Design Aspects of CTL Process With High Ash Indian Coal: An Efforts Towards Development of CTL Technology

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Overview of Coal to Liquids

- CTL process: aspects of technology components

- CTL Technology developments efforts
  - Methodology
  - Experimental facilities/pilot plants
  - Demonstration plant
  - Operating results/observations

- Summary
Coal to liquids (Transportation liquids)

**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
- Suitable with low ash coal

**Indirect coal liquefaction**

- Mature & established but complex, less efficient
- Low-octane gasoline, ultra-clean diesel
- CO₂ capture & power co-production
- Use existing refining technologies
- Meet all current & projected specifications for sulfur & aromatic

*Any carbon-bearing feedstock*
Incentives of CTL Technology Developments

- Coal is relatively more abundant than oil and gas

- Technologically Feasible
  - Significant advancements made over the years and undergoing major improvements currently

- Economics
  - At present not encouraging but Capital and operating costs – downward trends
  - Expected to be more profitable in the rising prices of oil & gas scenario

- CTL is an umbrella term for a group of technologies
  - Varieties of feeds stock > syngas > polygeneration
  - Energy security/ expanding energy basket
PRODUCT FLEXIBILITY OF SYNGAS

- Power & Steam
- Carbon Source
- Iron Reduction
- Gasification
- Fuel/Town Gas
- Synthesis Gas
- H2
- Ammonia & Urea
- Methanol
- Dimethyl Ether
- Ethylene & Propylene
- Methyl Acetate
- Oxo Chemicals
- Polyolefins
- Acetic Anhydride
- Acetate Esters
- Ketene
- Diketene & Derivatives
- PVA
- VAM
- Synthetic Natural Gas
- Diesel/ Jet/ Gas Fuels
- Fischer- Tropsch Liquids
- Naptha

Delivering Excellence through People
### Fuels from syngas
- Combustion energy content of a product per unit volume is an important economic parameter.

### Chemicals from syngas
- Generally sold by weight for their chemical performance. Atom is an important first factor to discriminate between the various chemicals to be produced from syngas.

<table>
<thead>
<tr>
<th>Chemical</th>
<th>CO/H2</th>
<th>Atom selectivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Methanol</td>
<td>1 / 2</td>
<td>100</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>1 / 1</td>
<td>100</td>
</tr>
<tr>
<td>Ethylene glycol</td>
<td>2 / 3</td>
<td>100</td>
</tr>
<tr>
<td>Acetic anhydride</td>
<td>1 / 1</td>
<td>85</td>
</tr>
<tr>
<td>Propionic acid</td>
<td>3 / 4</td>
<td>80</td>
</tr>
<tr>
<td>Methacrylic acid</td>
<td>4 / 5</td>
<td>73</td>
</tr>
<tr>
<td>Ethanol</td>
<td>1 / 2</td>
<td>72</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>2 / 3</td>
<td>71</td>
</tr>
<tr>
<td>Ethyl acetate</td>
<td>2 / 3</td>
<td>71</td>
</tr>
<tr>
<td>Vinyl acetate</td>
<td>4 / 5</td>
<td>70</td>
</tr>
<tr>
<td>Ethene</td>
<td>1 / 2</td>
<td>44</td>
</tr>
</tbody>
</table>
REPORTED COMMERCIAL USE OF SYNGAS

- Largest - Manufacture of H2, more than half of which is used in the synthesis of ammonia.

- The second largest - in the synthesis of methanol.

- The third largest - conversion to paraffins, olefins and oxygenates via the Fischer-Tropsch reaction.

- The fourth largest - the hydroformylation OXO reaction.

The use of syn gas in the generation of electricity via IGCC has the potential for considerable growth.
CTL through ICL

Four Major Steps

- **Gasification:**
  - Coal preparation, Coal Gasification, Syngas Cooling, Particulate Control

- **Syngas Purification:**
  - Ammonia Scrubbing, Mercury Removal, Acid Gas Removal, CO2 Management

- **FT synthesis:**
  - Catalysts, Reactors (LTFT/HTFT), Water Separations/Product Recovery

- **Product upgradation:**
  - Hydrocracking, Hydrotreating, Isomerisation, etc.
CTL through ICL

Designers interest:
- Throughputs of the different feedstock,
- Optimal conditions for the design feedstock,
- Gas compositions,
- Heat effects,
- Quench requirements
- Startup and shutdown requirements,
- Process control requirements.
Problem due to high ash coals

• Erosions of equipment and boiler parts
• Difficulty in pulverization,
• Poor emissivity, poor flame temperature. Low irradiative transfer, more unburnt carbons.
• Excessive amount of fly ash and bottom ash,
• Lower combustion efficiency,
• Increase ash resistivity due to higher amounts of silica and alumina, reduction in ESP efficiency,
• Increased emissions
**Gasification**

- **Moving Bed Gasifier:**
- **Fluidized Bed Gasifier:**
- **Entrained Flow Bed:**

- Indian coals are characterized by:
  - High ash content (~ 40%),
  - Low calorific value,
  - Low sulfur,
  - High reactivity and
  - High ash fusion temperature.

- Entrained bed gasification results in loss in efficiency due to inherent high ash content of coal/molten ash penetrations/refractory spoiling.

- Fluidized bed gasifiers are more suitable to Indian coals.
Gasification

Key Issues with Gasifiers

- Kinetics (shrinking core?)
- Kinetic/equilibrium controlled?
- Operating P, Temp
- Coal/gas contact
- Syn gas compositions
- Sizing of the gasifier
- Effects of feed variations
- Material of construction
- Engineering Aspects
- Scale-up

Exothermic:
- Partial Combustion of Carbon
  \[ C + 0.5O_2 \leftrightarrow CO; \Delta H^0_{298} = -110.5 \text{ kJ/mol} \]
- Complete Combustion of Carbon
  \[ C + O_2 \leftrightarrow CO_2; \Delta H^0_{298} = -393.5 \text{ kJ/mol} \]
- Water Gas Shift Reaction
  \[ CO + H_2O \leftrightarrow CO_2 + H_2; \Delta H^0_{298} = -283.0 \text{ kJ/mol} \]
- Methanation
  \[ C + 2H_2 \leftrightarrow CH_4; \Delta H^0_{298} = -74.5 \text{ kJ/mol} \]
  \[ CO + 3H_2 \leftrightarrow CH_4 + H_2O; \Delta H^0_{298} = -205.8 \text{ kJ/mol} \]

Endothermic:
- Boudard Reaction
  \[ C + CO_2 \leftrightarrow 2CO; \Delta H^0_{298} = +172.5 \text{ kJ/mol} \]
- Steam Reforming Reaction
  \[ C + H_2O \leftrightarrow CO + H_2; \Delta H^0_{298} = +131.3 \text{ kJ/mol} \]
- Liberation of Bound Hydrogen
  \[ 2H \leftrightarrow H_2; \Delta H^0_{298} = +431.0 \text{ kJ/mol} \]

Gasifier Gas Composition (Vol %)

<table>
<thead>
<tr>
<th>Gas</th>
<th>Vol %</th>
</tr>
</thead>
<tbody>
<tr>
<td>H_2</td>
<td>25 - 30</td>
</tr>
<tr>
<td>CO</td>
<td>30 - 60</td>
</tr>
<tr>
<td>CO_2</td>
<td>5 - 15</td>
</tr>
<tr>
<td>H_2O</td>
<td>2 - 30</td>
</tr>
<tr>
<td>CH_4</td>
<td>0 - 5</td>
</tr>
<tr>
<td>H_2S</td>
<td>0.2 - 1</td>
</tr>
<tr>
<td>COS</td>
<td>0 - 0.1</td>
</tr>
<tr>
<td>N_2</td>
<td>0.5 - 4</td>
</tr>
<tr>
<td>Ar</td>
<td>0.2 - 1</td>
</tr>
<tr>
<td>NH_3 + HCN</td>
<td>0 - 0.3</td>
</tr>
<tr>
<td>Ash/Slag/PM</td>
<td></td>
</tr>
</tbody>
</table>
## Contaminants in Syngas/Allowable Conc

<table>
<thead>
<tr>
<th>Element</th>
<th>Conc in Coal</th>
<th>Species</th>
<th>Conc in Syngas</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>0.3 – 3.6 wt%</td>
<td>H₂S, COS, CS₂</td>
<td>750-7000 ppmv as H₂S and 25-200 ppmv as COS</td>
</tr>
<tr>
<td>N</td>
<td>1.1 – 1.6 wt%</td>
<td>NH₃, HCN</td>
<td>50-800 ppmv as NH₃</td>
</tr>
<tr>
<td>Cl</td>
<td>0.003 – 0.37 wt%</td>
<td>HCl, metal chlorides</td>
<td>170-830 ppmv as HCl</td>
</tr>
<tr>
<td>Hg</td>
<td>0.02 – 1 μg/g</td>
<td>Hg (g), Hg(CH₃)₂</td>
<td>1.3-63 ppbv</td>
</tr>
<tr>
<td>As</td>
<td>0.5 – 80 μg/g</td>
<td>As₂ (g), As₄ (g), AsH₃ (g), AsS (g)</td>
<td>84-1300 ppbv</td>
</tr>
<tr>
<td>Se</td>
<td>0.2 – 1.6 μg/g</td>
<td>H₂Se (g)</td>
<td>32-2600 ppbv</td>
</tr>
<tr>
<td>Cd</td>
<td>0.1 – 3 μg/g</td>
<td>Cd (g), CdS (condensed), CdCl₂ (g)</td>
<td>11-340 ppbv</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Application</th>
<th>Catalyst/Constraint</th>
<th>S</th>
<th>CO₂</th>
<th>Other Poison</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>Environmental/Engineering</td>
<td>≤ 40 ppm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen</td>
<td>Cr/Fe; Zn/Cu; Co/Mo</td>
<td>≤ 0.1 ppm</td>
<td>≤ 10 ppm</td>
<td>Cl, Hg, As</td>
</tr>
<tr>
<td>Ammonia</td>
<td>Ni; Cr/Fe; Zn/Cu</td>
<td>≤ 0.1 ppm</td>
<td>≤ 10 ppm</td>
<td>Cl, Hg, As</td>
</tr>
<tr>
<td>SNG</td>
<td>Cr/Fe; Zn/Cu; Ni</td>
<td>≤ 0.1 ppm</td>
<td></td>
<td>Cl, Hg, As</td>
</tr>
<tr>
<td>Fischer-Tropsch</td>
<td>Co; Fe</td>
<td>≤ 0.1 ppm</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
F-T Synthesis

Synthesis Gas \( xH_2 + yCO \) → F-T Reactor (Cat: Co/Fe) → Syncrude (Long chain aliphatic HC, mainly n-paraffins) \((-CH_2^-)_n\)

Available Technology: Fixed bed/Fluidized bed/Slurry bed

- CO hydrogenation: \( nCO + 2nH_2 \) → \((-CH_2^-)_n + nH_2O\) \(-152 \text{ kJ/mol}\)
- Water gas shift: \( CO + H_2O \) ↔ \( H_2 + CO_2 \) \(-41 \text{ kJ/mol}\)
- Methanation: \( CO + 3H_2 \) ↔ \( H_2O + CH_4 \) \(-206 \text{ kJ/mol}\)
**FT Reactor Types**

**Fixed Bed Reactor (FB)**
- Multitubular design
- Diameter limited by slow heat removal
- Good for heavy liquid & waxes
- Conversion per pass is limited, difficult to replace deactivated catalyst

**Slurry Reactor**
- Very high heat transfer rate
- High conversion per pass
- Higher catalyst activity with better selectivity
- Catalyst regeneration by continuous purge and feed
- Uniform temperature distribution
- Difficult to separate catalyst and Product
Product Refining

Long chain waxy HC

(-CH2-)n

Product Refining

Naphtha, Kero, Diesel, Waxes

- Hydroprocessing Section
  - Hydroisomerisation / hydrocracking of n-paraffins to iso-paraffins of desired length & boiling range
  - Mild hydrocracking at 300-350 deg C & 30-50 bar
  - Reactivity increases with increasing number of paraffins
    ✓ Maximum yield of middle distillates
    ✓ Minimum yield of C4 & lighters

- Distillation Section
  - Conventional distillation for product fractionation

- Gas Processing & Wax Finishing as necessary
CTL Technology Development Efforts
EIL-BPCL-THERMAX-CHT
Pilot plants and mathematical tools

- HPTGA
- Gasifier unit
- Syngas cleaning unit
- Cold stand Slurry column
- Facilities for catalyst formulations/testing
- Batch reactor/fixed bed/continuous for catalyst testing/FT kinetics

- Mathematical model
  - Gasifier
  - Slurry bubble FT reactor
  - CFD model of SBCR
Gasification Studies: Kinetics Using HPTGA

- HPTGA along with MS for gas analysis have been installed at EIL-R&D complex
  - Design pressure: 50 bar
  - Design temp: 1100°C

- Various type of coal viz. high ash coal, lignite, petcoke are being studied

**Objectives:**

- Investigations of coal gasification reactions at high pressure, high temperature, high ash coal
- Insights to Coal gasification ‘reactivity’
HPTGA + MS Expt. Setup at EIL, R&D Lab

- P, T CONTROL & SAFETY SYSTEM
- GAS DOSING SYSTEM
- MICROBALANCE SYSTEM
- MS FOR ONLINE ANALYSIS
Mathematical Modeling of Gasifier

Issues of FBG at High Pressure

- Complex hydrodynamics
- Complex reaction kinetics (impact of ash layer not known)
- Kinetics at high pressure
- Multiphase, multi-component reactor modeling - solution is a challenge
Model Predictions

![Graph showing temperature distribution across the height of a gasifier. The graph plots temperature (K) along the y-axis against height of gasifier (m) along the x-axis. The temperature decreases from a peak at the start of the gasifier to a constant value near the end.]
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 And Syngas cleanup at EIL-R&D Gurgaon complex:

**Gasifier:**
- ID: 200mm
- Height: 11000mm
- Capacity: 150 kg/h high ash coal, 25 m Structural height

**Syn gas clean up:**
- 21 m structural height

**Enclosed ground flare:**
- 35 m
Pilot Gasifier: Issues being addressed

- **Process Design**
  - Coal Characterization and kinetics
  - Estimation of process parameters (T, P, C/O2, C/Steam, Flux etc)
  - Gasifier sizing (dia, height)
  - Quench System
  - Cyclone
  - Deep leg/j leg

- **Mechanical Design**
  - Coal preparation unit
  - Feed injection system
  - Ash/Solid removal
  - Loop seal
  - Distributor
  - Exchangers
Gasifier operation Strategy

- Operation was planned stepwise
  - Combustion
  - Gasification
    - Air mode
      - Gradual rise of pressure
    - Enriched O2
      - Gradual rise of pressure
  - O2 & Steam
    - Gradual rise of pressure
Gasification experiments (Air mode)

SYN GAS FLARED IN GROUND FLARE WITH BLUE FLAME
Gas Cleaning:
- Removal of $\text{H}_2\text{S}$, COS, HCN, CO$_2$, NH$_3$, Particulates.

Basis:
- Adoption of Conventional Technologies & Novel Processes

Pilot facilities created for syngas clean up
- Water scrubber with EIL’s proprietary structured packing
- HCN/COS Converter
- AGR unit
Syngas Cleaning Pilot Plant

Capacity: 350 Nm³/h
Operating pressure: 30 bar
FT Technology Development Approach

- Catalysts & Kinetics (Iron/Cobalt based)
- Hydrodynamics of SBCR (Pilot plant/CFD studies)
- Development of mathematical model for SBCR
  - Conversion/Yield and selectivity/Sizing of reactors
Flow Regime/scale up issues
SBCR Pilot Plant at EIL, R&D
Effects of Various Parameters on Gas Holdup

Gas holdup & distribution of small and large bubbles affected by various parameters

- Superficial gas velocity
- Pressure
- Gas density
- Physical properties of liquid
- Solid concentration
- Reactor size
- Types of gas distributors
SBCR FT Reactor Modeling

- **Reactions:**
  - Paraffins: \( nCO + (2n+1)H_2 \rightarrow C_nH_{2n+2} + nH_2O \)
  - Olefins: \( nCO + 2nH_2 \rightarrow C_nH_{2n} + nH_2O \)
  - Water gas shift: \( H_2O + CO \leftrightarrow CO_2 + H_2 \)

- **Kinetics (in-house with Co/Fe)**
- **Hydrodynamics (pilot plant, CFD)**

**Target:** The model can be used for
  - Design reactor
  - Optimization & scale up
  - Trouble shooting
  - Control
FT Reactor Model : Syngas Conversion

Comparison of Model Output

<table>
<thead>
<tr>
<th></th>
<th>Lit</th>
<th>Model</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Reactor details</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reactor diameter ($D_T$), m</td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>Dispersion height (H), m</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Vertical cooling tube dia, mm</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>No of tubes</td>
<td>6000</td>
<td>5300</td>
</tr>
<tr>
<td><strong>Operating conditions</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temp, $^0C$</td>
<td>240</td>
<td>240</td>
</tr>
<tr>
<td>Pressure (P), bar</td>
<td>30</td>
<td>30</td>
</tr>
</tbody>
</table>
BDEP of a Demonstration Unit

Broad aim

- Reasonably large size/integrating all the components.
- Locate near to a refinery site
- In long term demonstration of key components and carrying out wider range of experiments

BDEP/ capacity 1700 TPD high ash coal being prepared along with costing to demonstrate the technology and to understand the missing links if any
Summary

- CTL is an option for clean transport fuels will be attractive through technological advancement and reduced availability of oil and gas.
- Although CTL is known, still there several issues of design with high ash coal need to be assessed in Indian context.
- There are various technical components in CTL Process viz. coal gasification, syngas cleaning, FT synthesis and product upgradation.
- Experience of CTL with high ash coal is emerging. There are various issues to be experienced or to be assessed experimentally specially with gasification.
- EIL, BPCL, Thermax Ltd and CHT are engaged in developing CTL Technology based on high ash Indian coal.
Conclusions…

- Various sizes of experimental facilities have been created for gasification, syngas clean up, FT synthesis at EIL,R&D and BPCL,R&D to address various issues of design.
- Based on both experimental and Mathematical models it is planned to develop the complete CTL technology.
- Setting up a demonstration plant of capacity ~1700 TPD high ash coal is being assessed towards demonstration and commercialization of CTL unit.
- It is hoped that numbers of offshoots technology will be useful and also will open several research front.
- Moreover syngas (an umbrella feed) will remain an answer to the chemicals, power, H2, SNG in crisis of gas/oil availability and will add flexibility in energy basket.
Thank You

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## DCL Vs ICL

<table>
<thead>
<tr>
<th></th>
<th>DCL Process</th>
<th>ICL Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal to Liquefaction, TPD</td>
<td>4448</td>
<td>----</td>
</tr>
<tr>
<td>Coal to Gasifier, TPD</td>
<td>2136</td>
<td>9230</td>
</tr>
<tr>
<td>Total</td>
<td>6584</td>
<td>9230</td>
</tr>
<tr>
<td>Diesel, BPD</td>
<td>13090</td>
<td>13625</td>
</tr>
<tr>
<td>Naphtha, BPD</td>
<td>5389</td>
<td>6375</td>
</tr>
<tr>
<td>LPG, BPD</td>
<td>1521</td>
<td>--</td>
</tr>
<tr>
<td>Total products, BPD</td>
<td>20000</td>
<td>20000</td>
</tr>
<tr>
<td>Total Energy Input, BTU/D</td>
<td>186587</td>
<td>237432</td>
</tr>
<tr>
<td>Total Energy Output, BTU/D</td>
<td>112221</td>
<td>114857</td>
</tr>
<tr>
<td>Overall thermal Efficiency, %</td>
<td>60.14</td>
<td>48.37</td>
</tr>
<tr>
<td>Product yield, BBL of product per ton of dry</td>
<td>3.04</td>
<td>2.17</td>
</tr>
<tr>
<td>CO2 generation, kg/bbl of product</td>
<td>434</td>
<td>706</td>
</tr>
</tbody>
</table>
## 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>
</tr>
<tr>
<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></td>
<td>NH₃ &lt; 10 ppmv</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>HCN &lt; 10 ppbv</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>H₂S, COS, organosulfur</td>
<td>CO₂ &lt; 0.5%</td>
<td></td>
</tr>
<tr>
<td>MEG (for cryogenic H₂−CO separation)</td>
<td>1.5</td>
<td>&lt;100 ppbv</td>
<td>O₂, strong acids, HCN, dienes</td>
<td>CO₂ &lt; 100 ppmv</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>H₂O &lt; 10 ppmv</td>
</tr>
<tr>
<td>SNG</td>
<td>3.0</td>
<td>&lt;20−100 ppbv</td>
<td>Halides, As</td>
<td></td>
</tr>
<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>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Halides &lt; 10 ppbv</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Alkaline metals &lt; 10 ppmv</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Tars, phenols</td>
<td></td>
</tr>
<tr>
<td>DRI</td>
<td>0.5−∞ (CO + H₂)</td>
<td>&lt;0.3%</td>
<td>Hg, As, Se</td>
<td></td>
</tr>
<tr>
<td></td>
<td>&gt;2 (CO₂ + H₂O)</td>
<td>preferred &lt; 100 ppmv</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>preferred &gt; 11</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>N₂ &lt; 6%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>preferred &lt; 1%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>CH₄ 3−4%</td>
</tr>
</tbody>
</table>
**CTL Technology Components/Development Approach**

**Coal**
- C, H, N, S, O, Metals (Fe, Ni, Na etc)
- Ash

**GASIFIER**
- \( C + \frac{1}{2} O_2 \rightarrow CO \)
- \( C + O_2 \rightarrow CO_2 \)
- \( C + 2H_2 \rightarrow CH_4 \)
- \( CO + H_2O \rightarrow H_2 + CO_2 \)

**Air/O2**

**STEAM**

**SYN GAS**
- \( H_2 \)
- CO
- \( CO_2 \)
- \( H_2O \)
- \( CH_4 \)
- \( H_2S \)
- COS
- \( N_2 \)
- Ar
- \( NH_3 + HCN \)
- Ash/Slag/PM

**Power MP/LP**

**FISCHER-TROPSCH REACTOR**
- \( CO + 2H_2 \rightarrow (CH_2) + H_2O \)
- \( CO + 3H_2 \rightarrow CH_4 + H_2O \)
- \( H_2 + CO = CO_2 + H_2 \)

**GAS COOLING & CLEANING**

**CO2**
- \( H_2O \)
- \( H_2S \)
- COS
- \( NH_3 + HCN \)
- Ash/Slag/PM

**PRODUCT UPGRADE/SEP PHYCAL SEP**
- LPG
- NAPTHA
- DIESEL

**FG C2/C3**

**GASIFIER SECTION**
- TGA PILOT GASIFIER OPERATING DATA GASIFIER MODEL DESIGN METHOD

**GAS CLEAN SECTION**
- PILOT PLANT OPERATING DATA NOVEL SCHEME DESIGN METHOD

**FT SECTION**
- CATALYST DEV MICRO REACTOR KINETIC DATA COLD FLOW/CFD MODEL REACTOR MODEL DESIGN METHOD

**DEMO PLANT**
- INTEGRATE A+B+C FOR LARGE CAPACITY PROCESS PACKAGE ENGINEERING PROCUREMENT COMMISSIONING

**COMPETITIVE TECHNOLOGY**
- LOOK BACK FOR UPGRADEATION