From Coal Gas to Liquid Product
The Topsøe TIGAS Process
Outline

- Introduction
- Gasification Technologies
- WGS
- Acid Gas Removal
- Removal of Trace Component
- Methanol/DME/Gasoline synthesis
- Delayed CO$_2$ removal
- Conclusions
What is Gasification?
Gasification Technologies

Pre-Screening

GE (Texaco)

- FEEDSTOCKS
- PROCESS
- PRODUCTS
- COAL
- HEAVY OIL
- PETROLEUM COKE
- COKE
- NATURAL GAS
- WASTE
- OXYGEN
- SULPHUR REMOVAL
- ELECTRICITY
- HYDROGEN
- AMMONIA
- ALCOHOLS
- METHANOL
- BY PRODUCT: SULPHUR
- BY PRODUCT: SLAG

GSP (Future Energy)

- REACTOR WITH COOLING SCREEN
- BURNER
- PRESSURE WATER
- COOLING WATER
- GASEOUS EXIT
- GAS OUTLET

SCGP (Shell)

- QUENCH GAS BLENDER
- HP STEAM
- LP STEAM
- TOS GAS TREATMENT
- OXYGEN
- PULVERIZED COAL

E-Gas (ConocoPhillips)

- E-Gas™ Entrained-Flow Gasifier
- First stage
- Second stage
- Steam gas producer
- Air
- Fuel gas

KBR

- Gas cap
- Gas quench
- Steam, oxygen
- Tar
- Slag quench
- Slag lock

Lurgi

- Lump-coal, coal briquettes and limestone
- Coal lock

Wyoming

Rentech, Inc.

Haldor Topsoe
<table>
<thead>
<tr>
<th>Gas Dry</th>
<th>Gasifier</th>
<th>BGL</th>
<th>Uhde Shell/ Prenflo</th>
<th>Conoco- Philips E-gas (Dow)</th>
<th>G.E. Texaco</th>
<th>GE Texaco Quench</th>
<th>KRW Transport</th>
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<tbody>
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<td>CO</td>
<td>54</td>
<td>62.7</td>
<td>50.3</td>
<td>49.6</td>
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<td>H₂</td>
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<td>38.8</td>
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<td>10.4</td>
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<td>0.1</td>
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<td>N₂ + Ar</td>
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<td>5.3</td>
<td>1.9</td>
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<td>**Eₖ (LHV)</td>
<td>47.1%</td>
<td>47.4%</td>
<td>46.7%</td>
<td>45.1%</td>
<td>39.7%</td>
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<tr>
<td>**Eₜ (LHV)</td>
<td>51.3%</td>
<td>49.8%</td>
<td>49.4%</td>
<td>48.3%</td>
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<td>kg coal/kg O₂</td>
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<td>1.52</td>
<td>1.26</td>
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<td>Nm³ syngas/Nm³ O₂*</td>
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<td>3.42</td>
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Synthesis gas conditioning Water Gas Shift (WGS) and COS hydrolysis (CKA)

Coal gas: $H_2/CO < 1$

- **CKA**
  - Synthesis gas conditioning
  - Water Gas Shift (WGS)
  - COS hydrolysis

- **WGS**
  - $H_2/CO = 3$ (SNG)
  - $H_2/CO = 2$ (MeOH/FT)
  - $H_2/CO = 1$ (TIGAS/DME)
  - $H_2/CO = \infty$ ($H_2$, $NH_3$)

**SSK**
- High activity in sulphur-containing gas
  - 50 ppm – 5% $H_2S$
- Active catalyst in low concentrations of CO (0.1-5%)
- Converts COS to $H_2S$
- Converts $HCN$
- Active between 200°C and 500°C
Acid Gas Removal

- Many possibilities
- Rectisol is favoured in chemical plants
- 3 out 4 IGCC use MDEA
- Hot (warm) gas cleanup may enter
- Guard bed ahead of Synthesis Catalysts
Gas Composition exit an MDEA

<table>
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<tr>
<th>Gas</th>
<th>PPM</th>
<th>Element</th>
<th>Concentration</th>
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<tr>
<td>H₂</td>
<td>-</td>
<td>As</td>
<td>4 μg/Nm³</td>
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<tr>
<td>Ar</td>
<td>-</td>
<td>Cd</td>
<td>5</td>
</tr>
<tr>
<td>N₂</td>
<td>-</td>
<td>Co</td>
<td>8</td>
</tr>
<tr>
<td>CO</td>
<td>-</td>
<td>Cu</td>
<td>6</td>
</tr>
<tr>
<td>CO₂</td>
<td>-</td>
<td>Cl</td>
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</tr>
<tr>
<td>H₂O</td>
<td>-</td>
<td>Zn</td>
<td>17</td>
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<tr>
<td>CH₄</td>
<td>0.009%</td>
<td>Mn</td>
<td>50</td>
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<tr>
<td>H₂S</td>
<td>0.2 ppm</td>
<td>Fe</td>
<td>250</td>
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<tr>
<td>COS</td>
<td>12 ppm</td>
<td>Ni</td>
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<tr>
<td>CS₂</td>
<td>2 ppm</td>
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</tr>
<tr>
<td>HCN</td>
<td>1 ppm</td>
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</tr>
<tr>
<td>NH₃</td>
<td>3 ppm</td>
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1. Active carbon
2. Hydrolysis
3. HTZ
4. Zeolite
5. Guard
Gas Cleaning Pilot

Compression / Heating

Active carbon: ÷ Carbonyls and...

CKA: COS, CS₂, HCN hydrolysis and ÷ Cl

HTZ: ÷ H₂S

Zeolite + guard ÷ NH₃ ÷ As

Chemistry
TNGAS
Topsøe Integrated Gasoline Synthesis

- Simple process layout
- Low recycle rates
- No methanol condensation / re-evaporation
- Moderate pressure


- Off-gas
- C₃-C₄
- Gasoline
- Water
TIGAS Demonstration Plant

1 T/d

7000+ run hours

Houston TX
MeOH/DME Synthesis
– Low H₂/CO

\[ 2\text{H}_2 + \text{CO} \rightarrow \text{CH}_3\text{OH} \quad -90.7 \] 

\[ 2\text{CH}_3\text{OH} \rightarrow \text{CH}_3\text{OCH}_3 + \text{H}_2\text{O} \quad -23.6 \]

\[ \text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2 \quad -41.1 \]

\[ 3\text{H}_2 + 3\text{CO} \rightarrow \text{CH}_3\text{OCH}_3 + \text{CO}_2 \]
Eq. Conversion vs. Pressure - low H₂/CO

- T = 240°C
- Feed Gas (mol%):
  - H₂ = 51
  - CO = 48
  - CO₂ = 1
$H_2/CO = 1$ is optimum for DME.
Gasoline synthesis

- $\text{CH}_3\text{OH} = -\text{CH}_2- + \text{H}_2\text{O}$
- DME = $2-\text{CH}_2- + \text{H}_2\text{O}$
- $3\text{H}_2 + 3\text{CO} = \text{DME} + \text{CO}_2$
- $2\text{H}_2 + \text{CO} = \text{CH}_3\text{OH}$

$2\text{CO} + \text{H}_2 = -\text{CH}_2- + \text{CO}_2$
Coal Gas to Gasoline

- **Gasoline**
- **C₃-C₄**
- **Water**
- **Gasoline Synthesis**
- **MeOH/DME Synthesis**
- **CO₂ Removal**
- **CO₂**
- **Off-gas**
- **C₃-C₄**
- **Gasoline**
- **Water**

- **LOW RECYLE RATE (R/M < 1)**
- **REDUCED STEAM CONSUMPTION (LESS MODULE ADJUSTMENT)**
- **"DRY" FEED (low P₃H₂O)**
- **IMPROVED CONVERSION**
- **LESS PROCESS CONDENSATE**

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HALDOR TOPSØE
Multiple catalytic functions in loop enable co-processing of other feed streams

Direct co-feed of *aqueous* bioethanol – save ethanol distillation cost
"Single-Pass" TIGAS

- 60-70% single-pass syngas conversion

Flowchart:
- MeOH/DME (From Gasifier)
- Gasoline Synthesis
- Separation
- Off-Gas to Gas Turbine
- Light Ends
- Gasoline
- Water
TIGAS CCSR

O₂ → Oxygenate Reactor → SEP → Gasoline Reactor → Separation

- CO₂/DME
- H₂/CO/MeOH/H₂O
- Light Ends
- Gasoline
- Water

Hi-P CO₂/N₂ → Combustor or Gas Turbine

H₂/CO/CH₄/C₂H₆/N₂ → Light Ends

~50-90% CO₂/DME
Conclusions

- TIGAS can utilize a wide range of synthesis gas
- TIGAS offers a highly efficient CCS solution