Ammonia From Coal

Daniel Tse
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A Changing World …

- Growing population & energy density
- Fuel sourcing complexity
- Increasing environmental requirements
- Escalating security concerns
- Technology & talent globalization
- Heightened investor demands

Everyone under pressure
Traditional Ammonia Manufacturing
Natural Gas based manufacturing

Natural Gas → Gas Cleanup → SMR → Shift → Ammonia Synthesis

Nitrogen
Natural Gas Challenges

Clean Air Act
- Many gas turbines installed as clean power generation

LNG
- Intense NIMBY opposition to LNG terminals
- Increases foreign energy dependency

Canadian Oil Sands
- Reduces or eliminates WCSB natural gas exports from Canada
Projected Natural Gas, N. America Dry Productive Capacity, Henry Hub Pricing

Source: Cambridge Energy Research Associates
60303-10

Source: Cambridge Energy Research Associates
60303-11
The solution: Ammonia from coal
Coal based manufacturing

Air → ASU → Nitrogen

Coal → Gasification → Shift → Gas Cleanup → Ammonia Synthesis
Why Coal?

- High/volatile natural gas prices
- Availability of natural gas/LNG
- Global Recoverable Reserves
  - Oil 40 yrs, NG 70 yrs, Coal 192 yrs
- Need for fuel diversity
GE’s Gasification Technology

Potential feedstocks:
- Coal
- Heavy oil
- Petroleum coke
- Asphalt
- Orimulsion
- Natural gas
- Other low-value streams

Gasifier: quench or heat recovery options available

Oxygen

Syngas

Marketable Byproduct: Slag

Sulfur removal/Future CO₂ capture for enhanced oil recovery or sequestration

Potential end products:
- Power
- Hydrogen
- Steam
- Ammonia
- Chemicals
- Methanol
- Fischer-Tropsch Liquids (zero sulfur diesel)
Feeds (GE’s Commercial Experience)

Gas
- Natural Gas
- Refinery Off Gas

Solids
- Petroleum Coke
- Coal

Liquids
- Crude Oil
- Fuel Oil/Heavy Fuel Oil
- Naphtha
- Vacuum Residue
- Asphalt/Deasphalter Residue
- Visbreaker Tar
- Steam Cracked Tar
Gasification makes Syngas

Feed
- Hydrocarbon
- Oxygen
- Water

Syngas
- Hydrogen
- Carbon Monoxide
- Energy
Simplified Chemistry

\[4 \text{ CH} + 2 \text{ H}_2\text{O} + \text{ O}_2 \rightarrow 4 \text{ H}_2 + 4 \text{ CO}\]

Coal + Water + Oxygen \rightarrow Hydrogen + Carbon Monoxide
Gasification – Multiple Cleaner Coal Solutions

- **Syngas**
  - (H₂ + CO)
  - **Gasification Technology**

- **Power (IGCC)**
  - Greenfield
  - Polygen
  - Refueling
  - Site Repowering

- **Refineries**
  - Hydrogen
  - Steam
  - Power

- **Chemicals**
  - Methanol
  - Formaldehyde
  - MTBE
  - Acetic acid
  - Amine
  - DME
  - Ammonia
  - Urea
  - Ammonia nitrate/sulfate
  - Oxochemicals: Butanol, Ethylhexanol

- **Coal to Liquids**
  - Cleaner Diesel
GE’s Gasification Technology

- Developed in the 1940’s by Texaco
- Commercialized in the 1950’s
- Entrained flow
- Oxygen blown
- Top down
- High pressure
- Short residence time
Two Configurations for Coal/Petroleum Coke

- Quench
- Radiant Syngas Cooler (RSC)
Quench Configuration

- Hot syngas immediately quenched by direct water contact
- Allows pressures up to 1,250 psi
- Lower capital cost
- Lower thermal efficiency
- Shorter construction cycles
- Syngas is warm and saturated with water which is perfect for subsequent shifting
- Proven gasifier sizes up to 900 ft³
RSC Configuration

- Hot syngas first cooled by generating steam before quenching
- Limits pressures to ~650 psi
- Higher capital cost
- Higher thermal efficiency
- Lower $/kW in power applications
- High pressure steam to 2,000 psi
- Longer construction cycles
- Proven in 1,800 ft³ size
Sour Water Gas Shift Reaction

GE's syngas has higher hydrogen/carbon monoxide ratio than other gasification technologies making it ideal for applications requiring water gas shift reactions.

\[
\text{CO} + \text{H}_2\text{O} \rightarrow \text{H}_2 + \text{CO}_2
\]
Why Not Consider Gasification?

- Established technologies
- Fuel flexibility
- Addresses environmental issues
The solution is not new
## GE Energy Feed and Product Matrix

<table>
<thead>
<tr>
<th></th>
<th>Gas</th>
<th>Liquids</th>
<th>Solids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fischer-Tropsch</td>
<td>1950</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>1953</td>
<td>1956</td>
<td>1988</td>
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<tr>
<td>Chemicals</td>
<td>1957</td>
<td>1961</td>
<td>1982</td>
</tr>
<tr>
<td>Power</td>
<td>-</td>
<td>2000</td>
<td>1984</td>
</tr>
<tr>
<td>Quench</td>
<td>1953</td>
<td>1956</td>
<td>1982</td>
</tr>
<tr>
<td>Syngas Cooling</td>
<td>1950</td>
<td>1959</td>
<td>1984</td>
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</table>
Decades of Experience

Current/Future Operating Gasification Plants
Startup Dates


Montebello Test Facility Operations

1946

120MW IGCC
Technical Demo
Cool Water

250MW IGCC
Commercial Demo
TECO/Polk Power

Experience with Coal

>3 GW GE IGCC Experience

1,132 760 1,120 (MWs)

Syngas Power Syngas & Power

Experience

Pilot Demo Commercial

900sTPD (China) Coal to Ammonia / Urea
Huainan

2000sTPD / 250MW (USA) Coal to Power
TECO/Polk

1650sTPD (China) Coal to Ammonia / Urea
Weihe

1800sTPD (China) Coal to Town Gas / Methanol
Shanghai

550sTPD (China) Coal to Ammonia
Lunan

800sTPD (W. German) Coal to Oxo-chem/H2
SAR

1650sTPD (Japan) Coal and Petroleum Coke to Ammonia
UBE

Cool Water

1000sTPD / 120MW (USA) Coal to Power

1100sTPD (USA) Coal to Methanol / Acetic Anhydride
Eastman

190sTPD (USA) Coal to Ammonia
TVA

165sTPD (W. German) Coal to Oxo-chemicals
RAG/RCH

25sTPD plant at Montebello USA research lab

GE Gasification & IGCC Experience Leadership

- Gasification leader since 1948 with 62 facilities operating worldwide
- First coal gasification plant in 1978
- 21 gas turbines operating on synthesis gas, 900,000 operating hours
- IGCC leader: >3 GW with GE technologies
- >6 centuries team gasification experience
GE’s Solids Gasification Technology

- Developed in the 1970’s
- Commercialized in the 1980’s
- Coal/Water slurry
- Pump fed
- Fluxant for petroleum coke
- Lockhopper for coarse slag removal
- Syngas train identical to heavy oil gasification
GE’s Gasification Coal and Petroleum Coke Plants - USA

2010

2000

2010

1983

2011

1996

Petroleum Coke

Coal

Pet. Coke/Coal Blend
GE’s Gasification Coal and Petroleum Coke Plants – Rest of World
GE Gasification Technology Ammonia Experience

Plants

<table>
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<tr>
<th>History</th>
<th>Today</th>
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<tbody>
<tr>
<td>54 built</td>
<td>16 commercial operation</td>
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<tr>
<td></td>
<td>2 engineering/construction</td>
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</table>

Gasifier Vessels

<table>
<thead>
<tr>
<th>History</th>
<th>Today</th>
</tr>
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<tbody>
<tr>
<td>138 built</td>
<td>36 commercial operation</td>
</tr>
<tr>
<td></td>
<td>5 engineering/construction</td>
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Coffeyville Resources Nitrogen Fertilizers LLC
Operating Since 2000
Gasifies Petroleum Coke
Produces Hydrogen for Ammonia
Captures Carbon Dioxide for Urea
Our commitment to gasification
GE’s Corporate Commitment to Gasification

- GE’s 2005/6 Annual Reports
- ecomagination™
- Significant media presence
- Jeff Immelt global city tours
- National TV commercial
Investing for Success

Step Increases in Product Development

<table>
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<tr>
<th>Year</th>
<th>Avg/yr '01-'04</th>
<th>'05</th>
<th>'06</th>
<th>'07</th>
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<tr>
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<td>10*$Y</td>
<td>20*$Y</td>
<td>30*$Y (est.)</td>
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</table>

- **Gasification Technology**
- **Power Generation Technology**
- **Advanced Technologies**

- **Technology**
- **Power Generation**
- **Advanced Technologies**

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Staffing

- **June-04**
- **Dec-05**
- **Dec-06**

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Image credits: GE Imagination at Work
GE and BP Signed HOA To Accelerate Use of Low Carbon Power Generation

Hydrogen Power Projects
- Utilize advantaged fossil fuels (coal, petcoke)
- Produce high H2 fuel gas to burn in gas turbines
- Capture CO₂ (~90%)
- Utilize CO₂ for Enhanced Oil Recovery (EOR)
- Future storage in Saline Aquifers

Value Through Collaboration
- Combine technology company with an operations company
- Leaders in gasification, power and CCS
- 10 – 15 projects over next decade
- Carson, CA is first gasification project
Leveraging The “Bigger GE”

Global Technology Team

Houston, TX – Process & Product Design & IGCC Experience
Niskayuna, NY – Materials, Design, System Analysis
Shanghai, China – Materials, Chemistry, Instrumentation
Schenectady, NY/ Salem, VA – Controls, Simulation
Bangalore, India – Computational, Experimental
Greenville, SC – Design, Adv Materials & Manufacturing
Irvine, CA – Gasification Modeling & Experimental Experts

300 Engineers & Scientists
Business Model

Screening
- Screening Study (Optional)
- Block Level Detail
- ±30% Factored Cost Estimate

Feasibility
- Paid Feasibility Study (Optional)
- Major Equipment Level Detail
- ±20% Cost Estimate (by Owners Engineer)

FEED
- Process Design Package
- Preliminary Engineering Detail
- ±10% Detailed Cost Estimate (by EPC)

EPC
- Technical Services
- Critical Equipment Supply

Operations
- Startup Support
- Technical Services
- Users Conferences
Why Gasification Makes Sense

• Proven technology - commercial operation today
• Fuel flexibility – lower cost fuels than natural gas
• Energy security – domestic coal supplies
• Public acceptance – competitive cleaner coal alternative
Ammonia From Coal

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