Sector Overview from a European Perspective: Experiences of Gasification Technologies in Europe

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5 to 6 November 2012, Johannesburg
Agenda

- Evolution and status of commercial-scale European gasification technologies
- Market and technology trends and development drivers for gasification
- Pilot and demonstration-scale gasification research at the IEC
- Current and upcoming research tasks
Gasification Technology Generations

1st generation
- Lurgi dry ash
- Winkler
- Koppers-Totzek

2nd generation
- GE
- HTW
- Shell
- Phillips66
- SFGT
- etc.

3rd generation
- BGL
- KBR
- MHI
- OMB
- PWR

Since 1920s 1970s ~1990

Development Fixed Bed Gasifiers

1920’s/30’s
- Lurgy Fixed Bed Dry Bottom

1932
- Hirschfelde plant

‘40s/’50s/’60s
- Development & several plants from Lurgi

1950’s
- Sasolburg plant

1953
- Schwarze Pumpe plant

1964
- Lurgi/British Gas develop BGL gasifier

1970’s – 90’s
- Several commercial units

1990’s
- Pilot scale+demo scale units in Westfield

2000
- Commercial scale at Schwarze Pumpe

2003
- Sasol FBDB, Lurgi FBDB
- Envirotherm acquires technology
Development SCGP & Prenflo

1941
Koppers-Totzek

1974
Shell-Koppers

1974
Krupp acquires Koppers → Krupp-Koppers

1981
Krupp-Koppers

1994
Krupp-Koppers acquires Uhde → Krupp-Uhde

1997
Buggenum IGCC

1998
Puertollano IGCC

Sources: Uhde brochure; GT 618 1500e 10/2010 Uhde/TK PM; 22.09.2010
S. van Paasen; Technology Development for Shell Coal Gasification Technology; 5th International Freiberg Conference; 2012
Development SFGT

- 1941: Oil POX TU BAF
- 1976: DBI & GSP & TU BAF
- 1984: Gasifier at Schwarze Pumpe plant
- 1991: Noell acquires Technology
- 2000: Preussag AG
- 2003: Sustec & Future Energy
- 2006: Siemens

Adapted from Morehead, 2006
- Developed as Lurgi dry bottom gasifier in the 1920th/30th in Germany

- Application: FT, SNG, MeOH, Ammonia, Power, Chemicals
Today, 75% of global coal gasification capacity

131 gasifiers in operation

- Vresova 26 Power
- Sasol Synfuels, Secund, SA 80+4 Liquid fuels & chemicals
- Dakota Gasification Company, Dakota, USA 14 SNG
- Shanxi-Tianji Coal Chemical Company, CHN 5 Ammonia
- Yima, CHN 2 MeOH

Current activities:
- Jindal Steel & Power, Angul plant
  225,000 Nm³/hr Syngas from 7 gasifiers, start up 2013

Projects under developments
- 8x Coal to SNG
- 7x Coal to Liquids
- 3x Coal to Chemicals
- 1x Coal to MeOH
- 4x Coal to Fertilizer
- 1x Coal to Power

Next technology steps
- Mark+ (60 bar, twin coal lock, 5.05m outer diameter)

Adapted from: M. Weiss; GTC Conference; 2011
Fixed Bed – BGL

- Envirotherm co-owns BGL process since 2003
- Application: Syngas production from various feedstocks

- Commercial plants
  - Schwarze Pumpe (SVZ) plant, GER
    2000-2007: Coal and solid waste (75 %wt) to MeOH
  - Hulunbeier plant, Inner Mongolia, CHN
    since 2011: Ammonia & Urea from briquetted lignite

- Current activities
  - Yituo project, Luoyang, CHN
    Fuel gas from hard coal (start up: 2013)
  - Ordos Tuke, Inner Mongolia, CHN
    Ammonia & Urea from bituminous coal (start up: 2013)
  - Shriram Project, Dharma, Orissa, IND
    Ammonia from high ash hard coal (start up: 2015)
  - Pilot scale gasifier Freiberg, GER
    Investigate slag behavior at elevated pressure (40 bar)
Project under development

- SHED project, South Heart, North Dakota, USA
  - H₂ and CO₂ (EOR) from briquetted lignite (on hold)

Next technology steps

- Stirrer for caking coals
- Increase pressure to 40 bar
- Increase diameter from 3.6 to 4 m

Adapted from: M. Olschar; 5th International Freiberg Conference, 2012
ThyssenKrupp Uhde acquired HTW process from RWE in 2010
Application: High reactive feedstocks of moderate particle size

Commercial plants
- Berrenrath, GER
  1985-1997: 720 t/d (140 MW\textsubscript{th}) lignite to MeOH

Project under developments
- VärmlandsMetanol, SWE
  600 t/d (111 MW\textsubscript{th}) forest residues to MeOH
- Sundrop Fuels, Louisiana, USA
  Forest residues to 3500 barrel/d fuel
Envirotherm acquired CFB gasification process from Lurgi/Lentjes in 2003
Application: High reactive feedstocks of moderate particle size; air blown

Commercial plants
- CEMEX cement plant near Berlin, GER
  since 1996: 600 t/d of coal & secondary fuels to fuel gas
- RWE-essent plant, Amercentrale, NL
  since 2000: 500t/d wood to power and heat
- Jindal Steel and Power Co. Ltd., Barbil/Orissa, IND
  since 2011: 2x 550 t/d high ash coal to fuel gas

Source: Envirotherm presentation 13.10.2011
1974: Koppers & Shell developed pressurized version of Koppers-Totzek gasifier (Koppers experienced in coal gasification; Shell experienced in pressurized oil gasification)

- Approx. 20 running plants worldwide
- Over 47,000 t/d coal intake to Ammonia, MeOH, Hydrogen, Power
- Highest installed capacity (> 25,000 MWth of syngas) of all technologies
- High efficiency associated with comparatively high CAPEX

 Selected commercial plants

- NUON IGCC plant, Buggenum, NL
  - since 1994: 2000 t/d coal & biomass to power (253 MWel)
- Sinopec project, Zhijiang, Hulunbeier, CHN
  - since 2005: 2000 t/d coal to chemicals
- Shenhua, Majiata plant, CHN
  - since 2008: 4500 t/d coal to fuel
- Shenuha, Ningmei plant, CHN
  - since 2010: 10,000 t/d coal to PP
- Datang MTP, Inner Mongolia, CHN
  - Since 2011: 8400 t/d coal to PP
Current activities
- 4 CtL and CtC in China (Hebi, YYTH Shuifu, Datong) & Vietnam (Vinachem) summing up to > 10,000,000 Nm³/d

Selected projects under development
- “2CO” IGCC+CCS project, Powerfuel, 900 MW, Hatfield, GB
- NUON Magnum IGCC, 1200 MW, NL (on hold)
- Perdaman Chemicals & Fertilizers, CtChemicals, AUS (on hold)
- Korea West Power, 2 IGCC projects, KOR

Next technology steps
1) Replace 2 stage heat exchanger by water quench (gas quench remains)
2) Replace gas quench and heat exchanger by full water quench + turn gasifier upside down → gasifier on top quench chamber below (dip tube)

Adapted from Paasen, IFC 2012
1974: Koppers & Shell developed pressurized version of Koppers-Totzek gasifier (Koppers experienced in coal gasification; Shell experienced in pressurized oil gasification)

Commercial plants
- Puertollano IGCC, ESP
  - Since 1998: 2600 t/d coal & pet coke to power (335 MW_{el})

Projects under development
- TransGas CtL project, Mingo County, USA
- PA Energy IGCC, Somerset, USA
- ICM CtL project using PDQ, Tugrug Nuur, Mongolia

Next technology steps
- Replace heat exchanger (PSG) by full water quench (PDQ)

Adapted from Radtke, 2012
Siemens acquired GSP technology in 2006 from SUSTEC AG/Future Energy
Application: Fine grained coals to power or MeOH; developed for salty coals

Commercial plants
- Membrane wall gasifier in SVZ plant, GER
- Refractory lined SFGT gasifier in Vresova IGCC, CZ
  since 2006: 3 t/h of liquid by-products from 26 Lurgi FBDB gasifiers to power
- NCPP project, Shenhua Ningxia, CH
  since 2011: 5x 2000 t/d coal to Polypropylene

Current activities
- 24 x 2000 t/d coal to chemicals plant in Shenhua Ningxia, CHN
- Texas Clean Energy IGCC 400 MW, Summit Power, constructions start: 2013

Next technology steps
- Place radiant HE between gasification chamber and quench chamber
Industrial Coal Gasification in EU

Puertollano IGCC since 1998, Prenflo

Adapted from: ELCOGAS; 2001

Schwarze Pumpe 1964-2010, Lurgi dry ash, GSP, BGL

Adapted from: Sander; GTC conference; 2003

Vresova, since 1969, Lurgi, GSP

Adapted from: Bucko; GTC conference; 1999

Buggenum IGCC since 1994, Shell

Adapted from: Kanaar, GTC conference; 2002

CEMEX plant, since 1995, CFB

Adapted from Vattenfall Europe, 2008

Adapted from: A: Laugwitz et al.; Availability analysis of integrated gasification combined cycle (IGCC) power plants, In: Oakey, J.E. (Edt.); 2011
Global Gasification Market

- Coal is main feedstock for gasification
- Chemicals and liquids are main products
- 8 IGCC power plants worldwide (EU, USA, JPN)
- Shell, Lurgi dry bottom, GE, SFGP highest installed capacities

### Share of Coal in the Gasification Market

#### Product

<table>
<thead>
<tr>
<th>Product</th>
<th>Syngas Capacity (MW)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemicals</td>
<td>19,396</td>
<td>46.7</td>
</tr>
<tr>
<td>Fischer-Tropsch fuels</td>
<td>14,096</td>
<td>33.9</td>
</tr>
<tr>
<td>None-Fischer-Tropsch fuels</td>
<td>861</td>
<td>2.1</td>
</tr>
<tr>
<td>Gaseous fuels</td>
<td>1,900</td>
<td>4.6</td>
</tr>
<tr>
<td>Power</td>
<td>5,315</td>
<td>1.8</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>41,569</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

#### Country

<table>
<thead>
<tr>
<th>Country</th>
<th>Syngas Capacity (MW)</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>20,369</td>
<td>49.0</td>
</tr>
<tr>
<td>South Africa</td>
<td>14,096</td>
<td>33.9</td>
</tr>
<tr>
<td>USA</td>
<td>4,405</td>
<td>10.6</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>776</td>
<td>1.9</td>
</tr>
<tr>
<td>Japan</td>
<td>861</td>
<td>1.8</td>
</tr>
<tr>
<td>Spain</td>
<td>588</td>
<td>1.4</td>
</tr>
<tr>
<td>Netherlands</td>
<td>466</td>
<td>1.1</td>
</tr>
<tr>
<td>Others</td>
<td>126</td>
<td>0.3</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>41,569</strong></td>
<td><strong>100.0</strong></td>
</tr>
</tbody>
</table>

- Especially in China, with
  - Olefines
  - Ammonia
  - Fuels
  - SNG

- 8 IGCC power plants worldwide (EU, USA, JPN)

- approx. 60 Mt/a coal (daf)

Own calculations based on:
DOE’s Gasification Database. National Energy Technology Laboratory, 2012
Global trends:

- Moderate growth for IGCC plants (only 3 out of 32 announced projects realized since 2008)
  - Edwardsport & Kemper County (USA) and Tjianjin IGCC (GreenGen-Project) (CHN)
- Growing interest in polygeneration, e.g. Texas clean energy project (Summit)
- Continued growth of CtX in China

- Substitution of crude oil by other energy sources (natural gas, biomass, coal, shale gas)
- Increasing utilization of low-grade coals (esp. high ash contents) in particular in emerging economies
- Emerging shale gas utilization competing with CtX

- Reduction of CO$_2$ emissions and commercialization of CO$_2$ end use, e.g. for EOR
- Partial CO$_2$-capture concepts, e.g. Kemper County

Technology trends

- 3$^{rd}$ generation gasification technologies and concepts
  - Compact gasifiers (PWR)
  - Mild Gasification (INCI)
- New components
  - Solid feed pumps (PWR, GE)
  - Advanced refractory materials
Development Drivers

**Reduction of Capital Cost**
- Increase in single unit capacity
- Integration of dry feed pumps

**Adaption to Low Grade Feedstock**
- Inclusion of full water quench in portfolio
- New concepts

**Product optimized Process**
- Increase in gasification pressure
- Migration from slurry to dry feeding or slurry drying
- Inclusion of syngas cooler in portfolio
- Inclusion of full water quench in portfolio

- GE
- Siemens
- Lurgi FBDB
- Phillips66
- Lurgi FBDB
- Shell
- Prenflo
- Siemens
- INCI
- Phillips66
- GE
- PWR
IEC – Scientific Approach

Modeling-based research at IEC:
- CFD: Gaseous and liquid fuels: POX
  - Coal: fixed bed, entrained flow and fluidized bed
- Flow Sheet: Comprehensive stationary and dynamic modelling, concept development and technological, energetic, ecological and economic evaluation

Experimental research at IEC:
- Lab Scale: Low and high-temperature conversion of coal and biomass
- Large Scale: POX + ATR of gaseous and liquid fuels
  - Slagging fixed bed + fluidized bed coal gasif.

Dependent on:
- Fuel characteristics and conversion behavior
- Process conditions
- Process technology
Demonstration of the INCI Gasifier = Internal Circulating mild transport gasifier
Funded by the German Federal Ministry of Economics and Technology (BMWi)

- Design and demonstration of a 100 kW mild transport gasifier (standard pressure)
- Gasification of coals of different grades
- Prove superior performance for processing low grade coals
- Gasifier modeling (flow sheet & CFD)

Plant features:
- Ambient pressure
  \[ T \leq 1.100 \, ^\circ C \] (resistively heated, flame \[ \approx 1.800 \, ^\circ C \])
- Atmosphere: \( \text{H}_2\text{O}, \text{O}_2, \text{CO}_2, \text{H}_2, \text{CO}, \text{Ar}, \text{N}_2 \)
- Feed: coal and coke dust (\( \leq 0.5 \, \text{mm}, \leq 15\,\text{kg/h} \))
- Measurement equipment: - Online-GC
  - Online-FTIR
  - Radiometric densitometry
  - Particle Image Velocimetry
  - Thermography (visible light range)
- 9 levels of gas sampling, 3 levels with optical ports

Under commissioning
**IEC – Slag Bath Gasifier**

**Fixed bed slagging (slag bath) gasifier for the utilization of low-grade fuels**
Funded by the European Development Fund and the Federal State of Saxony (Sächsische Aufbaubank – SAB)

- Ground breaking: 05/2012
- Commissioning planned for 05/2013

**IEC activities/project objectives:**
- Operation of a 10 MW(th) slagging fixed-bed gasifier at 40 bar
- Investigating of slag formation and behavior at high pressures:
  - Studies on fuel influence
  - Collecting material property data
  - Application-oriented slag modeling
Feed and products:

- **Feed:**
  - 700 m³/h (STP) syngas from HP POX plant
- **Main product:**
  - Gasoline: 90 kg/h (approx. 120 l/h) meeting the Euro IV standard
- **By-products**
  - Fuel gas
  - Feed water

**New STF technology – process characteristics**

Funded by CAC Chemitz GmbH, the European Development Fund and the Federal State of Saxony (Sächsische Aufbaubank – SAB)

- Conversion in two steps:
  1. Syngas $\rightarrow$ Methanol
  2. Methanol $\rightarrow$ Gasoline

- Novel reactors for isothermal operation
IEC – POX Plant

Gasification modes
- ATR (autothermal catalytic reforming of natural gas)
- Gas-POX (autothermal non-catalytic reforming of natural gas)
- MPG (autothermal gasification of liquid feeds)

POX plant specifications
- Max. pressure: 100 bar
- Temperature: 1200 – 1500 °C
- Thermal power: 5 MW
  \( \approx 500 \text{ m}^3(\text{STP})/\text{h NG} \)
  \( \approx 500 \text{ l/h liquid fuels} \)
- Adjustable reactor volume
- Lurgi technology
- First test runs: 2004

Feedstock
- Natural gas
- Light or heavy fuel oils
- Residues of oil processing

Lurgi (Air Liquide Group)
### IEC – Syngas-Based Coal Utilization Concepts

#### Energetic coal utilization → Maximum efficiency and minimum CO₂ emission

<table>
<thead>
<tr>
<th>3&lt;sup&gt;rd&lt;/sup&gt; generation IGCC concepts including co-feeding of biomass and CCS</th>
</tr>
</thead>
<tbody>
<tr>
<td>(reasonable: 85% C retention) → C content in product 0%</td>
</tr>
</tbody>
</table>

#### Non-energetic & energetic coal utilization → Grid stability & flexibilization of power production

<table>
<thead>
<tr>
<th>Annex concepts</th>
</tr>
</thead>
<tbody>
<tr>
<td>Connecting coal gasifier and synthesis to conventional large-scale power plant</td>
</tr>
<tr>
<td>Optional coupling of regenerative H₂ &amp; generation of peak electricity from synthesis products</td>
</tr>
<tr>
<td>→ C-Einbindung abhängig von weiterer Nutzung der Syntheseprodukte</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Stand-alone polygeneration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Static or flexible coupling of CC power unit and CtL unit</td>
</tr>
<tr>
<td>Optional coupling of regenerative H₂ und co feeding of biomass</td>
</tr>
<tr>
<td>→ C content in products depends on share of power generation and product type</td>
</tr>
</tbody>
</table>

#### Non-energetic coal utilization → Long-term option of coal utilization w/o CCS and with co-feeding of biomass

<table>
<thead>
<tr>
<th>Conventional CtL concepts for substitution of crude oil based routes</th>
</tr>
</thead>
<tbody>
<tr>
<td>→ C content in products depends on coal quality and synthesis product 40–55%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>New material driven coal utilization opening new markets along the value chain</th>
</tr>
</thead>
<tbody>
<tr>
<td>→ Maximize C content in product up to 70%</td>
</tr>
</tbody>
</table>
IEC – Quality-Dependent Staged Coal Conversion

Production of specialty chemicals by extraction, pyrolysis und gasification

Goal:
New highly efficient processes and process chains yielding max. added value from coal (biomass)

Requirements:
- Process chain approach according to:
- Production of specialty chemicals (e.g. waxes) in line with market instead of mass products (e.g. tars)

Boundary conditions:
- In the future increasing share of „difficult refining coals“, e.g. wax content < 8 \%wt
- Demand for minimum CO₂ emissions

Important tasks:
1. Structural assessment of coals and products (Benefit from improved measurement techniques)
2. Development of new, high efficient, product-selective processes at lab-scale (esp. extraction)
3. Analyzing process chains using flowsheet simulation and evaluation of value-added chain applying “SocioEcoEfficiency-Tools”
IEC – Research on Industrial-Scale Gasification I

Goal:
- (Further)development to 3rd generation (not optimizing existing processes)

Requirements:
- Processing of „difficult“ (low rank, low grade, salty), ash-rich (>30 %), fine-grained (washery tailings) coals with high ash-fluid temperatures and co-gasification of biomass
- High cold-gas efficiency at high loads high fuel flexibility
- Bigger capacities: 1.000–2.000 MW(th)
- Suitability to high pressure syntheses → gasification pressure 60–100 bar
- High reliability (fuel flexibility)
- Fundamental technical simplification (geometry, plug flow, feeding system)

Important tasks
1. Forward modeling of gasification → CFD of reactive flows in large reactors
   → Designing reactor geometries applying validated models
   → Reality validation of models in lab-scale and pilot-scale

2. Validation experiments → Coal dust gasification flame equipped with special measuring technology
   → Reality gasifier slag experiments (slag bath gasifier)
3. 3rd generation gasifier design → Mild Gasification with internal heat integration (COORVED/INCI), transport principles and coal feeding for highest pressures
   → Proof of principle, demonstration experiments

4. New process components → lock hopper free solids pressurization and depressurization system
   → New chemical/physical gas cleaning (e.g. plasma)

5. New high temperature materials → resistant to temperature swing and slags, self-healing ceramic materials

6. Dynamic Modeling → Single components and complete systems

7. Process chain modeling → High resolution, generic models for concept studies
Thank you for your attention – Questions?
Bernd.Meyer@iec.tu-freiberg.de
Fuel Research in Freiberg

1918
Sächsische Braunkohlenstiftung
Saxony State Lignite Research Foundation

1921
Braunkohlenforschungsinstitut
Lignite Research Institute

1947
Berufung Erich Rammler
Appointment Erich Rammler
BHT Coke

1949
Deutsches Brennstoffinstitut DBI
German Fuel Institute

1956

1960

1990

1991
Deutsches Brennstoffinstitut DBI
German Fuel Institute

1993
GTI

1994
CHOREN

2003
Start-up HP POX plant

2008

2009

2010
Start-up STF plant

2011

Syngas, Fuels, Electricity
Coke/Town Gas
Liquid Fuels
**IEC – Scientific Approach**

**Goal:** Leading research center in the field of fundamental research for high-temperature conversion processes in the base material industry

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**Multi-phase systems**

Characterization and determination of material properties of multiphase systems

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**Inter-phase phenomena**

Development of sub-grid models for heterogeneous & homogeneous reactions and (Direct Numerical Simulation)

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**Reacting flow systems**

Integration of sub models in 3D CFD simulations via detailed modeling of gas phase reactions
IEC – Scientific Approach

Goal
Development of efficient technologies for non-energetic utilization of fossil and biogenic Energy-Raw-Materials as alternative to oil and natural gas

Chemistry of coal
- Strukturaufklärung
- Einkopplung H₂ regenerativ
- NT-Konversion → HT-Konversion → Synthesegas
- Aufbereitung: Trocknung, Agglomeration
- Extraktion: NT-Pyrolyse, Hydrierung
- Vorwärmung: HT-Pyrolyse, Vergasung, Eintragssystem
- Reinigung: Konditionierung, Shift-Reaktion
- Werkstoff-Entwicklung
- Chemikalien: (Propylen, Olefine, Oxoalkohole)
- Strom (IGCC, Polygeneration)
- Speicher (SNG, MeOH)
- CO₂+{4H₂=CH₄+H₂O}

Products

Resources
- Partners: 9 partners from industry und science, 8 supporting partner
- Duration: 5 years
  01.01.2010-31.12.2014
- Staff: 25 scientific and 15 technical members

Funding
  - 40% Third-party
  - 60% BMBF

Co-funding