A Major Energy Opportunity in Central Europe

Peter van Vuuren

Commercialization of UCG Flow Scheme to Radically Improve Cost Performance and Life Cycle Impact

Peter van Vuuren
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Overview:

1. Why this study? (Where does UCG fit into?)
2. Study Scope
3. Cost Performance Results
4. Life Cycle Analysis Results (CO$_2$e, Air, Water)
5. Commercialisation and Future Advancement
6. Technology Risks
Why this study:

1. Where and how does UCG fit in to large scale commercial facilities and how should UCG be commercialised?
2. How does UCG flow schemes compare to its technology peers (Cost, Impact & Risk)?
3. Direction of development?

NGCC: Natural Gas Combined Cycle, IGCC: Integrated Gasification Combined Cycle, PC: Pulverised Coal
Scope of the Study:

Product & Place: Electricity in Central Europe

Technologies evaluated:
1. PC (Sub & Sup Critical)
2. NGCC
3. GE/CoP/Shell-IGCC
4. UCG-IGCC (UGCC)

Benchmarking methods:
1. Cost Performance (€/MWh)
2. Life Cycle Analysis (CO$_2$e, Water, Emission and Waste)

Base Studies: DOE/NETL Studies

Cost Performance
Cost Performance: Methodology

Base DOE/NETL Study \[^1\]

IGCC vs. PC vs. NGCC

GE IGCC

UCG-IGCC flow scheme workup

Combined Indexed Results

Cost of Electricity €/MWh, Central Europe, 2011

UCG-IGCC vs. GE IGCC

Capex -27%

Fixed Cost -20%

Variable Cost -31%

Efficiency +5%

Availability +6.3%

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\[^1\] Cost and Performance Baseline for Fossil Energy Plants, Volume 1, Rev 2: Bituminous Coal and Natural Gas to Electricity, Nov 2010, DOE/NETL

GE: General Electric, CAPEX: Capital Expenditure, IGCC: Integrated Gasification Combined Cycle, NGCC: Natural Gas Combined Cycle, PC: Pulverised Coal
Cost Performance: CAPEX & OPEX

**Fixed Cost** reduced by **20%**: (maintenance labour: -7%; PT&I: -13%)

**Variable Cost** reduced by **31%**: (maintenance material: -22% and ash handling: -9%)

**Efficiency** increased by **5%**, from 39% to 41.1% (HHV).

**Availability** increased by **6.3%** from 80% to 85% (+10% redundancy)

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Cost Performance Results

Cost of Electricity €/MWh, Central Europe, 2011

Costs: CO₂ cost @ €20/ton CO₂, NGCC @ 80% and 50% Dispatch, rest @ 100% dispatch

Cost of Electricity €/MWh, Central Europe, 2011

Costs: CO₂ cost @ €20/ton CO₂, NGCC @ 80% and 50% Dispatch, rest @ 100% dispatch

Life Cycle Analysis
UGCC’s advantage comes from combines mining, transport and energy conversion steps.

Life Cycle Analysis: CO$_2$e/MWh

<table>
<thead>
<tr>
<th>Technology</th>
<th>€/ton CO$_2$ @90% CCS</th>
<th>Increase in Elec Price of 90% CCS at 57 €/MWh basis</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td>60 (+30%)</td>
<td>92-97% (+28% for revamp)*</td>
</tr>
<tr>
<td>NGCC</td>
<td>80 (+30%)*</td>
<td>51-61% (+17% for revamp)*</td>
</tr>
<tr>
<td>IGCC</td>
<td>40-50</td>
<td>51-74%</td>
</tr>
<tr>
<td>UGCC</td>
<td>30-40</td>
<td>25%</td>
</tr>
</tbody>
</table>

Cost of CO$_2$ Removal for new power plants

*Increase CO$_2$ cost (€/t) by 30% for revamping existing power plants, due to electricity replacement requirements.

Life Cycle Analysis: Air, Waste, Water

- **CCS**: Carbon Capture and Storage
- **PC**: Pulverised Coal
- **IGCC**: Integrated Gasification Combined Cycle
- **NGCC**: NGCC: Domestic, LNG: Liquefied Natural Gas
- **CCCS**: Co-CCS
- **Demo**: UCG-Demonstration Facility
- **LC**: Life Cycle
- **CO2e**: CO2 Equivalent
- **VOC**: Volatile Organic Component

**Air Emissions**
- Emissions kg/MWh
- **No CCS** vs. **CCS**
- SubCPC, GE IGCC, NGCC D, NGCC LNG, UGCC

**Solid Waste**
- Graph showing waste generation with and without CCS

**Water Consumption**
- m³/MWh
- **CCS** vs. **No CCS**
- SubCPC, GE IGCC, NGCC D, NGCC LNG, UGCC

**Notes**
- H2O Withdrawal
- Waste H2O Outfall
- H2O Consumption

- **Pb**, **Hg**, **NH₃**, **CO**, **NOX**, **SOX**, **VOC**, **PM**, **Solids**

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CCS: Carbon Capture and Storage, PC: Pulverised Coal, IGCC: Integrated Gasification Combined Cycle, NGCC: D Natural Gas Combined Cycle - Domestic, LNG: Liquefied Natural Gas
Benchmarking Summary

Cost of Electricity and Equivalent CO₂ / MWh for Different Electricity Generation Technologies for Central Europe, 2011

CCS: Carbon Capture and Storage, PC: Pulverised Coal, IGCC: Integrated Gasification Combined Cycle, NGCC-D/LNG Natural Gas Combined Cycle – Domestic/Liquefied Natural Gas
CCCS: Co-CCS, Demo: UCG-Demonstration Facility, CO₂e: CO₂ Equivalent, COE: Cost of Electricity

Conventional IGCC
UCG changes performance curve of IGCC
Ideal UGCC

UCG Demo
No CCS

Ideal UGCC
CCCS 35%

UGCC
CCS 60%

UGCC
CCS 35%

SubCPC
No CCS

IGCC
No CCS

SubCPC
CCS 90%

NGCC LNG (80% Dispatch) CCS 90%

NGCC LNG (80% Dispatch) No CCS

NGCC D No CCS

NGCC D CCS 90%

NGCC LNG (80% Dispatch) CCS 90%
UGCC Flow Scheme Advancements

1. CO₂ Recycle to the UCG Cavity
   • Improves overland transport of UCG feed
   • Reduces water usage and gas liquor handling systems
   • Reduces capacity requirements of the IW
   • Has synergies with CCS
   • More robust process
   • Higher and more stable CV of pure gas

2. In-well Partial SHIFT/COS Hydro
   • More robust water management
   • More robust CO₂ and sulphur management

3. ITM Oxygen Production
   • Reduce capital and operating cost of oxygen generation
   • Increased thermal efficiency

4. H Class GT
   • Increased thermal efficiency

Reduce COE By 10-20%

UCG Commercialisation

UCG Commercialisation Roadmap
Gasification and Processing Options

Gasification Syngas

- Combined Heat and Power Generation
  - Methanol & Higher Alcohols
  - Substitute Natural Gas (SNG)

  - FT Syncrude
    - Hydrogen
    - To Hydrogenation (Pet refining & Others)
    - To Hydrocracking
    - To Ammonia Synthesis
    - Possible Fuel-Cell Fuel

  - To Refining Upgrading to Naphtha Steam Cracker
    - Alpha Olifins
    - Lube Oil Based Stock
    - Special Waxes

  - Gasoline & Diesel Fuel
    - Ethylene & Propylene
    - Urea (fertiliser)

- To Oxo Chemicals & Derivatives
  - Butanediol
  - Butanol
  - MTBE
  - Formaldehyde
  - DME
  - Acetic Acid
  - Acetaldehyde
  - Acetic Anhydride
  - Chloromethanes
  - DMT
  - MMA
  - Methyl Amine

- Possible Fuel-Cell Fuel

To Refining Upgrading to Naphtha Steam Cracker

- Alpha Olifins
- Lube Oil Based Stock
- Special Waxes

- Ethylene & Propylene
- Urea (fertiliser)

Possible Fuel-Cell Fuel
1. Electricity generation is more robust and forgiving than catalytic processes (no H₂/CO control, no catalyst poisoning) and therefore less restrictive,

2. Economy of scale for electricity generation levels earlier than for CTX options (400 MWe vs. “1 500 MWe” for CTL) requiring less capital than CTX for a commercial scale plant,

3. Electricity generation produces an end product (commodity product) and more regularly has an existing product distribution network and a predictable market,

4. IGCC flow schemes have synergies with UCG and have a good environmental profile,

5. IGCC as a whole and its primary technology blocks have been well developed and demonstrated and leave the door open for poly-generation options.

CCGT: Combined Cycle Gas Turbine, IGCC: Integrated Gasification Combined Cycle, CTL: Coal to Liquids, CV: Calorific Value, CTX: Coal to X
Which IGCC Flow Scheme for UCG?

**Feeds**
- Air
- Enriched Air
- \(O_2 + \text{Steam}\)
- \(O_2 + \text{CO}_2\)

**UCG**
- L-CRIP, P CRIP
- LVW
- Well technology
- Ignition technology
- CRIP Technology
- Depth, Pressure & Monitoring

**Water Treatment**
- Incineration
- Chemical Recovery
- Biological treatment

**Gas Cleanup**
- Rectisol
- Selexol
- CrystaSulf
- Sulfrox
- Thiopax
- Lo-Cat
- Amines
- Flexorb
- ADIP
- Sulfinol
- Claus
- ProClaus
- Selectox
- DOClaus
- OxyClaus

**Pre-treatment**
- Quench and Cool
- Hot Gas Cleanup
- Shift
- COS Hydrolysis
- Hg Removal

**Integration**
- ASU \(N_2\)
- Waste water reuse
- Gas liquor reuse
- \(\text{CO}_2\)
- \(\text{CO}_2&H_2S\)
- GT Air
- Steam

**Power**
- CCGT
- OxyOptions

**CTX**
- Polygen
- CCUS
## Which IGCC Flow Scheme for UCG?

<table>
<thead>
<tr>
<th>Feed</th>
<th>UCG</th>
<th>AGR</th>
<th>SRU</th>
<th>Integration</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>St + O₂</td>
<td>P-CRIP</td>
<td>1Step Selexol/</td>
<td>Oxy or ProClaus</td>
<td>Steam ASU</td>
<td>High Rank +400m Deep</td>
</tr>
<tr>
<td>St + O₂</td>
<td>P-CRIP</td>
<td>CrystaSulf</td>
<td>-</td>
<td>Steam ASU</td>
<td>High Rank +200m Deep</td>
</tr>
<tr>
<td>E-Air</td>
<td>P-CRIP</td>
<td>CrystaSulf</td>
<td>-</td>
<td>Air</td>
<td>Mid-High Rank +200m Deep</td>
</tr>
<tr>
<td>CO₂ + O₂</td>
<td>P-CRIP</td>
<td>2Step Selexol</td>
<td>Oxy or ProClaus</td>
<td>CO₂ ASU</td>
<td>Mid-High Rank +400m Deep</td>
</tr>
<tr>
<td>CoCO₂ + O₂</td>
<td>P-CRIP</td>
<td>1Step Selexol</td>
<td>-</td>
<td>CoCO₂</td>
<td>Mid-High Rank +400m Deep</td>
</tr>
</tbody>
</table>

**Know though feed!**
Road Map: Small Scale Commercial Demo

1. **Geo + Site**: Address geological, hydrological requirements for UCG
2. **POC**: Address underground infrastructure establishment to reduce risk
3. **Pilot Plant**: Explore operating envelope to upscale
4. **Demo**: Plant size and value chain will demonstrate all commercial aspects (availability, operatability, reliability, ground water management…).
5. **Full Commercial**: Quick commercialisation for various commercial possibilities.

Road Map: POC as first step of Small Scale Commercial Demonstration Plant, which is stepping stone to full scale commercialisation.

POC: Proof of Concept; CRIP: Continuous Retractable Injection Point; IRR: Internal Rate of Return
The Risks of UCG:
"Risk": Unstoppable Fire

1) Remove Heat
   - H₂O Quench
   - Water Influx

2) Shutoff Oxidant
   - De-pressurise
   - Flood Cavity

3) Remove Fuel

= Auto Shutdown

Rock Strata

Lithostatic Pressure

400 - 1000 m

Water Table

4.15 m

Deep Coal Seam

UCG Cavity

P_{UCG} < P_{H₂O}

Char

Ash

Syngas Oxidant

Hydraulic Pressure

300 - 800 m

Surface
Risk: But there are underground fires?

- Witbank, South Africa
- Not all sinkholes cause underground fires
- Underground fire: Chimney effect
- Slow smouldering underground fire
Risk: But there are underground fires?

Conditions for Ground Fires:
- Shallow (30-60m) reactive coal
- No water table above seam to seal
- Mined out areas and unstable cavity roof
- Sinkholes and fractures to surface

Conditions for Ground Fires:
- Remove Heat – cavity does not flood or run dry after flooding and reignite
- Remove Oxidant – connected to atmosphere
- Remove Fuel – very slow process of removing (burning) fuel
Risk: Underground Water Pollution?

- No Hydraulic Fracturing
- Well Seal
- Liquid Seal

Coal Seam

Process Wells

Danube

Water Table

See Level

400 m

600 m

400 m

400 m

100 m

8-15 m

\( P_{UCG} < P_{H2O} \)

Ash

Slow Water Ingress

Liquid Seal

No liquid flow
Risk: Underground Water Pollution?

Hydrologic character of coal and rock strata are measured and modelled to predict suitability and behaviour.

Groundwater level and quality is continuously monitored during and post gasification.

Heat flow is suppressed by counter current water influx to reduce the heat affected zone and enhances UCG efficiency.

Liberated organics from heat affected zone (close to cavity) are flushed into cavity.

Ash is sintered (melted) and left underground: Prevents leaching inorganic into water
1. Increased permeability occurs in goaf zone, increasing water influx into cavity.
2. Goaf needs to reseal to maintain a liquid seal and prevent a bridge in containment (pressure, gas or heat).
**Risk: Subsidence**

UCG Cavity design (size, width, pillars) can be used to control goafing and subsidence.

Deep mining (high strip ratio) prevents or reduces surface subsidence.

Bulking factor (rock breaking and rock swelling when introduced to water) fills the UCG void.

Ash is left underground and reduces the gasification void size. Also helps with reseal.
Geotech logging and rock mechanical modelling are used to predict goafing behaviour and design the UCG panel for or without subsidence.
Risk: Subsidence

Photo taken upwards in a limestone mine rock fall, showing bridging formation.

S/H (Strip ratio = Seam thickness mined out / Overburden thickness) - for UCG the ash is left behind and reduces the void (mined seam thickness).

UCG type, if circumstances allows

Class B
0,001 < S/H < 0,005

Class C
0,005 < S/H < 0,02

Class D
0,02 < S/H < 0,05

Class E
S/H > 0,05
Risk: Underground Site Selection

1) Favourable Economics for UCG Reactor Construction and Operation: Drilling, Welling...

2) Stable, Safe and Environmentally Acceptable Reactor: Geology, Goaf, Geohydrology, Permeability, Design...

Surface: No infrastructure above UCG (roads, buildings, water ways).

Rock Strata: Good competent, low permeability roof that provides a good liquid seal and reseals well after a goaf

Water Table: Stable and high water table

Coal Seam:
Deep: 150-600 m
Thick: 2-15 m
Low Falts
Low Displacements
High Rank and High Calorific Value
Low Permeability and Low Moisture
Risk: Control and Stable Production

1. **Gas Quality**: general composition, CV, Wobbe Index, flame speed, pressure, condensates, H$_2$/CO ratio and trace components
2. **Thermal Quantity**: volumetric flow rate, pressure drop, O$_2$ Yield and MWt
3. **Availability**: time on stream, ramp-up, maintenance requirements, redundancy

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**Feeds Control:**
Design, Feed compositions, Throughput...

**Gas Processing:**
Design for variability, Pressure, Cleaning, Shift, CO$_2$ removal, Mix, Hg removal, ...

**UCG Design:**
Technology, CRIP, dimensions, redundancy, goaf, ...

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Coal composition does not significantly change

Water table and water influx can change

Goaf can occur

Ash
Why this study: Original Objectives

1. Where and how does UCG fit in to large scale commercial facilities and how should UCG be commercialised?
2. How does UCG flow schemes compare to its technology peers (Cost, Impact & Risk)?
3. Direction of development?

NGCC: Natural Gas Combined Cycle, IGCC: Integrated Gasification Combined Cycle, PC: Pulverised Coal
Thank You
Questions
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Current Status of Project

1. Conceptual Engineering Completed
   a. BFD
   b. PFD
   c. Process Modelling

2. Site Selection

3. Underground Works
   a. Exploration
   b. Resource Modelling
Project: Engineering and Exploration

Conceptual Engineering Package

1. Design Basis
2. Conceptual Engineering Report
   i. BFD Development
   ii. PFD Development
   iii. Project Scoping
3. Scope of Facilities
4. Cost Estimation
5. Site Selection
6. Process Modelling
7. Environmental Permitting Process

Exploration Works

1. Exploration Licences
2. Exploration Drilling
3. Resource Modelling
4. Hydrological Studies and Modelling
Demo BFD

IP Sensitive Information Removed
IP Sensitive Information Removed
Modelling: Process and Resource

UCG Data Workup
- Coal Balance
  - C-Balance
  - S-Balance
  - N-Balance
- Water Influx
  - H-Balance
  - O-Balance
- Leak Balance
  - Ar-Balance
- Over Burden
  - C/O/H - Balance

Information Required for Model Calibration
- MHI HTG: Mass and Energy Balance Data
- FBDB: Mass and Energy Balance Data
- RM 1: Mass and Energy Balance Data

Process Model Development
- Model Creation
- Model Data Fitting and Calibration
- Use 7 Model Method for: Air, CO2, Steam Coal types

Hydro/Geological and Model Development
- Exploration activities to acquire data
- Hydrological, Rock-mechanical and Geological Models

Flow Scheme Development

Recommendations
1) Which Flow Scheme
2) Which Design Basis
3) Future Development
4) Which Site

Technology Blocks
- O2, AGR, SRU, FT, SHIFT...

Flow Schemes
- IGCC, FT, MeOH, SNG...
Site Selection

Above Ground Site Selection

Below Ground Site Selection

Site Selection
1. Site Information
2. Facility Layout
3. Site Evaluations
4. OBL Scope (water, grid connection)
5. Environmental Risk Management
6. Geological Studies
7. Hydrological Studies
8. Exploration Drilling
9. 3D Seismic
10. Resource licensing

Location Map of the 3D survey
Current Engineering Activities

1. UCG Infrastructure optimisation and design
2. Flow scheme optimisation
   - CO$_2$ recycle options
   - Enriched air appose to O$_2$
   - Gas Purification: CrystaSulf, Selexol options
3. Other design optimisations
   - Gas Cooling
   - Incineration
4. POC optimisations and integration
5. Permitting procedures
Artist impression of UCG Demo facility
Artist impression of UCG Demo facility
Questions