Multi product generation from Coal via gasification/catalytic gasification
Outline

• Introduction
• Coal Gasification
• Coal Liquefaction Technologies
• Multiproduct Generation
  • Syngas Cleaning & Conditioning
  • Fischer-Tropsch Synthesis
  • SNG
  • Methanol
  • DME
  • Ammonia
• Directional Economics
• Challenges & Opportunities
Future Energy Scenario - India

(a) Growth Vs Energy Demand Trend

(b) Energy Demand and Supply

India Imports –
78% of its oil,
35% of its gas, &
even 34% of Coal

International Oil & Gas Price, Shortage of Resources are bottlenecks for India’s Economic Growth

Source: India: Towards Energy Independence 2030

Fossil Resource Starving

Source: ExxonMobil 2014 Outlook for Energy
Gasification Feedstock

- Coal is at the leading position
- Planned 48 new plants; 93 gasifiers, 40 are coal based
- Plants under construction are mostly coal fired
- Planned addition of about 40,000MWth 7%- are coal fed and 30% are based on Petcoke

**Feedstock**

<table>
<thead>
<tr>
<th>Feedstock</th>
<th>Operating 2010</th>
<th>Under Construction 2010</th>
<th>Planned 2011-2016</th>
<th>Totals</th>
</tr>
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<tbody>
<tr>
<td><strong>Coal</strong></td>
<td>36,315</td>
<td>10,857</td>
<td>28,376</td>
<td>75,548</td>
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<tr>
<td>Syngas Capacity (MWth)</td>
<td>53</td>
<td>17</td>
<td>58</td>
<td>276</td>
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<tr>
<td>Gasifiers</td>
<td>201</td>
<td></td>
<td></td>
<td>276</td>
</tr>
<tr>
<td>Plants</td>
<td>53</td>
<td>17</td>
<td>58</td>
<td>276</td>
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<tr>
<td><strong>Petroleum</strong></td>
<td>17,938</td>
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<td>17,938</td>
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<td>Syngas Capacity (MWth)</td>
<td>138</td>
<td></td>
<td></td>
<td>138</td>
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<tr>
<td>Gasifiers</td>
<td>138</td>
<td></td>
<td></td>
<td>138</td>
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<tr>
<td>Plants</td>
<td>56</td>
<td></td>
<td></td>
<td>56</td>
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<tr>
<td><strong>Gas</strong></td>
<td>15,281</td>
<td></td>
<td>15,281</td>
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<td>Syngas Capacity (MWth)</td>
<td>59</td>
<td></td>
<td></td>
<td>59</td>
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<tr>
<td>Gasifiers</td>
<td>59</td>
<td></td>
<td></td>
<td>59</td>
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<tr>
<td>Plants</td>
<td>23</td>
<td></td>
<td></td>
<td>23</td>
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<td><strong>Petcoke</strong></td>
<td>511</td>
<td>12,027</td>
<td>12,938</td>
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<td>Syngas Capacity (MWth)</td>
<td>5</td>
<td>16</td>
<td>21</td>
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<tr>
<td>Gasifiers</td>
<td>5</td>
<td>16</td>
<td>21</td>
<td></td>
</tr>
<tr>
<td>Plants</td>
<td>3</td>
<td>6</td>
<td>9</td>
<td></td>
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<tr>
<td><strong>Biomass/Waste</strong></td>
<td>373</td>
<td>29</td>
<td>402</td>
<td></td>
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<td>Syngas Capacity (MWth)</td>
<td>9</td>
<td>2</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Gasifiers</td>
<td>9</td>
<td>2</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td>Plants</td>
<td>9</td>
<td>2</td>
<td>11</td>
<td></td>
</tr>
<tr>
<td><strong>Total Syngas Capacity (MWth)</strong></td>
<td>70,817</td>
<td>10,857</td>
<td>40,432</td>
<td>122,106</td>
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<tr>
<td>Total Gasifiers</td>
<td>412</td>
<td>17</td>
<td>76</td>
<td>505</td>
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<tr>
<td>Total Plants</td>
<td>144</td>
<td>11</td>
<td>37</td>
<td>192</td>
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</table>
End Destination of Syngas

- Chemicals leading position
- Plants under operation and construction are based on Shell technology
- Once planned capacities are added a larger proportion of plants will be sourced from GE
China Gasification - Applications

China: Product-wise distribution of "Coal" Based Plants

- No. Of Plants
  - Total no. of Coal based plants: 107
  - Methanol: 32%
  - Ammonia: 11%
  - SNH: 3%
  - Chemicals: 2%
  - Hydrogen: 2%
  - FT-Liquid: 1%

- Amount of Coal Gasified
  - Total Coal Gasified: 2,40,793 TPD
  - Methanol: 21%
  - Ammonia: 62%
  - SNH: 1%
  - Chemicals: 3%
  - Hydrogen: 4%
  - FT-Liquid: 8%
## China Coal Gasification Projects - Trend


<table>
<thead>
<tr>
<th>End Product</th>
<th>Number</th>
<th>Coal Consumed (TPD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>3</td>
<td>8,250</td>
</tr>
<tr>
<td>Electricity</td>
<td>1</td>
<td>3,690</td>
</tr>
<tr>
<td>FT- Liquid</td>
<td>4</td>
<td>51,200</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>2</td>
<td>9,000</td>
</tr>
<tr>
<td>Methanol</td>
<td>11</td>
<td>94,404</td>
</tr>
<tr>
<td>SNG</td>
<td>20</td>
<td>4,344,470</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>41</strong></td>
<td><strong>6,010,014</strong></td>
</tr>
</tbody>
</table>

### Coal Consumption by end use

- Ammonia: 9%
- Electricity: 1%
- Methanol: 16%
- SNG: 72%
- FT-Liquid: 1%
- Hydrogen: 1%

**Huge Investment in Coal to SNG Projects in China**
**Major Characteristics of Indian Coal (1)**

- **High Ash & Low Calorific Value** - (less energy/ton coal).
- **Low Sulphur** *
- **High Reactivity**
- **High Ash Fusion Temperature (AFT)**

*Some coal in Assam has high sulphur, low ash (2-10%).

**Distribution of Indian Coal According to Type**

- **Non Coking** 87.03%
- **Semi Coking** 0.65%
- **Medium Coking** 9.95%
- **Prime Coking** 2.01%
- **Tertiary Coal** 0.36%

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**Categories of coaliferous basins**

- Category I
- Category II
- Category III
- Category IV

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**Source:** Modified after Coal Atlas of India, 1983.
### Major Characteristics of Indian Coal (2) - Examples

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Coalfield (colliery)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>North Karanpura (Ashok/Piparwar)</td>
</tr>
<tr>
<td>Proximate (wt.%)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>Moisture</td>
</tr>
<tr>
<td>Ash</td>
<td>22.0–48.0</td>
</tr>
<tr>
<td>Volatile matter</td>
<td>23.0–29.0</td>
</tr>
<tr>
<td>Ultimate (wt.%)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td>H</td>
</tr>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>S</td>
</tr>
<tr>
<td>Gross calorific value</td>
<td>(HHV), (kcal/kg)</td>
</tr>
<tr>
<td>Ash fusion temps. (°C)</td>
<td>Softening point</td>
</tr>
<tr>
<td></td>
<td>Hemispherical point</td>
</tr>
<tr>
<td>Hardgrave grindability index</td>
<td>52–58</td>
</tr>
</tbody>
</table>


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<sup>a</sup> Analysed at 40°C and 60% relative humidity.
<sup>b</sup> Analysed as dry ash free (d.a.f.).
Coal vs. other fuels

**CTL** - Add hydrogen or reject carbon

**GTL** - Reject hydrogen or add carbon.

**CTG** - Add more hydrogen or reject more carbon.

Coal - Low hydrogen, carbon rich source
Applications of Coal Gasification

Gasifiers once solved energy problems - they might, yet again.
Coal technologies

**Single Stage Process**
H-Coal (HRI, USA)
Exxon donor solvent (Exxon, USA)
SRC-1 and II (Gulf Oil, USA)
Conoco zinc chloride (Conoco, USA)
Kohleol (Ruhrkohle, Germany)
NEDOL (NEDO, Japan)

**Two Stage Processes**
Catalytic two-stage liquefaction (US DOE and HTI, USA)
Liquid solvent extraction (British Coal Corporation, UK)
Brown coal liquefaction (NEDO, Japan)
Consol synthetic fuel (Consol, USA)
Lummus (Lummus, USA)
Chevron coal liquefaction (Chevron, USA)
Kerr-McGee (Kerr-McGee, USA)
Mitsubishi Solvolysis (MHI, Japan)
Amoco (Amoco, USA) …

**Entrained Bed**
GE
UDHE
Shell
MHI
CB&I (erstwhile Philips 66)
Siemens
OMB
MCSG
TPRI
HTL
Tsinghua
EAGLE etc

**Fluidized Bed**
UDHE (erstwhile HTW)
U-gas (SES)
(Transport) KBR,

**Moving/Fixed Bed**
SASOL / Lurgi
BGL, SEDIN

**Catalytic Hydro-gasification**
Greatpoint Energy
Research Triangle Institute (RTI)
Multiproduct Generation From Coal
Coal liquefaction technologies for synthetic fuels (1)

**Direct coal liquefaction**
(Partial dismantling of coal structure + H₂ addition)

- Gas Recovery Treatment
- Coal Liquefaction
- Hydro-treating
- Refining
- Gasoline
- Diesel Fuel
- H₂S, NH₃, CO₂
- C₁ - C₂
- LPG

**Indirect coal liquefaction**
(example - Fischer Tropsch synthesis)

- Gasification & Gas Cleaning
- Sulfur, CO₂ and Ash
- H₂ + CO Syngas
- Iron Catalyst
- FT Synthesis
- C₇H₈ Liquids & Wax
- Electric Power Generation
- Electricity
- Water & Oxygenates
- Ultra-Clean Liquid Fuels & Chemical Feedstocks

**Key Points**

- **Direct coal liquefaction**
  - High efficiency potential
  - No aromatics, high-octane gasoline, low-cetane diesel
  - Products w/ higher energy density
  - Water & air emissions issues
  - Higher operating expenses
  - 1 Commercial plant at China by Shenhua (~US$1.5 billion)
  - (~25000 BPD, 3.5 million t/a coal)

- **Indirect coal liquefaction**
  - Mature & established but complex, less efficient - fewer BTUs per gallon
  - Low-octane gasoline, ultra-clean diesel
  - CO₂ capture & power co-production
  - Use existing refining technologies
  - Meet all current & projected specifications for sulfur & aromatic
  - Production capacity >390000 bpd w/ largest operation by Sasol, South Africa

*Any carbon-bearing feedstock*
CTL Yields & Hybrid Coal Conversion

ICL product slate
~ 80% Diesel, 20% Naphtha
Diesel: Cetane: 70-75, Sulfur: <1 ppm
Aromatics: <4%, Sp. gravity: 0.780
Naphtha: RON: 45-75, Sulfur: Nil
Aromatics: 2%, Sp. gravity: 0.673

DCL product slate
~ 65% Diesel, 35% Naphtha
Diesel: Cetane: 42-47, Sulfur: <5 ppm
Aromatics: 4.8%, Sp. gravity: 0.865
Naphtha: Octane (RON): >100, Sulfur: <0.5 ppm
Aromatics: 5%, Sp. Gravity: 0.765

Hybrid concept
• Integrated
• Products complement each other
• Balance between process efficiency and final fuel quality by blending
• Improve process flexibility and maximize targeted product slate

Coal Gasification
Indirect conversion
Raw ICL Products
FT Tail Gas
Product Refining & Blending
Final Products
Hydrogen Recovery
Raw DCL Products
DCL Bottoms
Direct Coal Conversion
H₂
H₂
## Syngas Cleaning & Conditioning

<table>
<thead>
<tr>
<th>Product</th>
<th>H₂/CO</th>
<th>Total S</th>
<th>Poisons</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ammonia</td>
<td>∞</td>
<td>&lt;100 ppbv</td>
<td>CO + H₂O &lt; 20 ppmv</td>
<td>H₂/N₂ = 3.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>O₂ + CO₂ &lt; 10 ppmv</td>
<td>inerts &lt; 2%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Cl &lt; 100 ppbv</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>P, As</td>
<td></td>
</tr>
<tr>
<td>Hydrogen (by methanation)</td>
<td>∞</td>
<td>&lt;100 ppbv</td>
<td>Halides, As</td>
<td>CO + CO₂ &lt; 2%</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>O₂ &lt; 1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CO₂ ≈ 3%</td>
</tr>
<tr>
<td>Methanol</td>
<td>≈2.0 (H₂+CO₂)</td>
<td>&lt;100 ppbv</td>
<td>Halides &lt; 10 ppbv</td>
<td></td>
</tr>
<tr>
<td></td>
<td>≈2.05 (CO+CO₂)</td>
<td>&lt;100 ppbv</td>
<td>NH₃ &lt; 10 ppmv</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HCN &lt; 10 ppmv</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Fe/Ni carbonyls &lt; 10 ppbv</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>C₂H₂ &lt; 5 ppmv</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Unsaturates &lt; 300 ppmv</td>
<td></td>
</tr>
<tr>
<td>Oxo alcohols</td>
<td>≈1.0</td>
<td>&lt;100 ppbv</td>
<td>O₂, strong acids, HCN, dienes</td>
<td>CO₂ &lt; 0.5%</td>
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<tr>
<td>MEG (for cryogenic H₂–CO separation)</td>
<td>1.5</td>
<td>&lt;100 ppbv</td>
<td></td>
<td>CO₂ &lt; 100 ppmv</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H₂O &lt; 10 ppmv</td>
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<tr>
<td>SNG</td>
<td>3.0</td>
<td>&lt;20–100 ppbv</td>
<td>Halides, As</td>
<td></td>
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<tr>
<td>Fischer–Tropsch (dependent on process)</td>
<td>1.3–2.6</td>
<td>&lt;10 ppb to &lt;1 ppmv</td>
<td>NH₃, HCN &lt; 1 ppmv</td>
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<tr>
<td>DRI</td>
<td>0.5–∞ (CO + H₂)</td>
<td>&lt;0.3%</td>
<td>Halides &lt; 10 ppbv</td>
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<tr>
<td></td>
<td>&gt;2 (CO₂ + H₂O)</td>
<td>preferred &lt; 100 ppmv</td>
<td>Alkaline metals &lt; 10 ppmv</td>
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<tr>
<td></td>
<td>preferred &gt; 11</td>
<td></td>
<td>Tars, phenols</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Hg, As, Se</td>
<td></td>
</tr>
</tbody>
</table>

Syngas treatment and quality are critical.
Syn Gas and Polygeneration

**Pure CO**
- Acetic Acid
- Polyurethanes
- Speciality Chemicals
  - DMF, Polyketones, Formic Acid
- DMC, polycarbonates

**Syn gas / CO+H2**
- Methanol
  - \[ \frac{H_2-CO_2}{H_2-CO} = 2 \]
  - \[ CO+CO_2 \]
- SNG
  - \[ \frac{H_2-CO_2}{H_2-CO} = 3 \]
  - \[ CO+CO_2 \]
- Ammonia
  - \[ \frac{H_2}{N_2} = 3 \]
- Oxo-alcohols
  - \[ \frac{H_2}{CO} = 1 \]
- Synfuels
  - \[ \frac{H_2}{CO} = 2 \]
  - FT synthesis
Fischer-Tropsch Synthesis - Technology

**LT-FT: 220-250°C**
- **Cobalt catalyst**
- **Fixed Bed**
- **Shell SMDS**
- **BP**

**HT-FT: 350°C**
- **Iron catalyst**
- **Gasoline/Olefins/Chemicals**
- **Sasol SAS (FFB)**
- **Sasol Synthol (CFB)**

**TECHNOLOGIES**
- **BED Shell SMDS**
- **Sasol SPD**
- **Exxon Mobil**
- **Statoil**
- **Eni/IFP/Axens**
- **Conocophilips**

**Fluidised-bed reactor**

**Block Diagram**
- **SASOL SCHEME**
- **N₂** (from **O₂** Plant)
- **NH₃ Synthesis**
- **NH₄**
- **H₂**
- **Hydrofining**
- **Fuel Gas**
- **Wax**
- **Water**
- **Water to Bioworks**
- **Separation**
- **LPG**
- **Acids**
- **Oligomers**
- **Separation Purification**
- **Hydrofining**
- **Pt Reform**
- **Gasoline**
- **Diesel**
- **C₄-C₁₀**
- **C₄-LPG**
- **C₄-Gasoline**

**Eni/IFP/Axens**
Fischer-Tropsch Synthesis

<table>
<thead>
<tr>
<th>Compound class</th>
<th>Crude oil</th>
<th>HTFT syncrude</th>
<th>LTFT syncrude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear paraffins</td>
<td>major product</td>
<td>&gt; 20%</td>
<td>&gt; 60%</td>
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<tr>
<td>Naphthenes</td>
<td>major product</td>
<td>&lt; 1%</td>
<td>&lt; 1%</td>
</tr>
<tr>
<td>Olefins</td>
<td>none</td>
<td>&gt; 60%</td>
<td>&gt; 20%</td>
</tr>
<tr>
<td>Aromatics</td>
<td>major product</td>
<td>5-10%</td>
<td>none</td>
</tr>
<tr>
<td>Oxygenates</td>
<td>&lt; 1% O (heavies)</td>
<td>5-15%</td>
<td>5-15%</td>
</tr>
<tr>
<td>Sulfur compounds</td>
<td>0.1-5% S</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>Nitrogen compounds</td>
<td>&lt; 1% N</td>
<td>none</td>
<td>none</td>
</tr>
<tr>
<td>Metal containing compounds</td>
<td>phosphorines</td>
<td>carboxylates</td>
<td>carboxylates</td>
</tr>
<tr>
<td>Water</td>
<td>0.2%</td>
<td>major by-product</td>
<td>major by-product</td>
</tr>
</tbody>
</table>

**Property** | **HTFT** | **Crude oil derived**
---|---|---
T95 boiling point, °C | 363 | 360
Cetane number | 60 | 55
Viscosity at 40 °C, cSt | 2.2 | 2.8
Density at 15 °C, kg m⁻³ | 808 | 842
Total aromatics (HPLC) | 25 | 39

**Property** | **Units** | **Sasol SPD™ LTFT distillate**
---|---|---
Olefins | vol-% | < 1
Oxygen | ppm | 80
Aromatics | mass-% | 0.14
Density @ 20 °C | kg/ℓ | 0.765
Viscosity @ 40°C | cSt | 1.97
Cetane number | >72 |
O₂ stability | mg/100mℓ | 0.21
Net heating value | MJ/ℓ | 33.5
HFRR WSD | μm | 651
Fischer-Tropsch Synthesis (2) - Technology

Objective of efficient FT Process:
- Production of more valuable steam for powering the process
- Maintaining the selectivity to heavy hydrocarbons
- High material conversion efficiency

Heat recovery
- Better recovery - production of more valuable steam
  20% of the calorific value of the syngas is released during FT synthesis

Selectivity
- Sensitive to catalyst & operating conditions
  Cobalt based – Not suitable
  Iron based - Suitable

Product Slate
- Similar to LTFT
  Heavy products w/ high selectivity

MTFT
- Latest development (Synfuels China HTSFTP process)
- Higher overall energy efficiency

Future direction for a good FT process is that of most efficient energy conversion
Coal to SNG

**Natural gas consumption is significant**
- Demand outpacing production
- India - fourth largest LNG importer
- Imports expected to rise ~30% in 2015
- National coal reserves is the key

**Costly LNG import substitution**
- Country’s economic potential

**Easy to implement**
- Technology well developed

**Conventional fuel**
- Infrastructure already in place

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**Source wise supply of Natural Gas**
Expected growth at an average of 6.8% /year

<table>
<thead>
<tr>
<th>MMSCMD</th>
<th>2012-13</th>
<th>2016-17</th>
<th>2021-22</th>
<th>2026-27</th>
<th>2029-30</th>
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</thead>
<tbody>
<tr>
<td>Domestic sources</td>
<td>101.1</td>
<td>156.7</td>
<td>182</td>
<td>211</td>
<td>230</td>
</tr>
<tr>
<td>LNG Imports</td>
<td>44.6</td>
<td>143.0</td>
<td>188</td>
<td>214</td>
<td>214</td>
</tr>
<tr>
<td>Gas Imports (Cross-border pipeline)</td>
<td>0.0</td>
<td>0.0</td>
<td>30</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>145.7</td>
<td>299.7</td>
<td>400</td>
<td>454</td>
<td>474</td>
</tr>
</tbody>
</table>

(Source- ExxonMobil 2014 Outlook for Energy)
SNG From Coal – 5 MMSCMD

ASU

N2

Utility Block

O₂ = 72-768 TPH
Steam

140-150 TPH

SRU

Sulfur to storage

CO₂ rich stream

Gasification Unit

Coal Washery

Coal ~ 4.5 MMTPA
Ash = upto 35 %

Feed Coal = 6.2 MMTPA
Ash 40-45 %
VM=20-25%
FC=20-30%
Sulfur ~ 0.3 – 0.5 %

N2

CO Shift Technology

H₂S Removal

H₂S Removal

SNG (Methanation) 5 MMSCMD

CO₂ Removal

Power Block

Coal ~ 4.5 MMTPA
Ash = upto 35 %

Feed Coal = 6.2 MMTPA
Ash 40-45 %
VM=20-25%
FC=20-30%
Sulfur ~ 0.3 – 0.5 %
**Coal to SNG**

### Steam Oxygen Gasification

(Gasification + Gas Cleaning + Methanation)

Proven & commercially demonstrated.

Great Plains synfuels plant (since 1984) - 54 billion scf SNG from 6 million ton lignite

### Methanation - Haldor - Topsoe, Air-Liquide, MHI

### Hydrogasification

Exothermic

Uses H₂ to gasify coal - research stage

### Catalytic Steam Gasification

More efficient than steam gasification

Lower operating temperature (650°C - 700°C)

*GreatPoint Energy developed catalytic hydro-methanation process. Expected Pipeline quality SNG price - $3 per MMBtu (Fairley, 2007). Thermal efficiency – 70 -80%*

### Steam/Carbon

C + H₂O → CO + H₂

### Water Gas Shift

CO + H₂O → H₂ + CO₂

### Methanation

CO + 3 H₂ → CH₄ (Methane) + H₂O

### Overall

2C + 2H₂O → CH₄ + CO₂
## Comparison Convectional Vs. Catalytic

<table>
<thead>
<tr>
<th></th>
<th>High Temp. Oxygen Gaisification</th>
<th>Catalytic Gasification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gasification T &amp; P</td>
<td>&gt;1200 °C, 30 atm</td>
<td>&lt; 700 °C, 35 atm</td>
</tr>
<tr>
<td>Oxygen Plant</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Thermal Efficiency</td>
<td>61.9 %</td>
<td>71.4 %</td>
</tr>
<tr>
<td>Methanator</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Capital Investment $ per MSCF per day</td>
<td>$ 6250</td>
<td>$ 4688</td>
</tr>
<tr>
<td>Catalyst requirement</td>
<td>No</td>
<td>Yes (20% of coal, $500/ton)</td>
</tr>
<tr>
<td>Production cost $ per MSCF methane</td>
<td>6.10</td>
<td>5.12</td>
</tr>
<tr>
<td>End use</td>
<td>Multi-End use (Syn Gas, Methane, Power)</td>
<td>Methane production only</td>
</tr>
</tbody>
</table>
Coal to Chemicals (CTC) - Methanol

Methanol
- is starting point for the synthesis of a wide range of industrial Chemicals
- as an alternative fuel

“India imports large amount of methanol (about 80% of domestic demand in 2009),*

- ICI low-pressure methanol process
- Lurgi two-step reforming
- Haldor Topsoe two-step reforming process

MTG (Methanol to Gasoline) Process

\[ 2 \text{CH}_3\text{OH} \rightarrow \text{H}_3\text{C-O-CH}_3 + \text{H}_2\text{O} \]
\[ \text{H}_3\text{C-O-CH}_3 \rightarrow \text{Light alkenes} + \text{H}_2\text{O} \]
\[ \text{Light alkenes} + \text{H}_3\text{C-O-CH}_3 \rightarrow \text{Heavy alkenes} + \text{H}_2\text{O} \]
\[ \text{Heavy alkenes} \rightarrow \text{Aromatics} + \text{Alkanes} \]
\[ \text{Aromatics} + \text{H}_3\text{C-O-CH}_3 \rightarrow \text{Higher aromatics} + \text{H}_2\text{O} \]

METHANOL MATERIAL BALANCE – 5000 MTPD

ASU → Utility Block

O₂ = 150-170 TPH
Steam
300-325 TPH

Gasification Unit → ASU

Steam

Coal = 12-15 MMTPA
Ash = upto 35%

CO Shift Technology → SRU

O₂ = 150-170 TPH
Steam

SRU → H₂S Removal → CO₂ Removal

H₂S Removal → CO₂ Removal

Sulfur → Utility Block

SNG → CO Cold Box

CO → CO₂
H₂ → CO₂

Purge gas → Methanol Unit 5000 TPD

Coal Washery → CO Shift Technology

Feed Coal = 9-12 MMTPA
Ash = 40-45%
VM = 20-25%
FC = 20-30%
Sulfur ~ 0.3 – 0.5%

Power Block → Methanol Unit 5000 TPD
Coal to Chemical (CTC) – DME (1)

Licensor: JFE

Coal Gasification

DME Production

\( \text{H}_2, \text{CO} \) 

DME Usage

- Clean Fuel for
  - Residential
  - LPG substitute
  - Transportation
  - Diesel fuel
  - FC vehicle
  - Power generation
  - Gas turbine
  - Diesel co-generation
  - Chemical use

Licensor: Haldor-Topsoe

Lurgi, Toyo, MGC, SWI, etc.

Promising future, either as a fuel, or as an intermediate in the production of hydrocarbon fuels and chemicals

Nearly all of the DME is produced in China and is coal derived.”

Coal to Chemical (CTC) – DME (2)

DME as LPG Substitute

- Burns like Natural Gas
  Wobbe Index 52 (Natural gas 54)
  Boiling point -25°C (Propane -42)
  Vapour pressure 0.53 MPa (Propane 0.91)

- Handles like LPG
  Completely miscible in LPG
  Existing LPG infrastructure - Below 20 % DME.
  For neat DME, minor changes in sealing materials and burner tip.

Outstanding Diesel Alternative

- Clean-burning alternative to diesel
  Cetane number 55-60 (Gas oil 40-55)
  No smoke, no sulphur
  NOx : ~ 90% reduction
  CO2 : ~ 95% reduction

- Cost – Relatively moderate
  (with very high conversion efficiency)

- Energy density
  Lower than diesel (must be pressurized to be used in modified diesel engines)

Significant interest in this diesel substitute in Japan and other parts of Asia.

Today, 150,000 t/y as aerosol propellant, plus 300,000 t/y for emerging fuel market
Coal to Chemical (CTC) - Ammonia

World production approx. 152 Mt (2008)

- Natural gas, 67%
- Coal, 27%
- Naphtha, 2%
- Fuel oil, 2%
- Others, 1%
- CHINA 92%
- INDIA 24%
- EUROPE 31%
- 92% of Ammonia in China is produced through Coal against 0% in India

Commercial technology
- Johnson Matthey
- Linde
- Kellogg Brown and Root
- Haldor Topsøe
- Ammonia Casale
- Uhde

Global demand for ammonia, exceeded 170 million metric tonnes in 2013.......IHS report

<table>
<thead>
<tr>
<th></th>
<th>NG</th>
<th>Naphtha</th>
<th>Fuel Oil</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative investment</td>
<td>1.0</td>
<td>1.15</td>
<td>1.5</td>
<td>2.5</td>
</tr>
<tr>
<td>Relative sp. Energy requirement (based on LHV)</td>
<td>1.0</td>
<td>1.1</td>
<td>1.3</td>
<td>1.7</td>
</tr>
</tbody>
</table>

Relative ammonia plant investment and relative energy requirement for 1800 t/d NH₃
## Overall Cost Comparison (million US$, NG price at 8.59$/MMBTU$)

<table>
<thead>
<tr>
<th>Description</th>
<th>Clean Syn Gas</th>
<th>SNG (5MM SCMD)</th>
<th>Methanol 5000(MTPD)</th>
<th>Ammonia/Urea 3850(MTPD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project Cost (Billion USD)</td>
<td>9.5</td>
<td>0.183</td>
<td>0.476</td>
<td>0.464</td>
</tr>
<tr>
<td>Total Production</td>
<td>~1.8MM</td>
<td>5</td>
<td>5000</td>
<td>3850</td>
</tr>
<tr>
<td>Operating cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Variable</td>
<td>750</td>
<td>539</td>
<td>613</td>
<td>244</td>
</tr>
<tr>
<td>Fixed</td>
<td>310</td>
<td>9.1</td>
<td>22.5</td>
<td>24</td>
</tr>
<tr>
<td>Financial</td>
<td>1500</td>
<td>28.2</td>
<td>53</td>
<td>66</td>
</tr>
<tr>
<td>Total</td>
<td>2560</td>
<td>576</td>
<td>688</td>
<td>334</td>
</tr>
<tr>
<td>Net Cost</td>
<td>(-)550</td>
<td>(-)78</td>
<td>(-)242</td>
<td>(-)92</td>
</tr>
<tr>
<td>Cost of Production, USD</td>
<td>2010</td>
<td>258</td>
<td>672</td>
<td>306</td>
</tr>
<tr>
<td>9.5/MMBTU</td>
<td>8.5/MMBTU</td>
<td>270/MT</td>
<td>190/MT</td>
<td></td>
</tr>
</tbody>
</table>

Cost of Production, USD

- 9.5/MMBTU
- 8.5/MMBTU
- 270/MT
- 190/MT

Delivering Excellence through People
Gasifier Pilot Plant (FB Type)

- A coal gasification fluidized bed plant is designed and installed at EIL-R&D center
  - Capacity: 150 kg/h
  - O2 purity: 93% by volume
- The plant consists of
  - Coal crushing & feeding system
  - High pressure gasifier with ash removal system
  - Cyclones
  - Syngas cooling systems
  - Ash disposal system
  - Air separation unit, etc.
Gasifier Pilot Plant

Capacity: 350 Nm³/h
Operating pressure: 30 bar
Challenges & Opportunities

- Assess, source, market need, location for a project, energy security
- Complex High investment projects
- High Cost of New Technology, future with CO2 fixation and CCS
- Need to strengthen the R&D environment
- High Investments linked to price volatility, high risk
- Need Collaborative approach, partnerships
- Policies in place to give impetus to clean coal technologies
THANK YOU
World’s only commercial DCL plant

Shenhua DCL utilizes technology pioneered by DOE integrated with German and Japanese technologies, and combined with Shenhua innovations.

Production Capacity:
1.08 M tons/yr (~24,000 BPD) liquid products (mainly diesel & naphtha) from 3.5 M tons/yr coal

Plant Cost: $1.5 B USD
Indirect coal liquefaction

Gasification technology
- Shell
- Lurgi/Air Liquide
- ThyssenKrupp Uhde
- Prenflo
- Siemens GSP
- Choren

Hydrocarbon synthesis
- Sasol LT-FT
- Sasol HT-FT
- Shell MDS
- ExxonMobil MTG
- ...

CO₂ to atmosphere, storage or EOR

Coal preparation (milling and drying)

Coal → Gasification
- Gas cooling, dust removal and water scrubbing
- (Sour) CO shift
- Acid gas removal
- Synthesis
- If required: Product refining
- Synthesis product

CO₂ to coal conveying

Air separation
- Linde
- Air Liquide
- Air Products
- ...

Air separation
- Air Liquide
- Linde
- UOP Honeywell
- ThyssenKrupp Uhde
- ...

Hydrocarbon upgrading
- Shell
- Chevron
- Haldor Topsøe
- ...

Sulfur or Sulfuric acid

Delivering Excellence through People
Methanol-based fuel production

**TIGAS**  Topsøe Integrated Gasoline Synthesis

**MtG**  Methanol-to –Gasoline e.g.. ExxonMobil (Uhde)

**DtG**  Dimethyl ether-to-Gasoline (e.g.. Karlsruhe Institut für Technology)

**DtO**  Dimethyl ether-to -Olefins (e.g.. Karlsruhe Institut für Technology)

**MtO**  Methanol-to -Olefins  (e.g.. UOP, MtP by Lurgi/ Air Liquide)

**StF**  Syngas -to -Fuel (CAC, TU Freiberg)

**MtD**  Methanol-to -Dimethyl ether (eg Lurgi/ Air Liquide)

**StD**  Syngas -to -Dimethyl ether (eg JFE)

**COD**  Conversion of Olefins to Distillates (e.g. Lurgi/ Air Liquide)

**MtS**  MtSynfuels ® by Lurgi/ Air Liquide
### Challenges & Opportunities

| High Cost | - Exploit economy of scale  
|---|---|
| Production & handling in comparison to Petroleum / NG  
|   | - Extensive optimization to cut down CAPEX & OPEX  
| |   | - e.g. eliminate spare gasifier & cost reduction in utilities like oxygen  
| |   | - Use poly-generation option, Process integration  
| |   | - Locate plant near to coal source  
| Energy Efficiency & CO₂ Emissions | - CO₂ capture compliant technology. Exploit CCS & CO₂ chemical fixation  
| Varying quantities of O₂ & Organic impurities  
|   | ( If a CO₂ tax or other penalty is introduced and no other energy carrier than coal is available, the gasification route remains the most efficient in applying CO₂ capture and sequestration  
| |   | - As a result of extensive research; future technologies utilizing CO₂ e.g. methanol production from CO₂ (CAMERE Process) , Dry Reforming etc.  
| Low Hydrogen Carbon Source | - Exploit availability huge reserves available  
| low molar H/C ratio compared to hydrocarbons  
| |   | - A general advantage of coal as feedstock is the even distribution of large reserve across country.  
| |   | - Alternatively using for CO chemicals  
| Resource, Environment, & Industrial Policy Challenges | - Uniform Coal Policies & Government Support  
| | - High water & land usage, pollution  
| | - public resistance to coal use  
| | - Optimize & reuse water, if possible, locate at coastal location.  
| | - Optimize land usage – Exploit Process Integration Opportunities & UCG  
| Global Energy Scenario | - Energy security- Coal gasification always appears as an attractive option if competing energy carriers experience high price levels or national independence of energy supply plays a role  
| Oil price fluctuations, demand & supply, new technologies like shale gas, CBM etc.  
|   | - Gasification can be one way to use coal especially, if high ash contents are present. This is true for the residues of coal washing or other beneficiation processes. Price Competitiveness to be seen