Coal Conversion & Carbon Product Development at University of Wyoming

RICHARD A. HORNER
DIRECTOR SPECIAL PROJECTS & TECHNOLOGY
SCHOOL OF ENERGY RESOURCES
UNIVERSITY OF WYOMING (UW)
OUTLINE

• USA Coal Outlook

• New Non-energy & Fuel Market Opportunities for Wyoming Coal

• University of Wyoming Carbon Initiative
  - Transforming Wyoming Coal into High Performance Chemicals & Materials
Background – Coal Focus on Non Energy and Fuel Products

….general slowdown in North American energy consumption growth predicted largely through energy efficiency utilization

….coal demand challenge linked to abundant & cheap natural gas supply

Ref: BP Energy Outlook 2035 – Focus on North America, March 2016

© 2016 All rights reserved. Property of the University of Wyoming
Coal Perspective
New Market Opportunities

• Use coal as source for manufacturing non-metals and chemicals
  • Captures value beyond coal’s btu value

• Coal to chemicals plants are being built or planned in:
  • China, Germany & India
    • Generally, chemicals made through the syngas conversion route

• Rising Demand for carbon based chemicals & materials > GDP Growth Projections
  • Light-weighting
  • Substitution for metals (Existing Markets)
  • Superior functional performance of carbon materials over metals
  • New Markets for (carbon) material classes

China's chemical market will soon represent one-third of global demand

China's chemical market value by region and GDP ($ billion)

Notes: ROW is rest of the world. Figures may not resolve due to rounding.
Sources: Datamonitor, A.T. Kearney analysis
The first oil refining process was invented to upgrade “coal oil” more than 150 years ago - before Edwin L. Drake touched off a boom with his discovery of oil in Pennsylvania."
Coal to Non Energy & BTU Products
The possibilities are vast!

Reference: US Geological Survey
Coal Conversion to Non btu & Energy Products
A Mining and Power Industry Transformative Opportunity?

At the Mine

Coal Mine

- Existing Revenue Stream: $+
- New Revenue Stream: $++

Non btu & Fuel Products

At the Coal Fired Utility Plant

Non btu & Fuel Products

- New Revenue Stream: $++

Coal Fired Utility

- Existing Revenue Stream: $+

Carbon Capture

- Existing Revenue Stream: $-

© 2016 All rights reserved. Property of the University of Wyoming
Coal to Products
Technology
Today
Gasification

In gasification, the coal is blown through with oxygen and steam (water vapor), while also being heated (and in some cases pressurized).

Oxygen and water molecules oxidize the coal and produce a gaseous mixture of carbon dioxide ($\text{CO}_2$), carbon monoxide ($\text{CO}$), water vapor ($\text{H}_2\text{O}$), and molecular hydrogen ($\text{H}_2$).

$$3\text{C (i.e., coal)} + \text{O}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2 + 3\text{CO (syngas)}$$

The produced coal gas may also be further refined to produce additional quantities of $\text{H}_2$ if a Fischer-Tropsch reactor is added – undergoing a water gas shift reaction with water vapor

$$\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$$

**Advantage**: You turn coal into a single feedstock i.e. syngas

**Disadvantage**: Converting syngas to chemicals is energy intensive & costly eg compared to direct use of natural gas
In coal liquefaction, the coal is converted to liquids by hydrogen addition.

Typically an Fe catalyst is added to the coal which is often fed as a slurry with a solvent and/or recycled coal-tar added and reacted at between 400 to 500°C; at a hydrogen pressure of around 20 to 70 MPa.

\[ nC + (n + 1)H_2 \rightarrow C_nH_{2n+2} \]

**Advantage**: Multiple Product Yields Possible – Hedge Against crude oil!

**Disadvantage**: Product qualities generally poor, requiring further expensive refining.
The Coal Refinery
Adding Premium Value Beyond Energy Value

Petroleum Refinery (Hydrogen Addition)

Coal Refinery (Carbon Rejection)

Current Product Slate

Petrochemicals
- Olefins
- Acetyls
- Alcohols
- Aromatics
- Asphalt

Coal chemicals
- Gasoline
- Diesel
- Naphtha
- Aromatics
- Base Oil & Lubes

New Carbon Product Solutions

Derivative Coal Products

• Petrochemicals
  1st Order
  - Building materials
  - Paving Materials
  - Needle Coke
  2nd Order
  - Acetyls
  - Alcohols
  - Carbon Fiber
  - Carboxylates
  - Aerogels
  - Graphene

New Carbon Conversion Solutions

Common Product Families

Coal Intermediate Products

Investment in Carbon Engineering
- Deliberate Decomposition of Coal -
State Support: Wyoming Legislators provided a biennium Special Appropriation of $2 million to the School of Energy Resources (SER) at the University of Wyoming – starting August 2016, to pioneer the Carbon Engineering initiative (coal to non-energy products).

Current University of Wyoming Investment in Carbon Engineering Initiative

- Carbon Engineering Legislative Appropriation $1.5 million
- SER Legislative Appropriation (Non carbon Engineering) $0.6 million
- Discretionary Funds (SER Non-Legislative Appropriated) $0.6 million

TOTAL Expended Funds to July 2016 $2.7 million
Integration of multiple technologies to make high-volume products with low energy consumption & CO2 emissions

Manufacturing Approach:
- Multiple Feedstocks
- 2 stage Recovery
  - Solvent extraction platform
- High solid Product Yield
- Low-cost direct hydrocarbon recovery
- Low-cost syngas for chemicals

LOW TEMPERATURE
Primary Processing
- Biomass?
- Coal

HIGH TEMPERATURE
Secondary Processing
- Lime

Hydrocarbon Solvent Extraction

Hydrothermal (supercritical H2O / CO2 extraction)

Calcine

Carbidization

Syngas

CaC2 (to acetylene)

Soil Amendments

Construction Materials

Low Ash Coke

HC Liquids
- Aromatics
- Poly-cyclics
- Asphaltenes

Dry Methane Reforming

Extraction

Phenol

Syngas

NH3, S

CO2

Mixed-Gas

NatGas
Manufacturing Approach
- 2 stage Recovery
  - Hydro-pyrolysis platform
- High liquid Yield
- Indirect hydro-carbon recovery
- Low-cost syngas for chemicals

Integration of multiple technologies to make high-volume products with low energy consumption & CO₂ emissions

Gas Clean-Up
- NH₃, S
- CO₂
- Methane
- Ethane
- Propane

Dry Methane Reforming
- CO₂

Flash Pyrolysis & Fractionation
- Mixed Gas

Gas Clean-Up
- CH₄
- C₂
- C₃

Hydrocarbon Extraction
- C₆ to C₁₀ Aromatics

Trans-alkylation Hydro Treatment
- Benzene
- Xylenes
- Paraxylenes
- Polyethylene Terephthalate (PET)

Heavy Liquids
- Resins (Pitch, tars), fibers and surfactants
- Asphaltenes (asphalts, fibers, cokes)

Light Liquids
- Syngas conversion to methanol and/or, Ethylene Glycol

Very heavy Liquids
- Phenol

Char
- Lime
- Methane / H₂

Coal

Carbidization
- CaC₂ (to acetylene)
Objective: Establish economic and technical feasibility of a coal refinery

- Market Analysis and Systems Engineering Ongoing - provides project direction

- 15 Research and Development Projects seed funded
  - Converting Wyoming coal to intermediate liquids and solids
    - solvent & liquid extraction methods
    - co-processing Wyoming coal and biomass
    - super-critical coal processing
    - solid (carbide) products from coal – high temperature route
    - Gas to Liquids Treatment (CO₂, CO and CH₄)

- Recovering Valuable Products
  - Primary Intermediate Products
    - Rare earth elements
    - Construction and ‘green’ building materials
    - Agricultural Supplements
    - Paving and road materials

- Conversion Derivative Products
  - Carbon based fibre & engineered composites
  - Nano-carbon products
  - Graphene and graphitic products
  - Coatings and paints
  - Ceramic carbide & magnetic materials
Concluding Remarks

- Some possible focuses (for on-purpose manufacturing) already identified with local market pull.
  - Energy Performance Chemicals & Surfactants
  - Carbon-based Composite Materials
  - Agricultural, Construction & Building Materials

- Need to identify location, scale & scope of Wyoming Based Coal Refinery
  - More Than 1 Perceived
Thank You