Coal Gasification & Co-production of Chemicals & Fuels

Workshop on Gasification Technologies

Indianapolis, IN

June 11-12, 2007

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National Energy Technology Laboratory

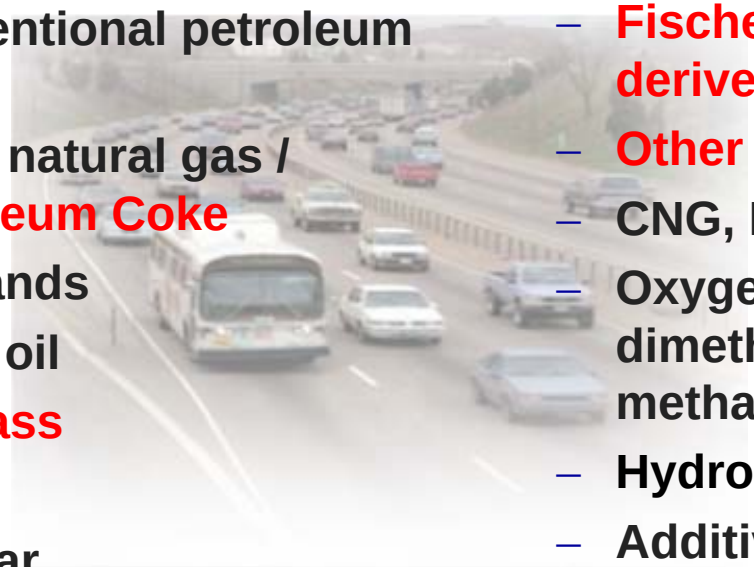
Office of Fossil Energy

Outline

- **Introduction to CTL Technology**
- **Present System Study Work**
  - 10,000 bbl/day feasibility study
  - 50,000 bbl/day baseline study
  - Incremental Impact of CO_2 Compression (in final draft)
- **Future Systems Work**
  - Coal + Biomass to Liquids
  - F-T reactor systems analysis
  - Upgrading/Refining systems analysis

Diverse Resources and Fuel Options Will be Needed to Meet Future Transportation Needs

- **Resources**
  - Conventional petroleum crude
  - Coal / natural gas / Petroleum Coke
  - Tar sands
  - Shale oil
  - Biomass
  - Water
  - Nuclear
  - Other Renewable



- **Fuels/Blendstocks**
  - Petroleum-derived fuels
  - Fischer-Tropsch (F-T)-derived fuels
  - Other coal-derived
  - CNG, LNG
  - Oxygenates, e.g. dimethyl ether (DME), methanol, ethanol
  - Hydrogen
  - Additives, e.g., octane and cetaner improvers
  - Electricity

Coal to Liquids Technologies

Conversion Technologies:

- Direct Liquefaction (Bergius Hydrocracking)
- Indirect (Gasification + Fischer-Tropsch) Liquefaction.

Direct Liquefaction - Dormant in the U.S. but being actively pursued in China. The Shenhua project in Inner Mongolia will bring a full scale single train, 20,000 BPD commercial unit into production in 2008 using Headwaters technology.

Inner Mongolia Coal Liquefaction Plant Schematic, China 2006

Direct Coal Conversion Projects

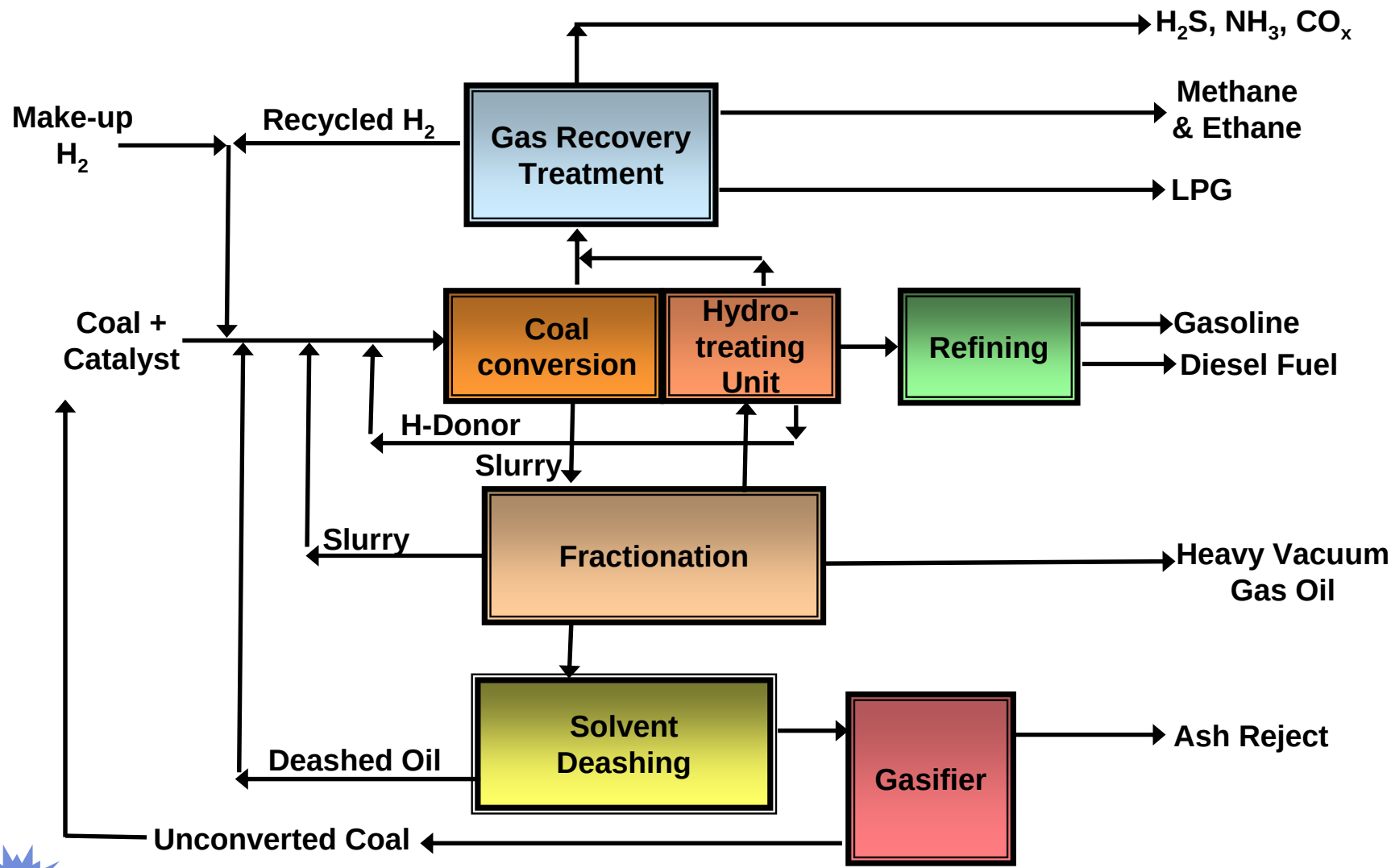
- Originally developed in Germany in 1917
- Used to produce aviation fuel in WWII
- US spent $3.6 billion on DCC from 1975-2000
- Headwaters Technology licensed to China in 2002

Lawrenceville, NJ
3 TPD

Catlettsburg, KY
250 – 600 TPD

Inner Mongolia, China
4,200 TPD

Direct Coal Conversion to Liquid Fuels



Indirect Coal Conversion

- **Originally developed in Germany in 1923**
  (Franz Fischer and Hans Tropsch)
- **Used to produce diesel fuel during WW-II**
- **Currently used to produce liquid fuels and chemicals in South Africa**

Example of Prior Large Scale US-based Facilities

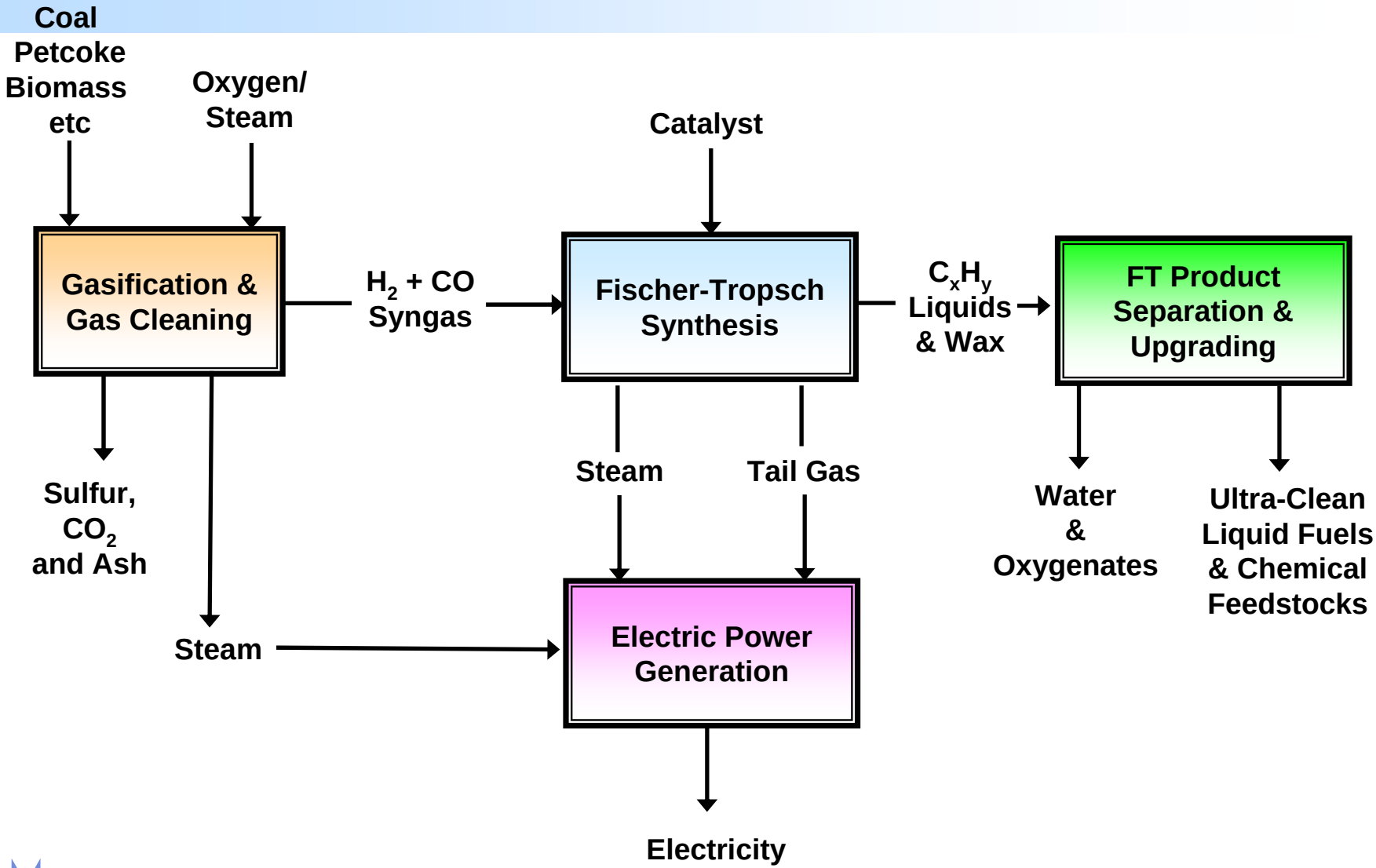
Brownsville, TX
7,000 bpd
GTL Plant

- Designed by HRI (Headwaters predecessor)
- First commercial use of High Temp. FT
- Operated 1950-55
- Shut down when oil price dropped due to Middle East oil discoveries.

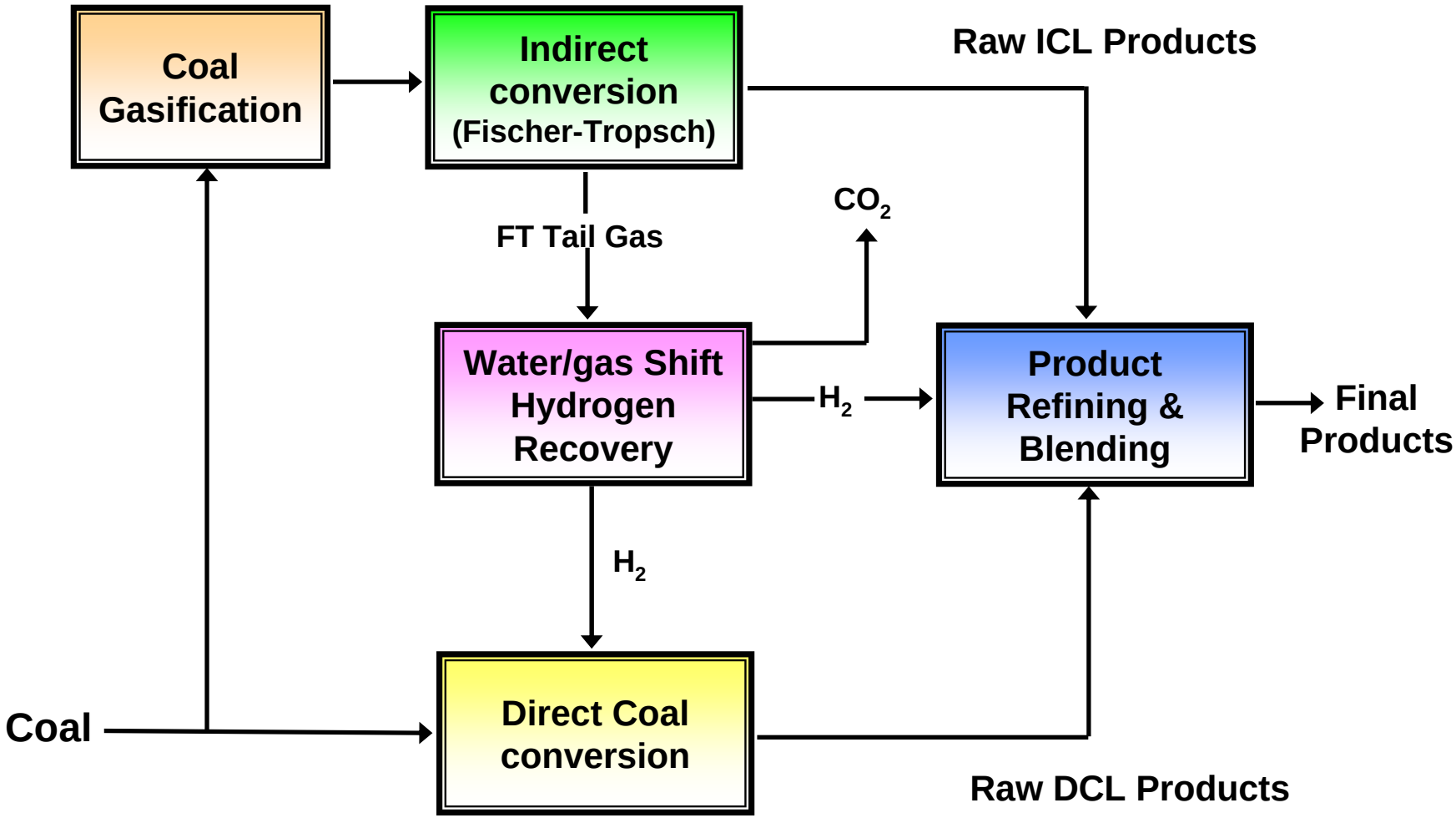
World Large Scale Facilities

Secunda, South Africa
150,000 bpd

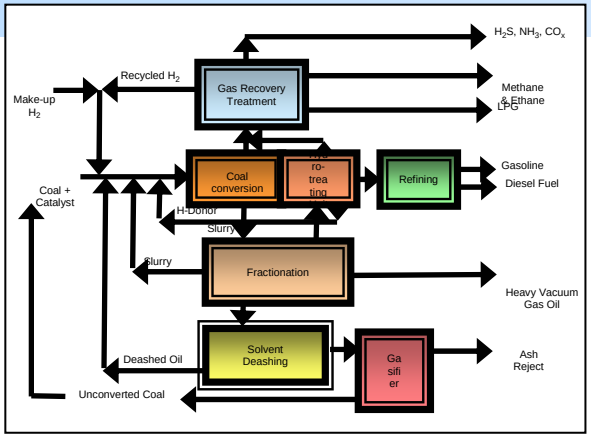
Indirect Coal Conversion



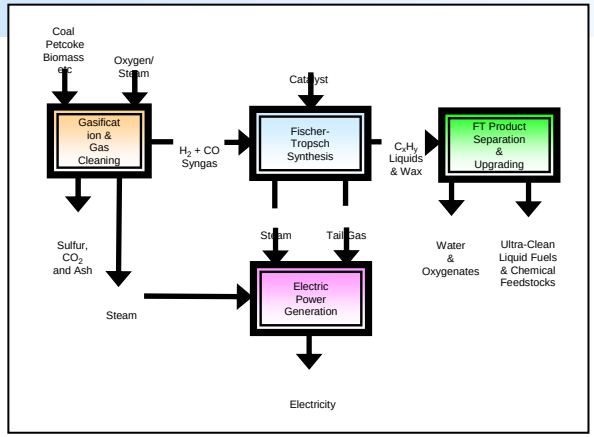
Hybrid Coal Conversion Concept



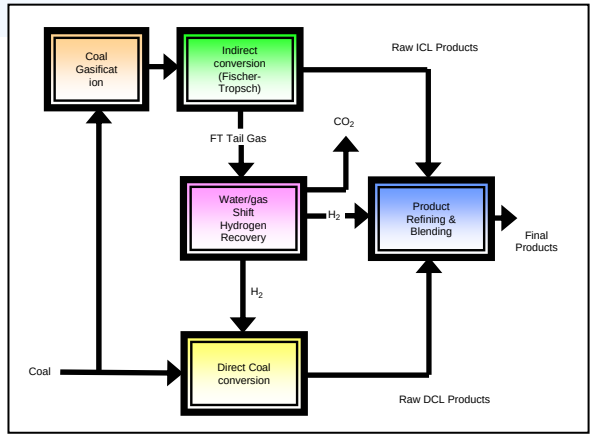
Coal to Liquids Technologies



Direct Liquefaction (Bergius Hydrocracking)



Indirect (Gasification + Fischer-Tropsch)



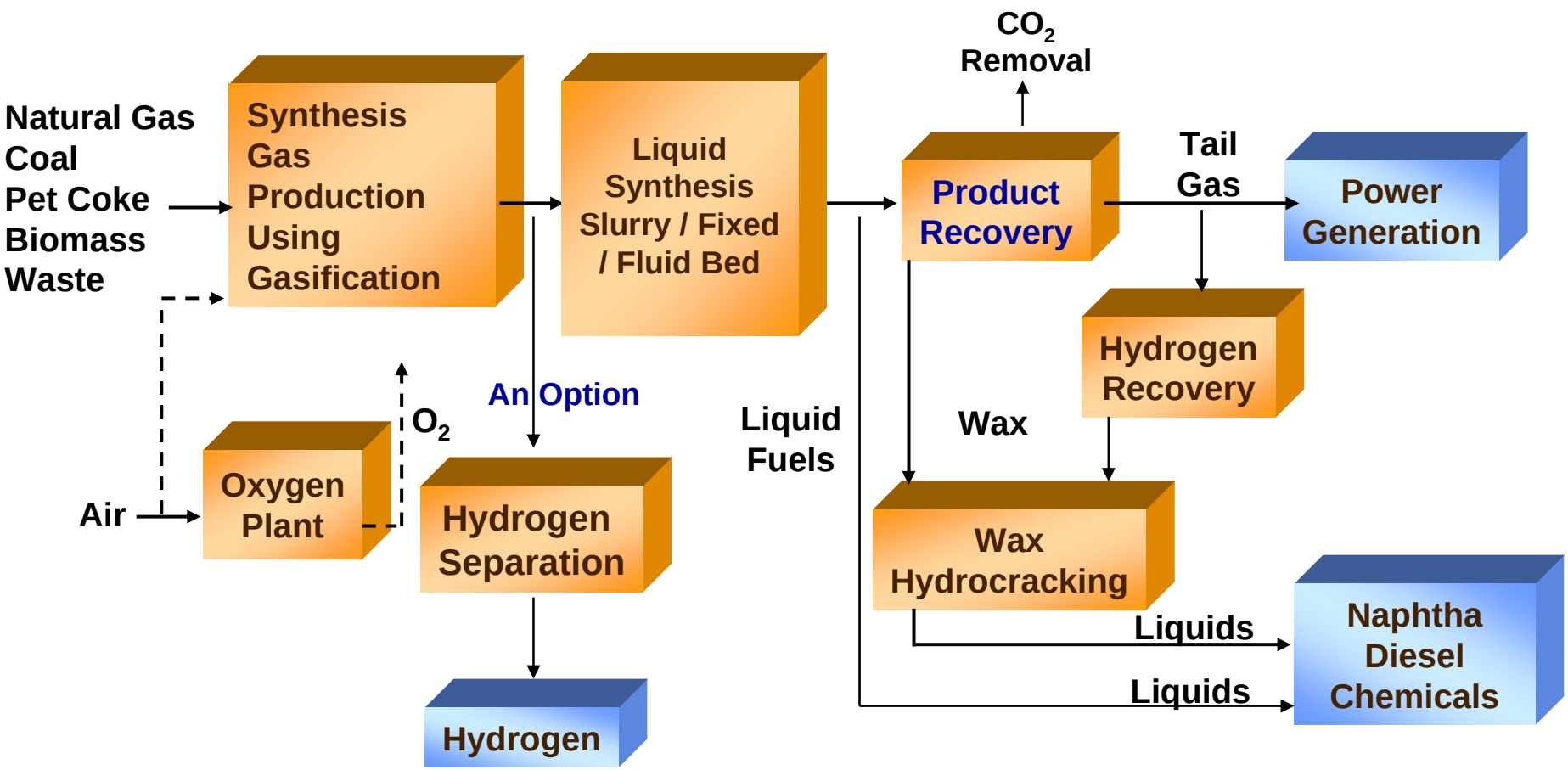
Hybrid Conversion Concept

- Produces high-octane gasoline
- More energy efficient
- Products higher energy density
- Low-cetane diesel
- Water & air emissions issues
- Higher operating expenses

- Ultra-clean diesel products
- Well suited for CO_2 capture
- Well suited for electric power co-production
- More complex
- Less efficient fuel production
- Produces low-octane gasoline
- Fewer BTUs per gallon

- Direct and indirect conversion facility built next to one another.
- Products of the direct and indirect conversion trains complement each other
- Can be blended to produce high quality diesel and gasoline.

Co-Production Technology Overview



Technology Players in the Game

Company	Process	Activities
	**Indirect** iron-based	South Africa, 160,000 bbl/d
	**Direct** iron-based --- **Indirect** iron-based	China, India & Philippines R&D Center Research project w/ DOE
	**Indirect** cobalt-based	Prior large GTL and small-scale CTL; Develop new catalyst
	**Indirect** iron-based	Illinois small-scale fertilizer plant; multiple planned projects in WY(2), MT, IL, WV, OH, MS R&D Center

Existing and Potential CTL Projects

Ref: from Headwaters Inc. J.N. Ward Senate Briefing 1-19-07

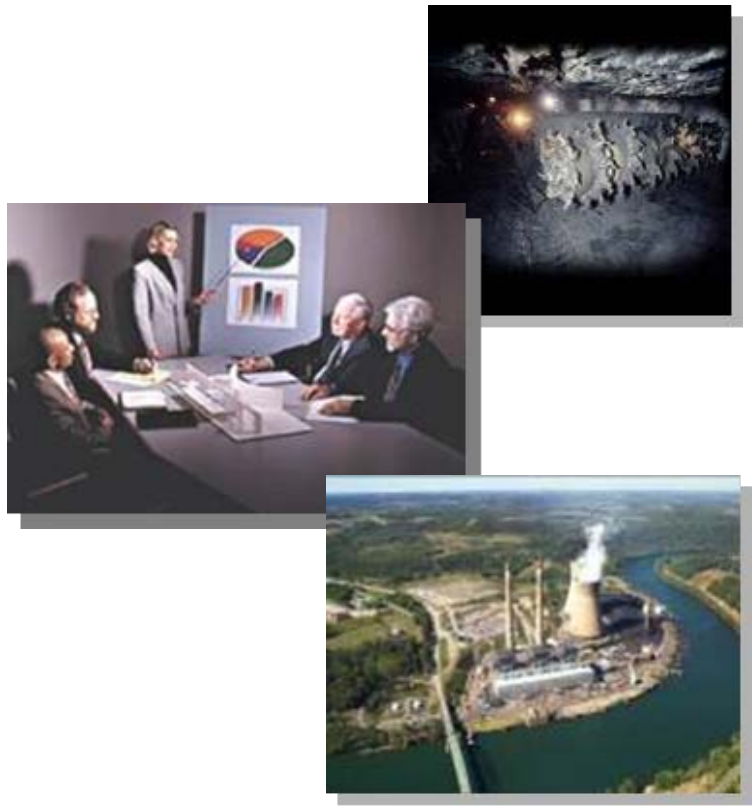
Summary of CTL Projects

Country/State	Owner/Developer	Capacity (bpd)	Status
World-Wide			
South Africa (2)	Sasol	230,000	Operational, new planned
China (7)	Shenhua, Lu'an Group, Yankuang, Sasol JV (2 studies), Shell/Shenhua, Siemens Headwaters/UK (pilot plant)	444,000 (initially)	Construction (3), planned (4)
India, Indonesia, Philippines	Oil India Ltd, Pertamina/Accelon, Headwaters	76,000	Construction (1), planning (2)
Australia / New Zealand	Anglo American/Shell, L&M Group	110,000	Planning (2)
United States			
AZ, OH, IL(3), WV(2)	Headwaters, Rentech, Baard Energy, DKRW, unspecified	Bituminous = 97,000	Engineering (1), Planning
MT(2), ND, WY, LA	DKRW, Montana, Headwaters, Rentech, Synfuels, Inc	Sub-bituminous/lignite = 262,000	Planning
PA and MS	Rentech and WMPI	Coal/petcoke and anthracite = 15,000	Planning

NETL Studies and Systems Analyses

Office of Systems, Analyses and Planning

Employing an Interdisciplinary Approach to Guide R&D and Support Energy Policy Development



Recent Studies Completed

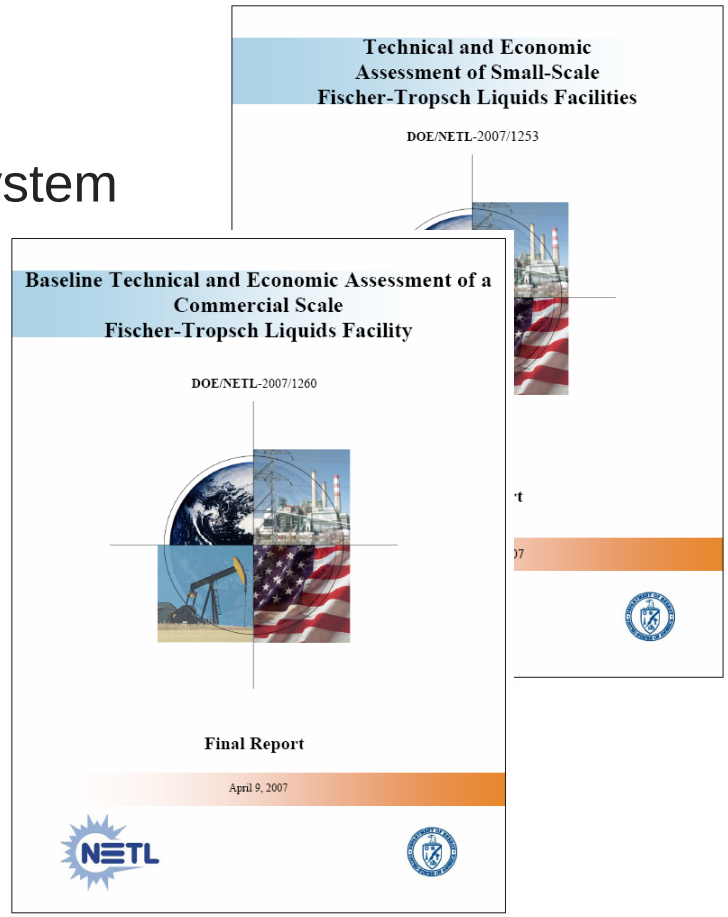
- **NETL Report "Baseline Technical and Economic Assessment of a Fischer-Tropsch Liquids Facility**

  – Small Scale 10,000 bpd facility; Stand-alone and Co-sited with IGCC system

  – Commercial 50,000 bpd facility; Baseline

  – Incremental Impact of CO_2 Compression (in final draft)

★ Represent the first detailed update since 1991



Study Methodology

- Energy and Mass Balance done with Aspen Plus™
- Borrowed from “Cost and Performance Baseline for Fossil Energy Power Plants”
- Capital and Operating cost estimated from bottoms up equipment list and sizing based on heat and material balance
- Financial Performance done with NETL Power Systems Financial Model

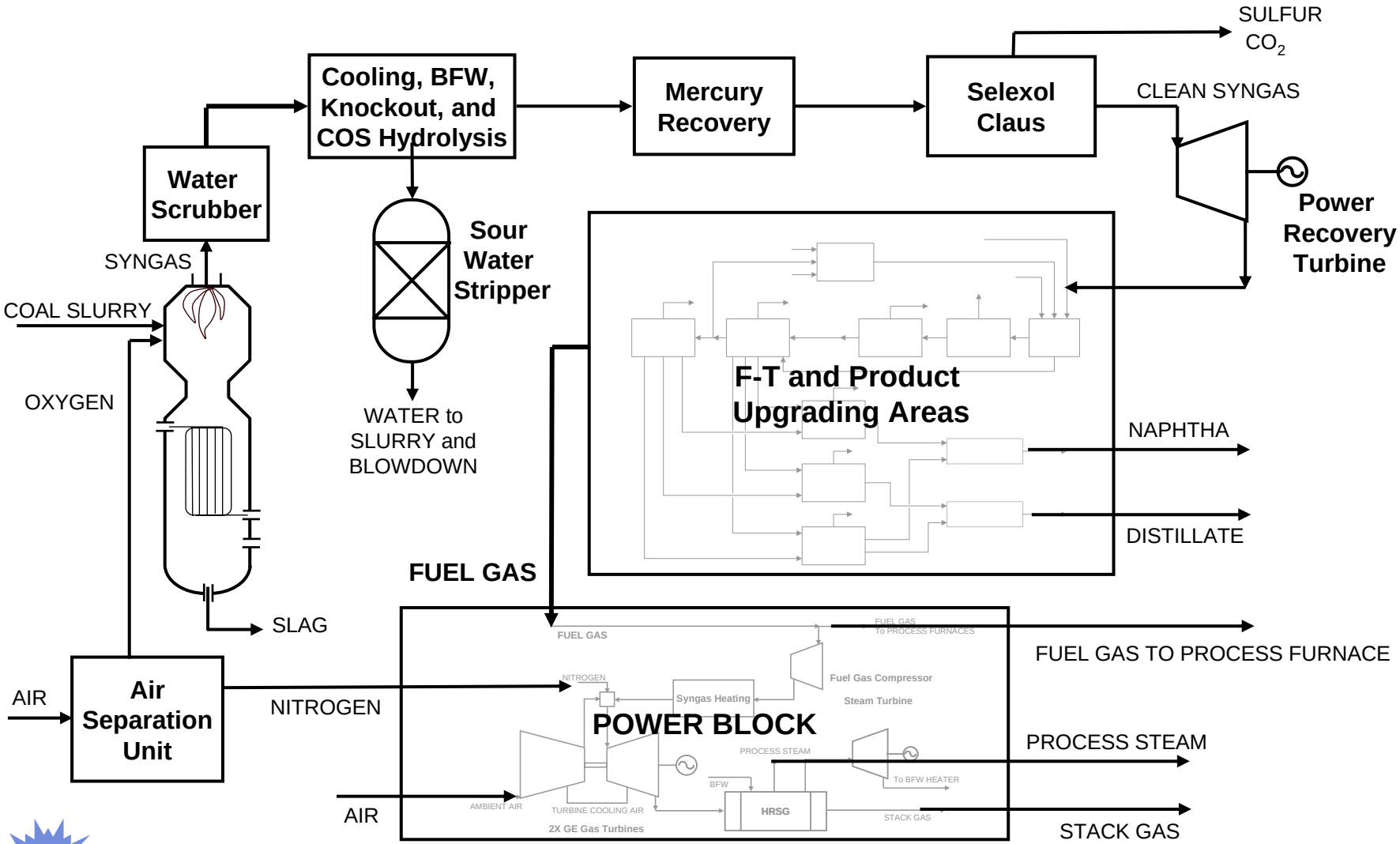
10,000 bbl/day CTL System Specification

- Pittsburgh #8 Bituminous coal
- GE gasifiers oxygen blown
- 3-phase slurry FT reactors w/Iron based catalyst
- Products are a Commercial Grade Diesel and Low Octane Naphtha
- Light end recycle around the FT reactor section
- Produce Parasitic Power with Small Excess Sold to Grid
- No Carbon Compression/Sequestration

50,000 bbl/day CTL Systems Specification

- Illinois #6 Bituminous coal
- E-Gas™ gasifiers
- 3-phase slurry FT reactors w/Iron based catalyst
- Products are a Commercial Grade Diesel and Low Octane Naphtha
- Light end recycle around the FT reactor section
- Produce Parasitic Power with Small Excess Sold to Grid
- Includes Carbon Compression/Sequestration

F-T Plant: Block Flow Diagram



Total Plant Cost

- **Includes**
  - Equipment
    - Initial chemicals and catalyst loadings
  - Materials
  - Labor
    - Direct and Indirect
  - Engineering and Construction Management
  - Project and Process Contingencies

- **Excludes**
  - Owner's costs
    - Land, licensing and permitting, AFUDC
  - Escalation to period of performance
  - Taxes (except payroll)
  - Site specific considerations
  - Labor incentives in excess of 5 day/10 hour work week
  - EPC premiums

Update of CTL Baseline Plant Economics

CTL Plant Size	Coal Feed Rate	Total Plant Costs	Costs per Bbl day	Net Electricity to Grid
Small -- 10,000 bbl /day	4,000 t/d	$800 M	$80,000	40 MW
Large – 50,000 bbl/day	24,500 t/d	$3,650 M	$73,000	120 MW
Required Selling Price range between $41-$60 per bbl dependant on coal type, region, and plant size				

Profile of a Coal-to-Liquids (CTL) Plant

- **Capacity: 10,000 bpd (3.1 million bpy, assume 85% availability)**
  - Naphtha: 4,262 bpd (44%)
  - Diesel: 5,347 bpd (56%)

- **Capital cost: $ 800 million**
- **Coal consumption: 4253 tpd (1.3 million tpy)**
- **NPV of $84.8 million @ 12% discount rate**
- **ROI of 14.3% with WOP of $61/bbl**
- **Land area: nominal 200 acres**

Ref: NETL Report "Technical and Economic Assessment of Small-Scale Fischer-Tropsch Liquids Facilities (February 2007)

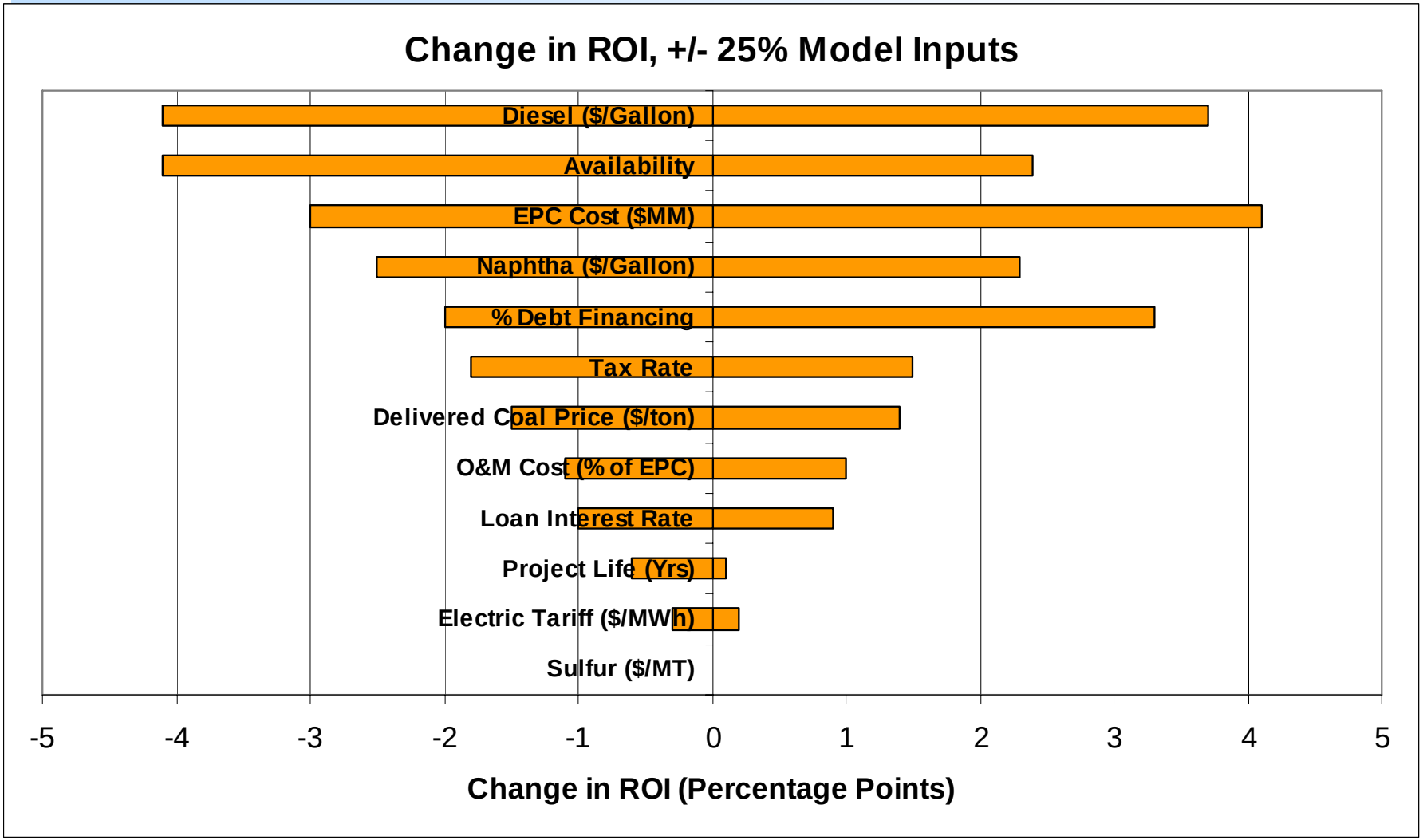
Profile of a Coal-to-Liquids (CTL) Plant

- **Capacity: 50,000 bpd (15.5 million bpy, assume 85% availability)**
  - Naphtha: 22,000 bpd (44%)
  - Diesel: 28,000 bpd (56%)

- **Capital cost: $ 3.65 billion**
- **Coal consumption: 24,500 tpd (7.6 million tpy)**
- **NPV of $1.5 billion @ 12% discount rate**
- **ROI of 19.8% with WOP of $61/bbl**
- **Land area: nominal 500 acres**
- **CO_2 recovery: 13,000 tpd (90%)**

Ref: NETL Report "Baseline Technical and Economic Assessment of a Commercial Scale Fischer-Tropsch Liquids Facility (March 2007)

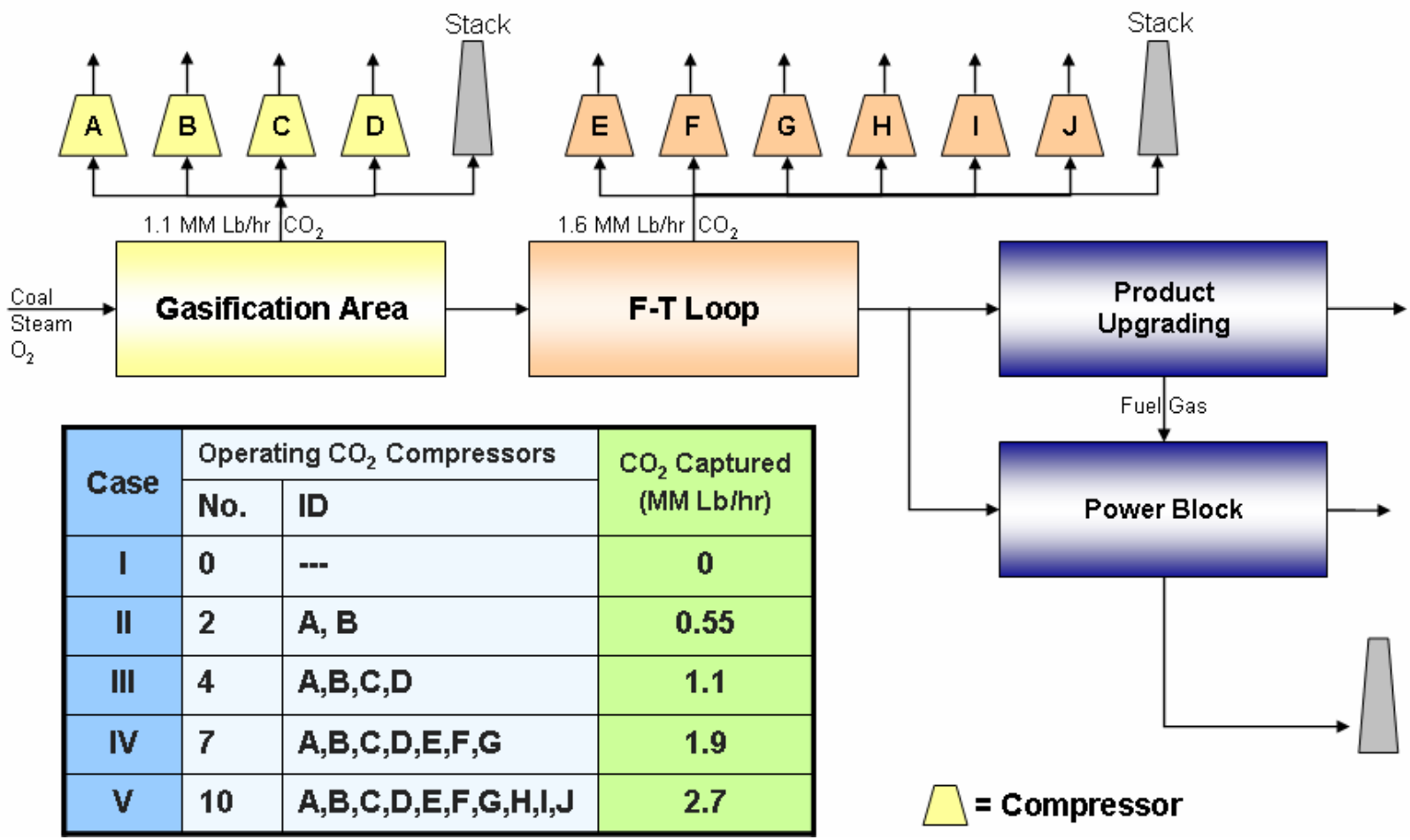
50,000 bbl/day Plant: Sensitivity of CTL ROI



Incremental Impact of CO_2 Compression: Base Plant Description

- Illinois #6 coal
- ConocoPhillips E-Gas™ gasification
- 2-stage Selexol™ acid gas clean-up
- Recycle to Maximize Liquids Production
- 3-phase F-T reactor with Iron catalyst
- Minimal upgrading to produce "syncrude" product
- Combined cycle power production to produce parasitic power with minimum excess

Block Diagram of Cases



Case	Operating CO_2 Compressors		CO_2 Captured (MM Lb/hr)
	No.	ID	
I	0	---	0
II	2	A, B	0.55
III	4	A,B,C,D	1.1
IV	7	A,B,C,D,E,F,G	1.9
V	10	A,B,C,D,E,F,G,H,I,J	2.7

Base Plant Capital Cost

Plant Section	Cost ($ million)
Coal and Slurry Preparation	**295**
Gasifier and Gas Clean-up	**1,989**
F-T Process	**653**
Power Block	**174**
Balance of Plant	**422**
Total Plant Cost (TPC)	**3,534**

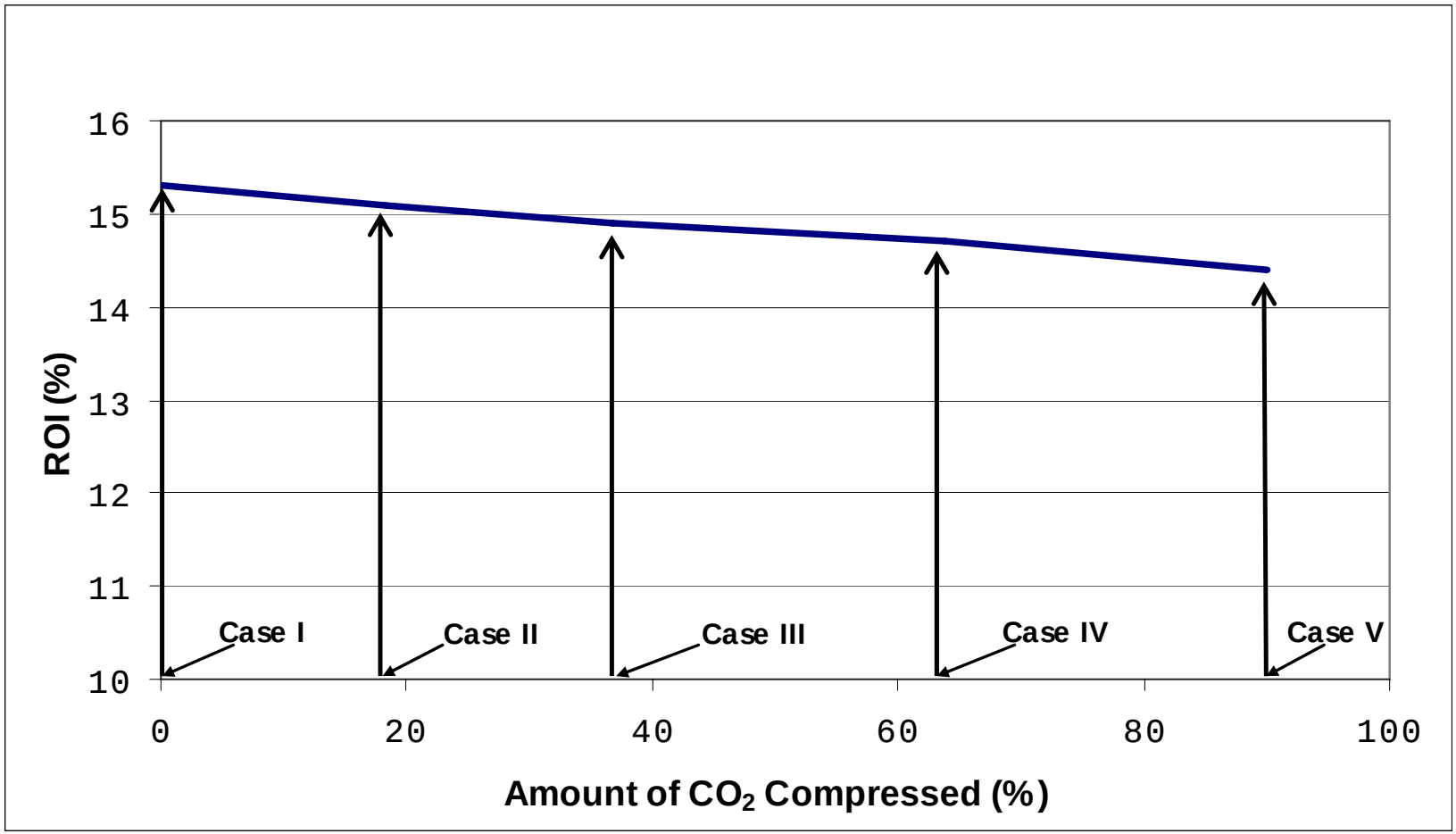
Base Plant Financial Performance

Major Inputs	
EPC Cost ($MM)	2,722
Syncrude Production (BPD)	49,433
Coal Feed Rate (TPD)	24,533
Major Results	
ROI (%)	14.4
NPV ($MM, 12%)	438
Payback Period (Yrs)	8
Crude Oil Price for 12% ROI ($/Bbl)	55

CO_2 Compression – Capital Cost

	CO_2 Compressed		No. of Compressors	Increase in Capital Cost from Case I ($ million)
Case	Lb/hr	STPD		
I	0	0	0	$0
II	551,195	6,614	2	$13.5
III	1,102,390	13,229	4	$27.0
IV	1,901,458	22,817	7	$47.2
V	2,700,525	32,406	10	$67.4

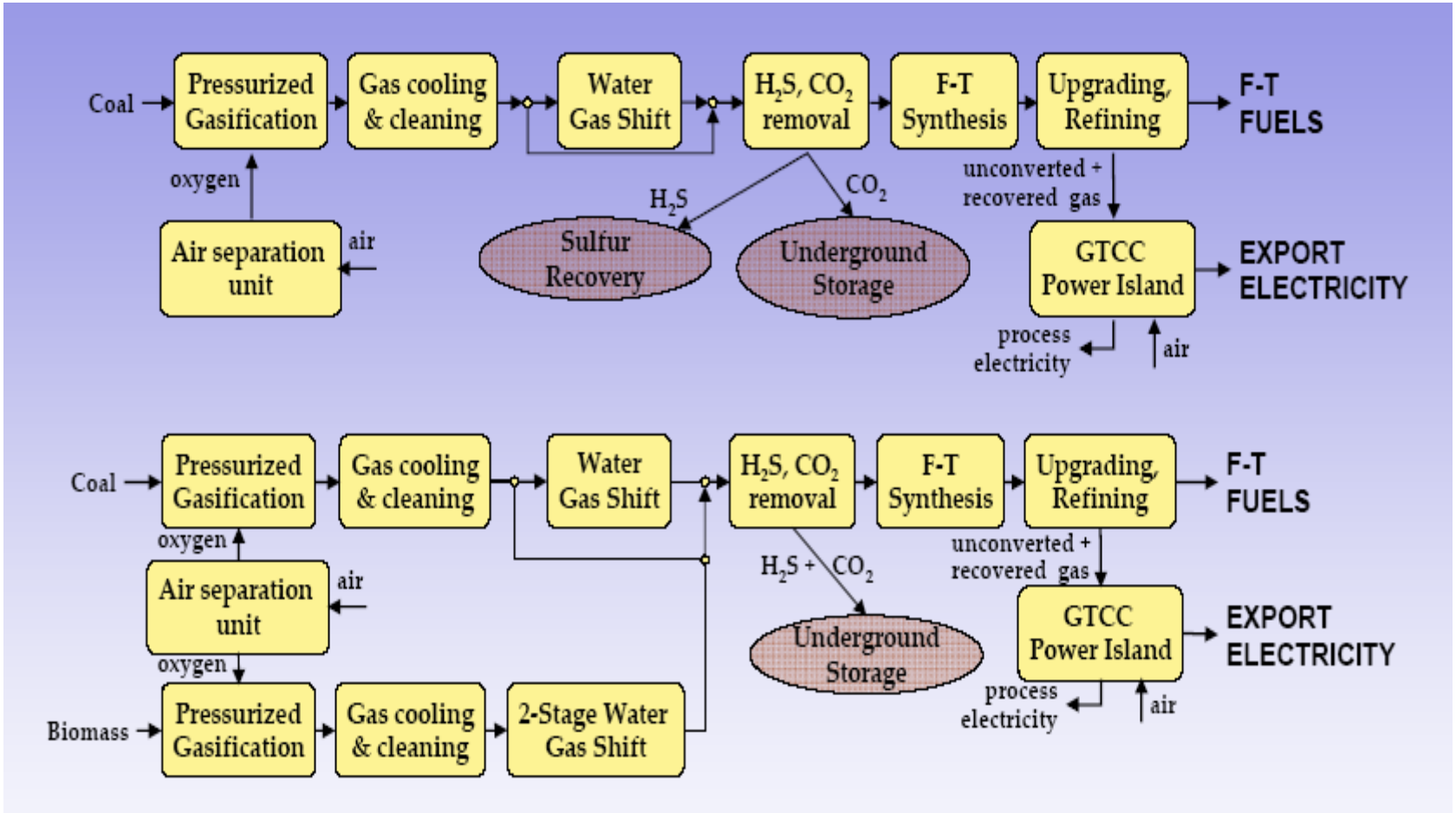
CO_2 Compression – Financial Performance



Future Work

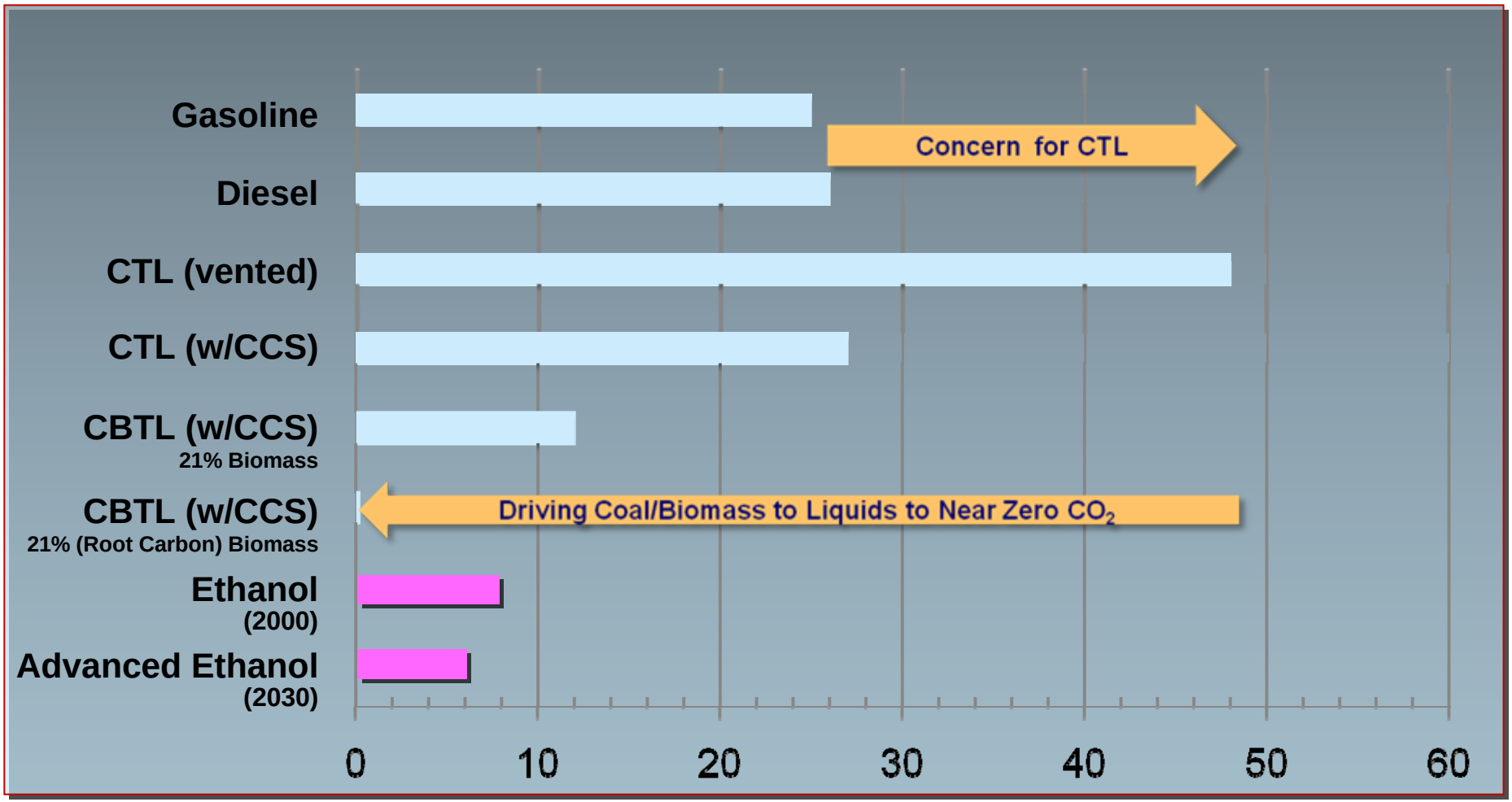
- Coal/Biomass-to-Liquids (CBTL)
- Systems Analysis to Understand FT Reactor Performance
- Information Gathering and Systems Analysis on FT Wax Upgrading Options

Co-Gasification of Coal and Biomass (Switchgrass): An Alternate Approach to Making Diesel Fuel from Biomass



Ref: Alternative Fuels Seminar, Robert Williams CSIS presentation December 2006

Greenhouse Gas Emission Rates For Fuel Production and Use



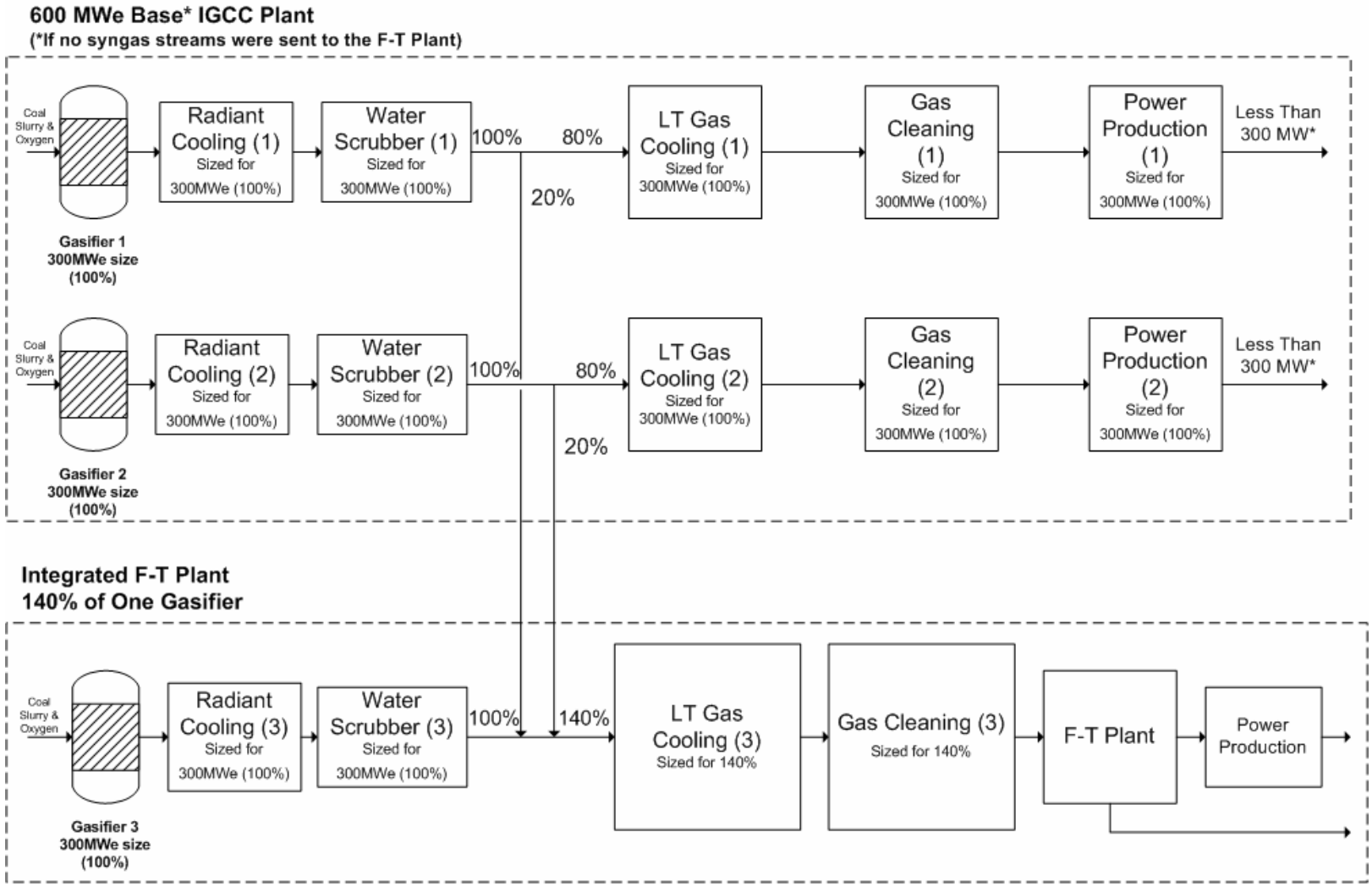
Reference: Princeton Professor Robert Williams, presentation to Lawrence Livermore Lab, January 12, 2007

Challenges

- **Market -- *Volatility poses market risk***
- **Technical – *Integration***
- **Infrastructure – *Growth in all areas***
- **Readiness – *Resources limited***
- **Environmental – *CO_2 concerns***
- **Legal/Policy – Authorities need to define a long term CO_2 liability framework**

Additional Material

600 MW IGCC/F-T Co-Sited



DOE CTL Development Study Results

- **Three thrust plan:**

1. **Facilitate Limited Early Learning Commercial Experience**
   - Support Treasury in Implementation of EPACT 2005
   - Co-Fund Site Specific Design Studies
   - Analyze Incentive Packages Directed at Promoting Early Commercial Experience

2. **Focused (existing) R&D activities:**
   - IGCC integrated with F-T process
   - Cost reduction
   - Improve environmental performance
   - Integrative analyses/modeling
   - International coordination & information exchange

3. **Fuels Formulation & Testing (w/DOD)**

NETL Work with Others

- **Strategic Unconventional Fuels Task Force**

  Oil Shale, Tar Sands, Coal, Heavy Oils, and CO_2 EOR

  - Department of Energy … OPI (Policy) & OFE (Fossil)
  - Department of Defense … Air Force and Navy
  - Department of Interior … BLM
  - Participating States … CO, KY, MS, UT, and WY

- **International Energy Agency – Coal Advisory Board**

- **National Petroleum Council – Global Oil & Gas Study**

Aviation Alternative Fuels Roadmap

Aviation Alternative Fuels Roadmap

- **The commercial sector and government must work together to promote/embrace alternative fuels to secure supply availability, to minimize price volatility, to improve operational and to explore the potential to reduce environmental impact.**

  ….. Adopted 5/24/06 by AIA/ATA/FAA sponsored workshop with DOE, DOD and NASA stakeholders

- **Follow-up meetings to further define Roadmap**

US Domestic Fleet in 2004

887,000+ bbl/day