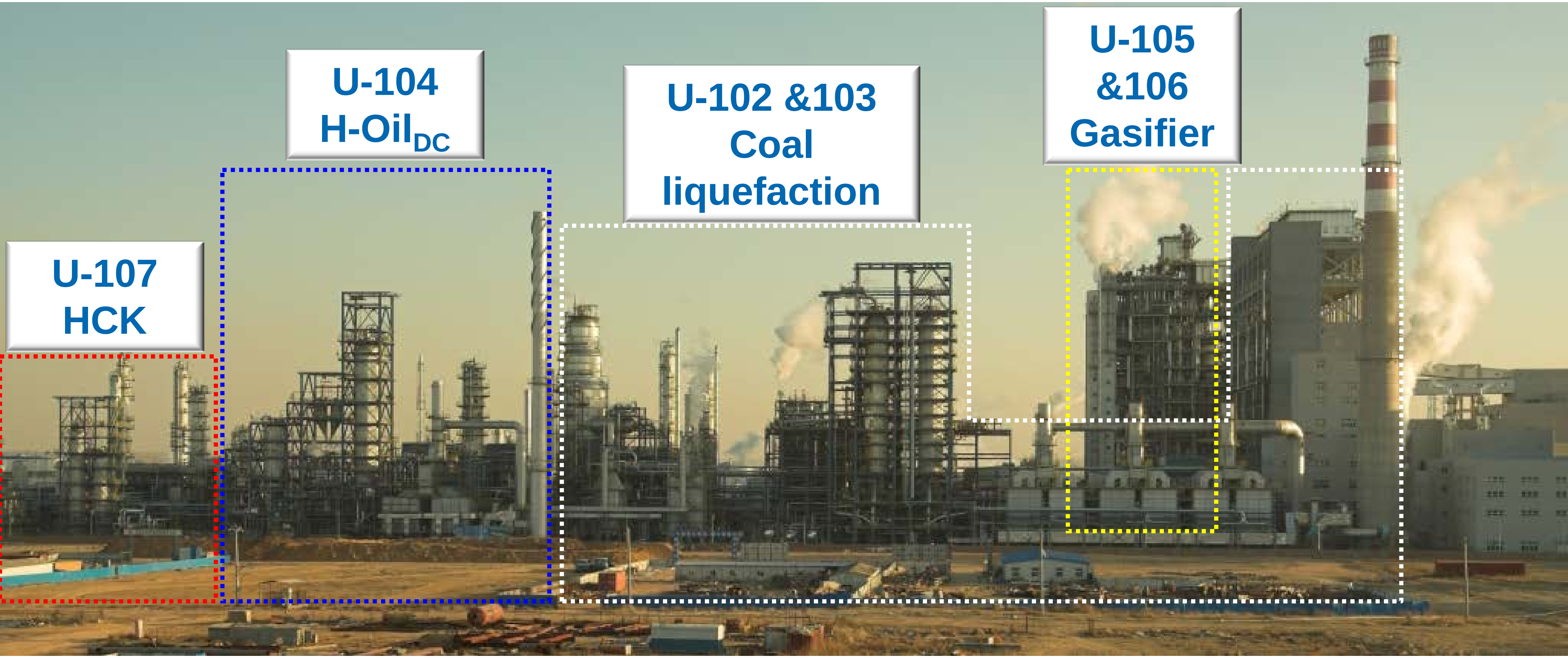
China - Shenhua Direct Coal Liquefaction Project

- First large-scale commercial direct coal liquefaction plant since World War II
  - Location: Majiata, Erdos City, Inner Mongolia
  - Overall scale: 5-Million TPA oil product (in two phases)
  - First train capacity: 1-Million TPA liquefaction oil
    - 6000 TPD coal feed – 20,000 BPD oil products



Products	Million TPA
LPG	0.1021
Naphtha	0.2499
Diesel	0.7146
Phenol	0.0036
Total	1.0702

Shenhua DCL Complex



- World's Only Operating DCL Complex
- Capacity: 6,000t/day of coal / 20,000 BPD of products
- Start-up December 2008

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Axens Services for
Shenhua Direct Coal Liquefaction Project

Axens Services

- Process License for H-Oil $_{DC}$
- Basic Engineering Design
  - Process Design Basis
  - Liquefaction and H-Oil $_{DC}$ Units
  - Review of EPC Documents
  - HAZOP Review Meetings
  - Equipment Inspections
- Operator Training
  - Operator Training Simulator (OTS)
  - Classroom Training
  - Training at Operating H-Oil Unit
- Commissioning and Start-Up Assistance
  - Equipment/P&ID Conformance Checking
  - Commissioning, Start-Up and Continuing Operations
- Catalyst Supply for H-Oil $_{DC}$

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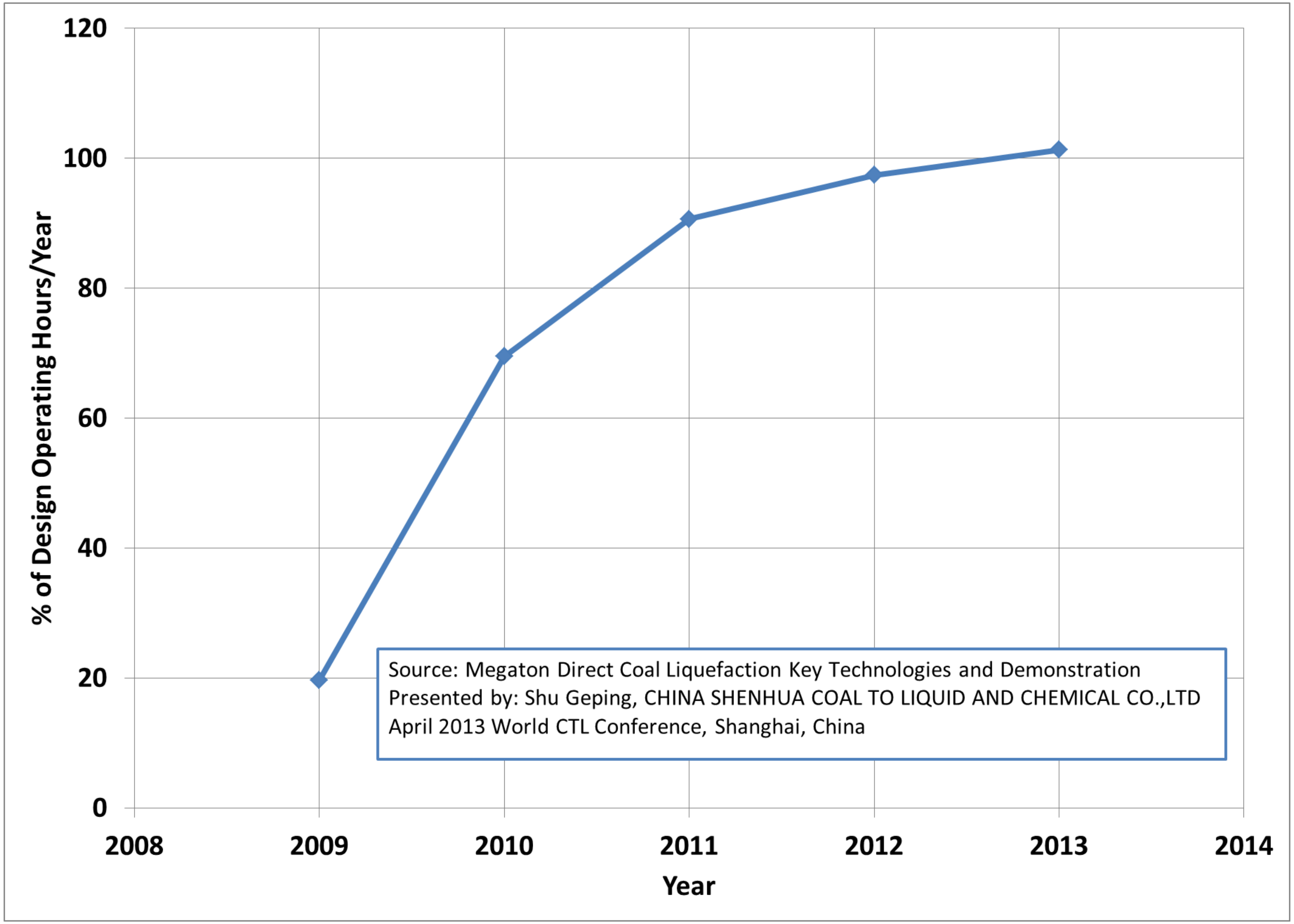
H-Oil and Coal Liquefaction Reactors

H-Oil Reactors

Coal Liquefaction Reactors

Shenhua DCL Plant has Met Operational Targets



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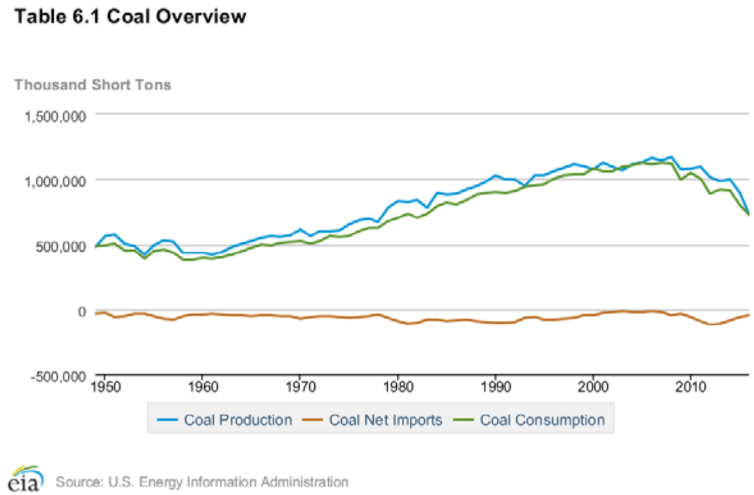
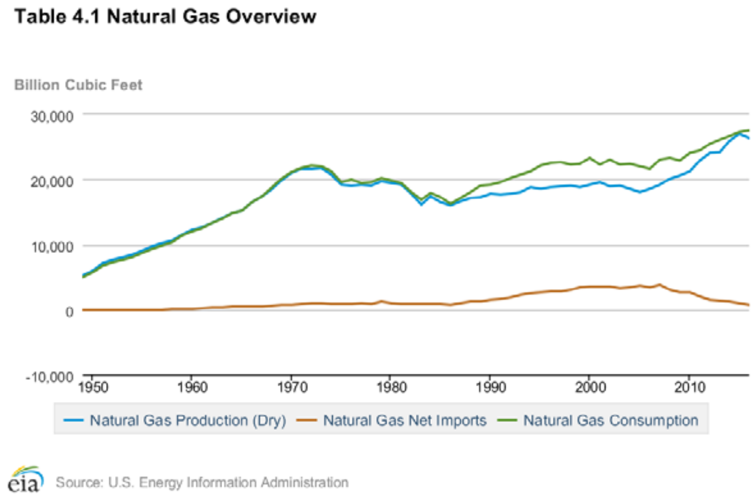
- Direct Coal Liquefaction Process Technology
- **The Case for Synergy with Natural Gas**
- A Commercial CTL Facility

US Coal and Natural Gas Supply

- Nearly balanced in production and consumption
- Net coal exporter
- Diminishing/low natural gas imports…expected to be a net gas exporter this year





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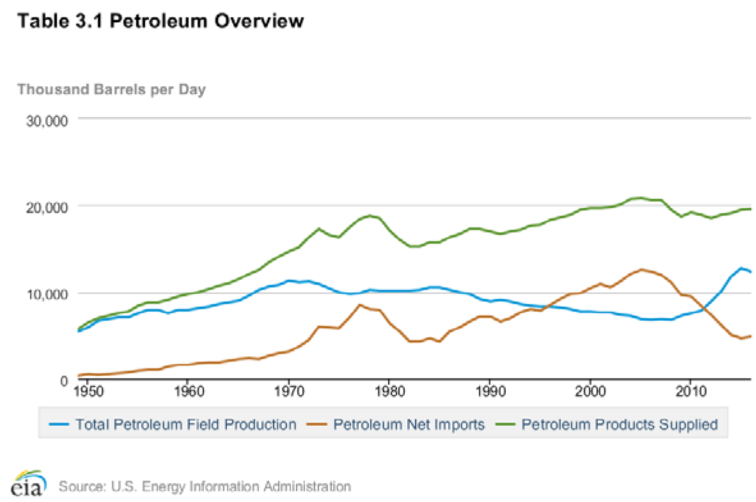
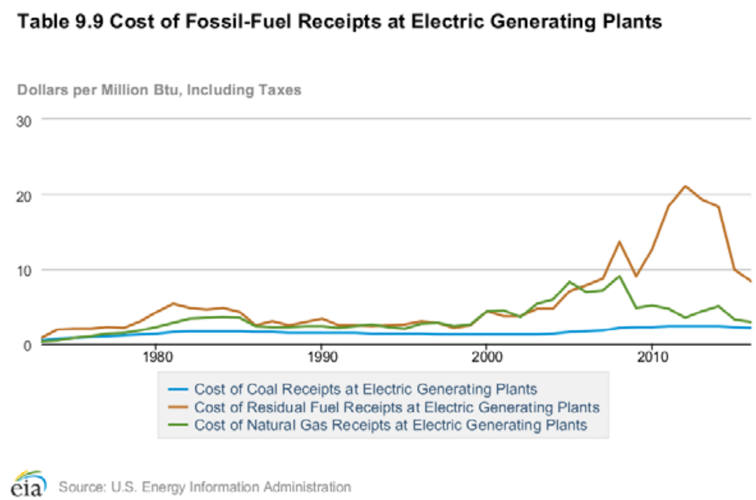
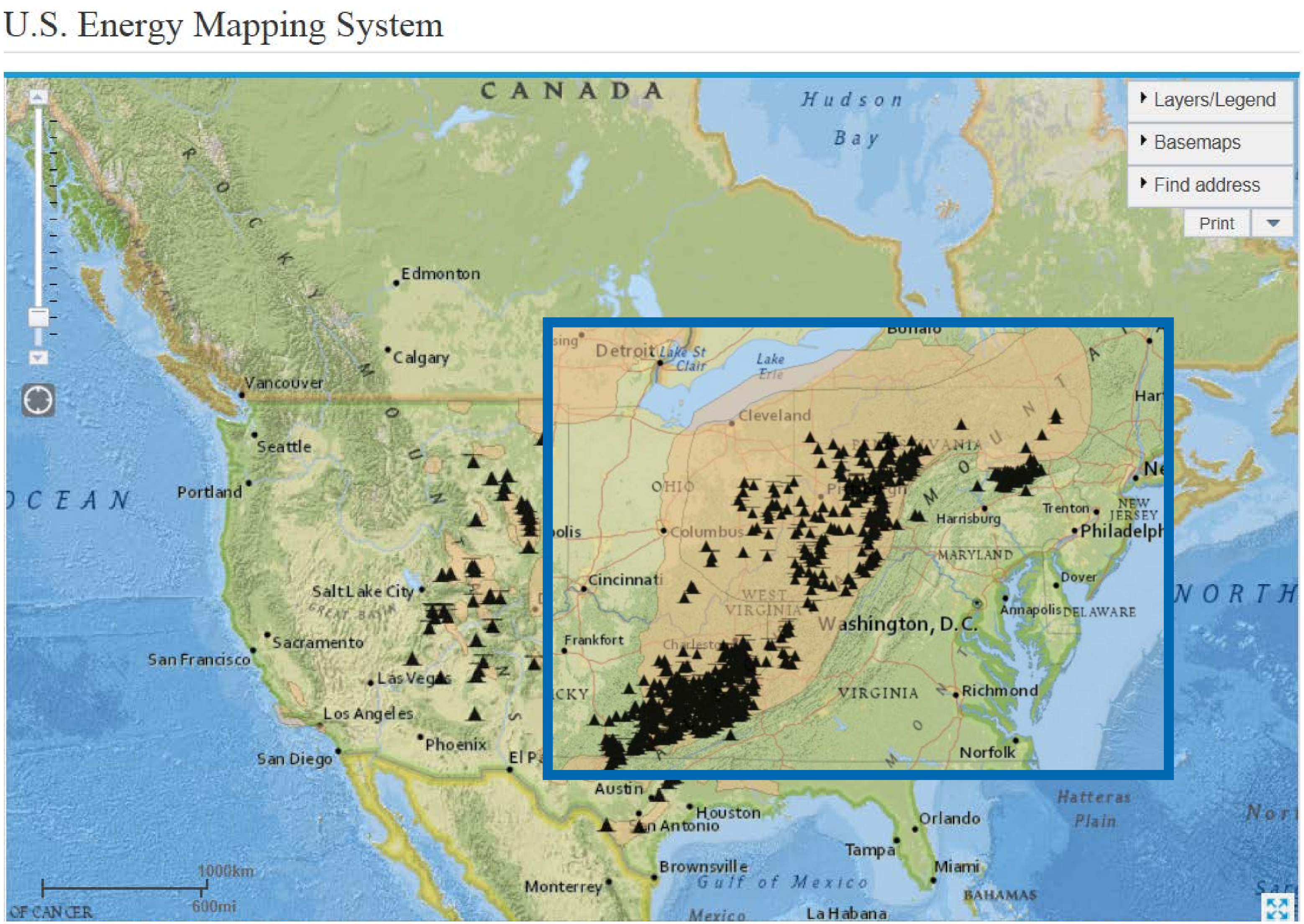
US Petroleum and Energy Prices

- Since 1950 US is a net petroleum importer
- Petroleum production has surpassed imports…but still a significant importer
- Even with low current oil price, coal and natural gas prices are significantly lower



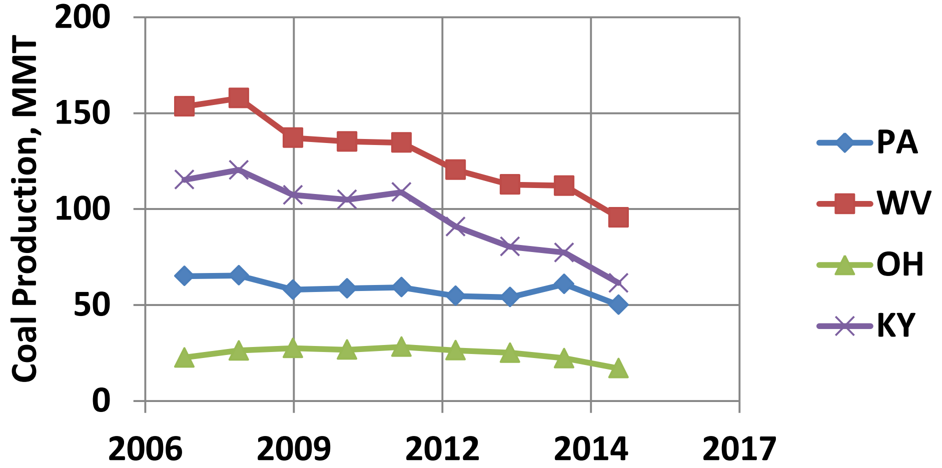


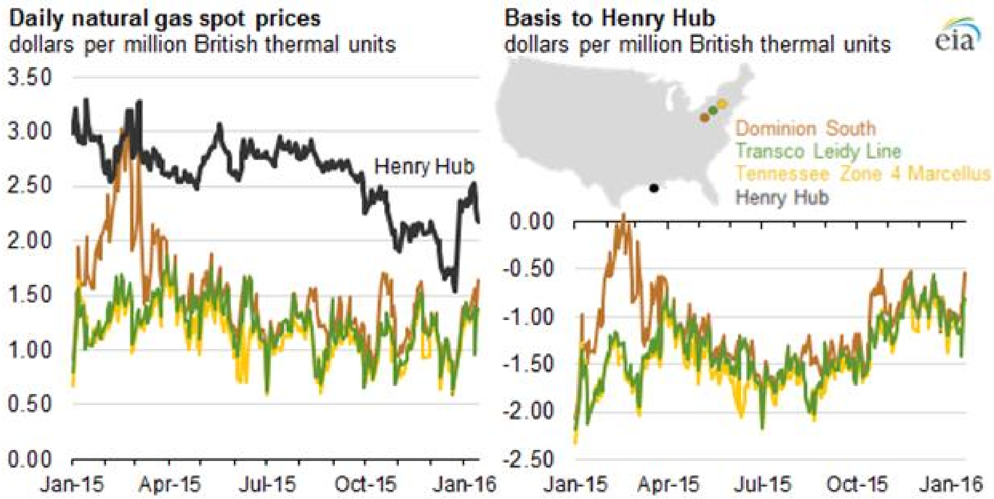
Location of US Coal Mines and Shale Gas Reserves – A Focus on Appalachia

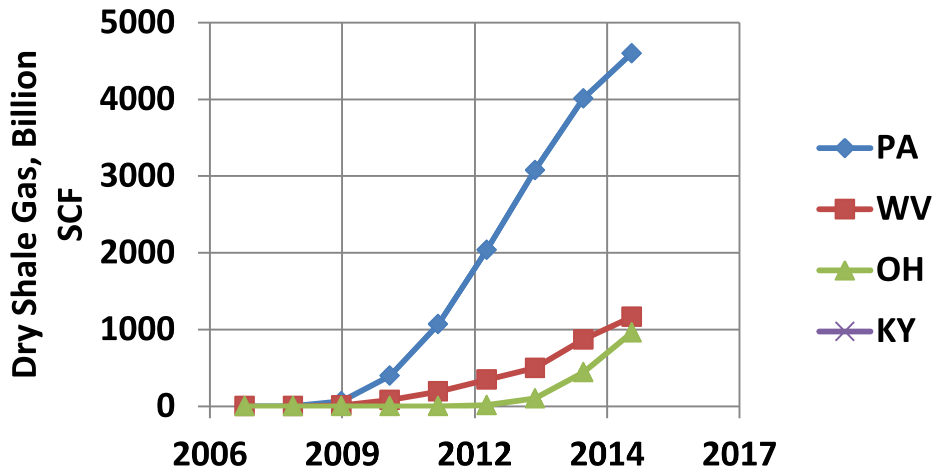


Appalachian Focus

- **Coal production peaked in 2008**
  - **Overall US coal production has declined by nearly 25 %**
  - **Appalachia especially hard hit declining by nearly 40 %**
- **Growth in shale gas production has been meteoric**
  - **Shale gas (local) price is discounted relative to Henry Hub market pricing**







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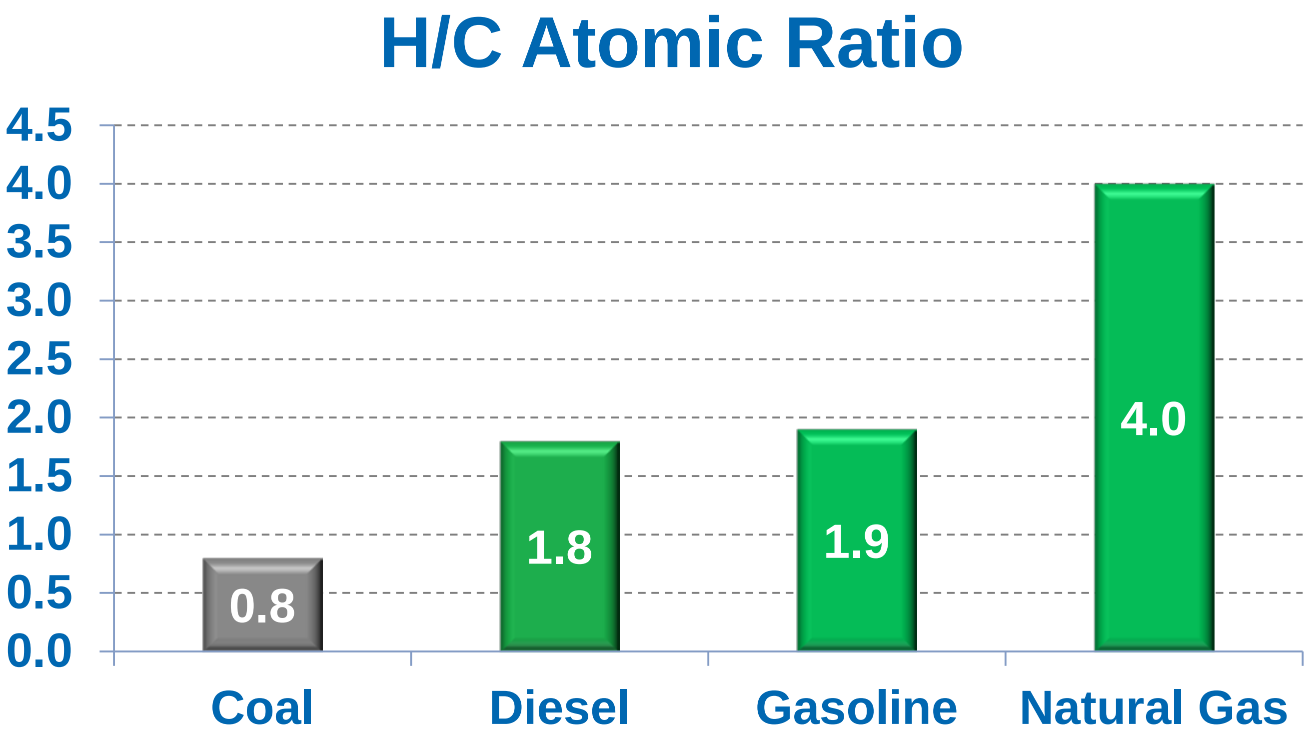
Coal Conversion to Liquid Fuel: Challenge



Increase hydrogen-to-carbon ratio to convert coal to liquid fuels

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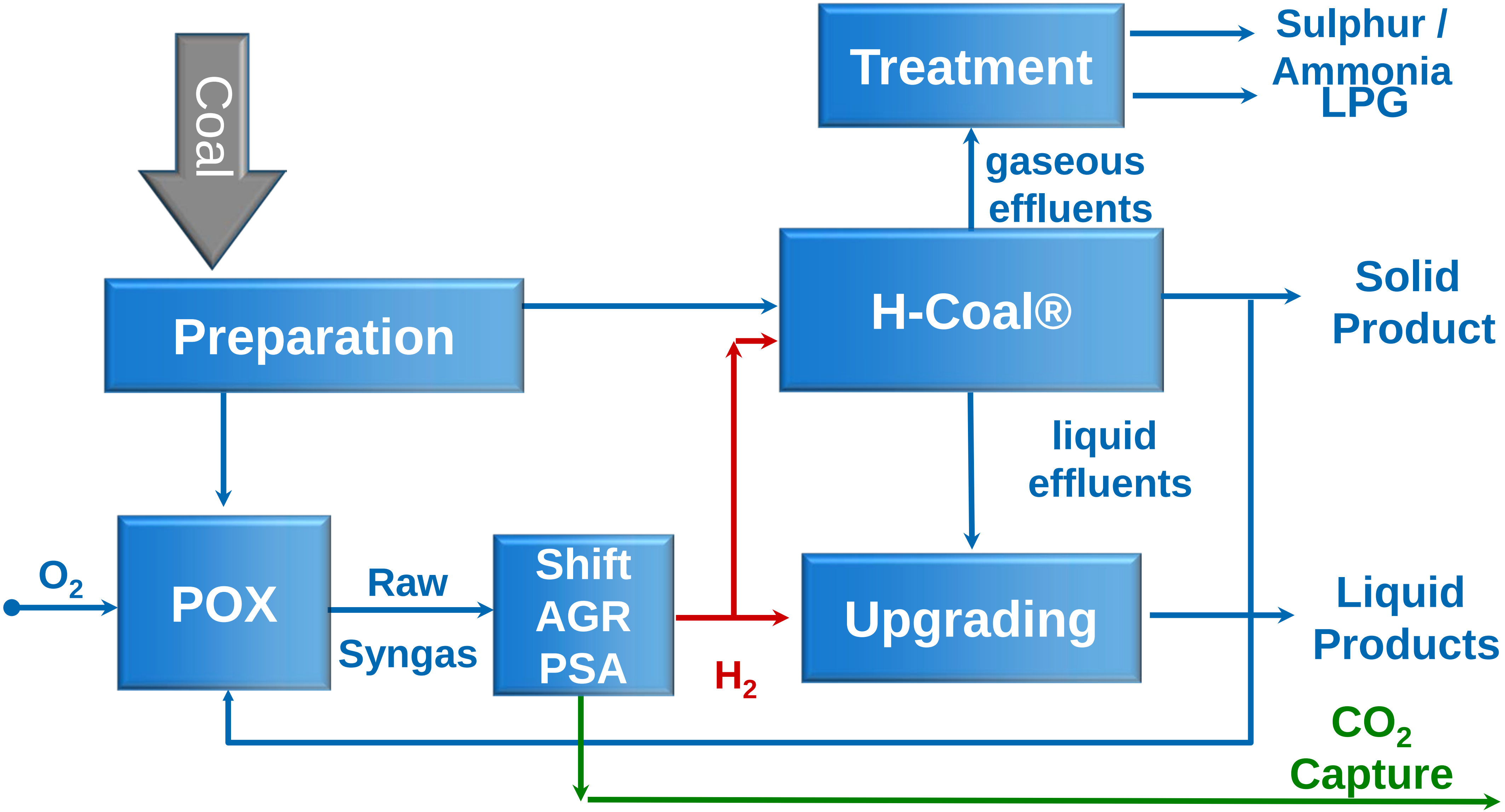
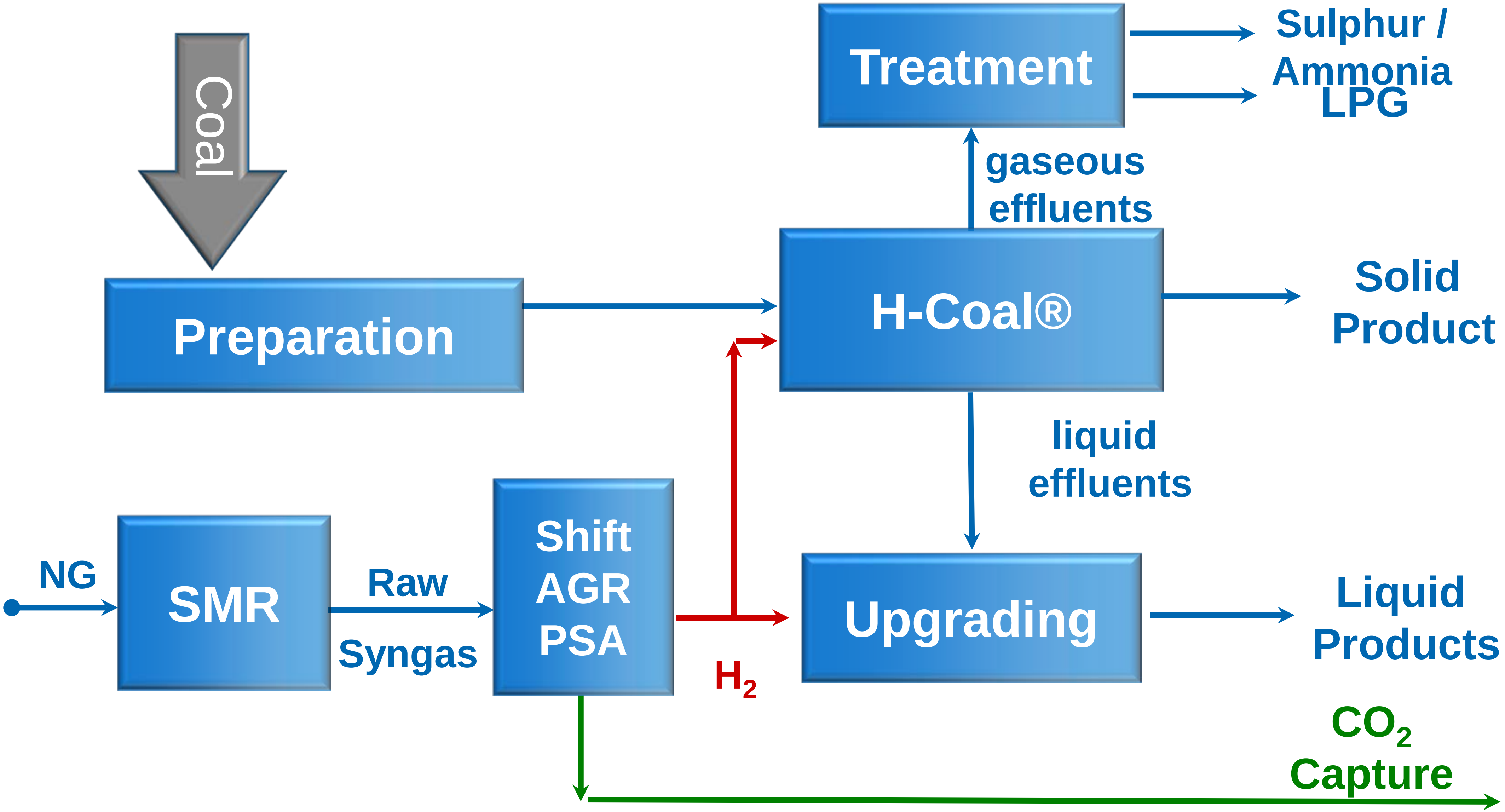
CTL - Liquid Fuels from Coal via H-Coal



CTL/GTL - Liquid Fuels from Coal and Natural Gas via H-Coal



Plant Material Balance

	CTL	CTL/GTL
Coal Feed, MF STPD		
To Liquefaction	8,000	8,000
To Gasification	2,953	-
Total	10,953	8,000
Natural Gas Feed, MMSCFD	-	72.3
Liquids, BPSD		
C3/C4 LPG	2,815	2,815
Gasoline	9,328	9,328
ULSD	15,972	15,972
LSFO	2,819	2,819
Total Liquids	30,934	30,934
Liquids, B/MT of Coal	3.1	4.3
CO2 Emissions lb/Bbl	224	192
Estimated Investment, MM$	4,636	3,118
Estimated Investment, $/BPSD	150,000	101,000

- **CTL Case**
  - 8,000 TPD coal feed to liquefaction…single train plant
  - Finished quality products meeting all ultra low sulfur fuel specifications
- **CTL/GTL Case**
  - Increase yield/ton of coal by 40 %
  - Reduce Investment by 35 %
- **CO2 Emissions (CO2 Capture included)**
  - CTL/GTL reduces CO2 emissions by 15 %
  - For reference Syncrude Canada CO2 emissions in 2012 were reported to be 222 lb/bbl of synthetic crude oil produced from Canadian oil sands

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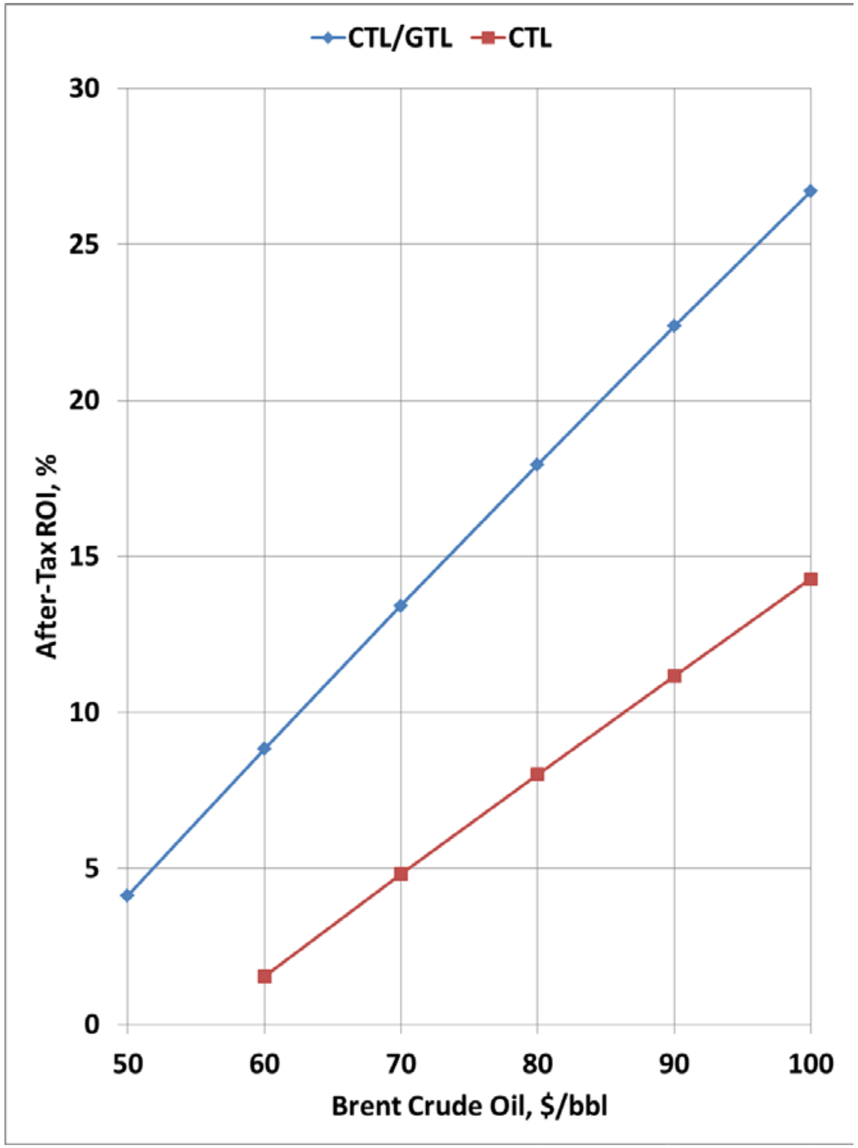
The Technology Synergy

		CTL	CTL/GTL		
Coal Feed to Liquefaction	TPD	8,000	8,000		
Coal Feed to Gasification	TPD	2,953			
Natural Gas	TPD			1,524	
Total	TPD	10,953			9,524
Carbon	W%	71.8	71.8	75.0	72.3
Hydrogen	W%	5.0	5.0	25.0	8.2
Nitrogen	W%	3.2	3.2		2.7
Sulfur	W%	1.4	1.4		1.2
Ash	W%	8.4	8.4		7.0
Oxygen	W%	10.3	10.3		8.6
H/C		0.8	0.8	4.0	1.4

The Economic Synergy



- High sulfur bituminous coal @ $30/T
- Natural gas $2.50/MMBtu @ Henry Hub
  - Discounted by $1/MMBtu for Appalachian location
- CTL/GTL significantly improves returns …mainly from reduced investment
- Economically viable with Brent at $65-75/bbl

Summary/Conclusions

- DCL is fully developed and a commercially deployed technology for production of high quality liquid fuels
- There are significant logistical, technical and economic synergies for use of natural gas in DCL, especially in the US Appalachian area
- With readily available CO2 capture technologies a DCL facility using natural gas has a lower carbon footprint than Canadian oil sands
- Economic returns on investment can be realized with crude oil price of $65-75/bbl

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