This document was created in response to a Freedom of Information request made to CSIRO.

FOI Number: FOI2016/29

Date: 3 June 2016

Request: Any publications relating to “Underground Coal Gasification” which have been drafted by or released by the CSIRO or written by another entity which sourced resources or collaboration or input from the CSIRO.

Document(s): 7-8

For more information, please refer to CSIRO’s FOI disclosure log at www.csiro.au/FOILog
Carbon Energy
Important considerations
Technology variants
General performance
Site distribution
Historical notes
UCG Process
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UCG Process - Cracking

Land surface

Water table

Stress cracking & increased permeability

Cracking above UCG cavity
Some roof fall into UCG cavity

Breakage & increased permeability

Water table

Land surface
UCG Process – Closure/Collapse

Land surface  Subsidence

Water table

Roof collapse into UCG cavity
Historical notes

- Underground coal gasification has been used in large-scale operations in countries of the former Soviet Union for over 40 years.
- Numerous experimental trials have been performed in Soviet states, the USA, Western Europe and a number of other countries.
- Over 15 million tonnes of coal have been gasified worldwide.
General performance

- Product gas quality can be similar to surface gasification on the basis of calorific value, but with higher methane and lower carbon monoxide content that is similar to fixed bed gasifiers.

- Published coal recovery data is inaccurate but it is typically reported to be in the range of 70-90% of the affected coal seam.

- Major influences on performance are the coal seam thickness, ash content of coal and the rate of water ingress.
Tunnel
Parallel Wells
Steeply Dipping Bed
Controlled Retreating Injection Point
Vertical Wells

There are variations on the technology that may be applicable to specific sites.
Vertical Wells (Various configurations used by Linc Energy/Ergo Exergy/Eskom)
Tunnel
(Xinwen Mining has 6 for town gas supply)
Operating rules

Potential problems

Site selection

Applications

Environmental impacts

Important considerations
- Syntheses of liquid fuels (Fischer-Tropsch)
- Production of chemicals (eg. fertilisers)
- Synthesise Feedstock eg.
- Domestic use as town gas
- Steam production
- Low emission electricity production
- Ofuel eg.

The product gas can be used as a:

Applications for the product gas
safe and efficient UCG operation
These provide the opportunity for a
(eg. buildings, roads, etc)
Minimal surface development
No good water aquifers
Minimal geological discontinuities
Thick coal seam
Desirable site characteristics
Site Selection
characterisation errors
problems are generally related to site
Drilling errors, root collapse and flooding
performance
overburden properties, can result in poor
such as the coal seam layout and the
Poor understanding of the site features,
These are chiefly aimed at environmental protection, in brief:

- Operating pressure must be maintained below the site hydrostatic head at all times

- Shutdown must occur gradually to allow water to re-enter the cavity at a controlled rate in order to react with residual organics while still at elevated temperatures
Carbon Energy is currently conducting a 100 day demonstration of technology and has agreements relating to potential ammonia and methanol synthesis applications.

In June 2008, CSIRO sold out of Carbon Energy. In July 2006, these were transferred to a spin-off company, now called Carbon Energy. These were transferred to a spin-off company.

CSIRO developed a suite of models for performance of UCG sites and processes and prediction of the operational and environmental impacts.
Content

- UCG Process
- Historical notes
- Site distribution
- General performance
- Technology variants
- Important considerations
- Carbon Energy
UCG Process - Start

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Start of UCG process
Historical notes

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- Over 15 million tonnes of coal have been gasified worldwide.
General performance

- Product gas quality can be similar to surface gasification on the basis of calorific value, but with higher methane and lower carbon monoxide content than high T entrained flow gasifiers
  - Gas quality similar to fixed bed gasifiers
- Published coal recovery data is inaccurate but it is typically reported to be in the range of 70-90% of the affected coal seam
- Major influences on performance:
  - coal seam thickness
  - ash content of coal
  - rate of water ingress
Technology variants

- There are variations on the technology that may be applicable to specific sites:
  - Vertical Wells
  - Controlled Retracting Injection Point
  - Steeply Dipping Bed
  - Parallel wells
  - Tunnel
Vertical Wells (Various configurations used by Linc Energy/Ergo Exergy/Eskom)
(used for European trials and some in USA)

Controlled Retracting Injection Point
Steeply Dipping Bed
(used by Carbon County UCG)

Product gas

Air/Oxygen
Operating Rules
Potential Problems
Site Selection
Applications
Environmental Impacts

Important Considerations
Potential Environmental Impacts

Surface subsidence

Increased Permeability

Contamination

Water usage

Water Table
Applications for the product gas

- Syntheses of liquid fuels (Fischer-Tropsch)
- Production of chemicals (e.g., fertilizers)
- SYNTHESIS FEEDSTOCK (e.g., domestic use as town gas, steam production, electricity production)
- FUEL (e.g., fuel gas)

The product gas can be used as:

-
Efficient UCG operation

These provide the opportunity for a safe and
dependable site characteristics

(eg. buildings, roads, etc)

Minimal surface development

No good water aquifers

Minimal geological discontinuities

Thick coal seam
Site characteristics

Coal seam thickness, m vs. Depth, m

- Eastern Europe & USSR
- Western Europe, Africa & UK
- USA
- China
- Australia-NZ
unsuitable site and/or unsuitable operations

Acquirer contamination relates to selection of an

generally related to site characterization errors

Drilling errors, roof collapse and flooding problems are

result in poor performance

poor understanding of the site features, such as the

Potential problems
Operating rules

- These are chiefly aimed at environmental protection, in brief:
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Applications relating to potential ammonia and methanol syntheses demonstration of technology and has agreements Carbon Energy is currently conducting a 100 day was not transferred no rights to use these models but retains other IP that In June 2008, CSIRO sold out of Carbon Energy and has company, now called Carbon Energy In July 2006, these were transferred to a spin-off sites and processes operartional and environmental performance of UCG CSIRO developed a suite of models for prediction of the
CSIRO Energy Technology
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Senior Research Scientist
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Underground Coal Gasification:
Technical Challenges

Andrew Beath
CSIRO Energy Technology
5th May 2009
to-liquids research

Energy Technology in 2007 to work on Coal-

Exploration & Mining

Underground Coal Gasification project with CSIRO

Join CSIRO in 1999: Post-Doc modelling of

the Sugar Research Institute

Past employment: R&D roles in Pacific Power and

mathematical modelling of reaction processes

Chemical Engineer with a background in

Who am I?
What is Coal Gasification?

Coal, Water, & Oxygen → Reaction → Heat, Char, Gas, & Tar

The key product is fuel or synthesis gas that contains carbon monoxide, hydrogen and methane, plus carbon dioxide and water.
What can the product be used for?
Stages of UCG

1. Start

- Land surface
- Water table

Different geological strata (e.g., sandstone, clay, etc.)

Start of UCG process
Growth of UCG cavity

Water flow

Water table

Land surface

2. Growth
3. Cracking

Land surface

Water table

Stress cracking & increased permeability

Cracking above UCG cavity
Some roof fall into UCG cavity

Breakage & increased permeability

Water table

Land surface
5. Closure/Collapse

Land surface  Subsidence

Water table

Roof collapse into UCG cavity
What happens at the UCG site?

Surface subsidence

Increased Permeability

Contamination

Water usage

Water Table
What makes a good UCG site?

- Required gas flow
- Coal permeability sufficient to allow the permeability
- Strong overburden with low
- Moderate water influx
- Thick coal seams
- Coal seam continuity
Characteristics of trial site around the world

- Eastern Europe & USSR
- Western Europe, Africa & UK
- USA
- China
- Australia-NZ

![Graph showing characteristics of trial site around the world](image)
Parallel Well CRIP (Controlled Retreating Injection Point)
CRIP (Steeple Dipping Bed)
Vertical Wells
Chamber
Different UCG techniques
Constructing the Gasifier
Linking of wells can be through natural or artificially enhanced coal permeability or drilling.
SDB (Steeply Dipping Bed)

Production

Injection
attitude studies) selection (+ additional risk analyses & societal
geotechnical & environmental modelling that could provide better justification for site
later extended to encompass geological,

3. Evaluate suitability for different product gas uses
2. Improve design, implementation and control
1. Demonstrate an understanding of UCG behaviour.

for specific site & design combinations.

Developing models to predict the performance...
CSIRO Modelling IP
(transfered to Carbon Energy in 2006)
Coal Model

Coal Model represents a lump of coal reacting with a hot gas. Included in the model are:

- Coal structural changes
- Heat transfer
- Drying
- Water flow
- Gas diffusion
- Reactions

Output is chiefly used in the cavity model.
Well-controlled andcharacterised sites are predictable

**Time into test, days**

**Gas concentration, volume%**

**Oxygen-blow, Knife Edge CRIP**

**CASE STUDY: Rocky Mountain 1, Trial (1987-88)**
Process Simulation - Combined cycle electricity generation

Note: Simplified for presentation the real simulation involves 50+ unit processes
400MW e IGCC type plant in Surat Basin Old
Specific Site Case Study

- Site Identification
- Characterisation
- Groundwater & Characterisation
- Surface Impacts
- Societal & Attitudes
- Financial Viability & Greenhouse gas
- Design & Performance
- Modelling
The Surat Basin Site

- About 300km west of Brisbane, Queensland.
- Coal outcrops are surface mined; no underground coal mining due to high ash content.
Module life 2.3 years

3 Modules for 400MW 

Module design

600 m

6 x 30 m

20 mm/lhr

Cavity Growth

UGG design - Parallel Well CRIP
Subsidence

400X

400 times vertical exaggeration

20X

20 times vertical exaggeration

1X Vertical Exaggeration
Groundwater changes

At end of gasification
Salt contamination

In coal seam
Maximum (20 years after operations)
Constant release - no reaction or adsorption
100 years after operation
Springbok sandstone
Benzene contamination
GHG Emissions and Cost Comparison

Cost of electricity, $/MWh

Greenhouse emissions, tCO₂/MWh

- Destec IGCC with Shift & CO₂ Removal from syngas
- UCG-IGCC with Shift & CO₂ removal from syngas
- Destec IGCC with CO₂ Removal from syngas
- UCG-IGCC using untreated syngas
- Natural Gas Combined Cycle
- Conventional Coal

CSIRO. Underground Coal Gasification: Technical Challenges
created (Carbon Energy)
commercial partner sought and a spin-off
expensive
Experimental demonstration was too
efficient
Environmentally sound & operationally
UCC plants can be engineered to be
specific size of the plant at the actual site
all modelling must be repeated for the
Each site is unique

General Findings
Current Situation

**Australia**

- **Carbon Energy**: performed 100d demonstration and have agreements aimed at ammonia, methanol & electricity in Qld and WA.

- **Linc Energy**: UCG-supplied small Fischer-Tropsch plant operating & plans for 100,000bbl/day in SA and 20,000bbl/day in Qld.

- **Cougar Energy, Energie Future, Liberty Resources, Waratah Coal, Westralian Gas & Power, Metallica Minerals (MetroCoal) & Central Petroleum** have expressed interest in UCG developments.

**Worldwide**

- **Yerostigaz (Uzbekistan)**: operated a site since 1965.

- **Eskom & Sasol (South Africa)**: pilot plant and have submitted EIS for their proposed sites.

- **Solid Energy (NZ), GasTech (USA), Swan Hills Synfuels (Canada), BCG Energy (UK), HUGE (Poland)** plus others have developments proposed.
environmental problems
• maintaining consistent operation without efficient installation of instrumentation for large sites

Longer term important challenges:

more linked to commercial and government support activities, the future success of UCG appears to be CSG project. While we continue to support their performed a successful demonstration based on the

Our commercial spin-off, Carbon Energy, has

Future Challenges of UCG
Thank you

Contact Us
Phone: 1300 363 400 or +61 3 9545 2176
Email: enquiries@csiro.au  Web: www.csiro.au
...Some examples of these follow:

- Poor process control
- Construction/Geological interpretation errors
- Groundwater contamination
- Groundwater depletion
- Extreme subsidence

Problems that have occurred at past sites are:

but some more novel problems as well. Gaseous emissions, such as greenhouse emissions,

UCC has the typical coal utilisation concerns of

Major Concerns/Past Problems
Extreme Subsidence
Hoe Creek #3 Trial (USA, 1979)

- Total of 11m of coal at 39-55m depth

Photo courtesy of Wyoming DEQ

CSIRO. Underground Coal Gasification: Technical Challenges
Groundwater Depletion
Groundwater sampling from near surface monitoring well
Pre-gasification pressure at center of coal seam
Declining hydrostatic head
Reduction in operating pressure
Gasifier Pressure
M16
M18
M17
500
750
1000
1250
Vibrating Wire Pressure (kPa)
30-Mar-02
28-Feb-02
29-Jan-02
Source: Blinderman & Fidler, Water in Mining 2003

Groundwater Contamination
Hoe Creek II (USA, 1977)

- Hoe Creek II ran at a 300kPa operating pressure
- The hydrostatic head dropped to essentially zero

![Graph of Dissolved Carbon](image)

- Baseline ~3ppm

![Graph of Sulphate](image)

- Baseline ~154ppm

CSIRO. Underground Coal Gasification: Technical Challenges
Rocky Mountain 1, USA

Carbon County, USA

Alcorisa, Spain

Thulin, Belgium

Well drilled under the coal seam

Wells in different coal seams

Constitution/Geology/Interpretation Errors

Undesired fault leaked gas between two reactors
Most sites have had gas quality decline with the length of operation, some including oxygen contamination of the product gas. Variability in the hydrostatic head results in operating pressure changes, which could be significant to any process using the product gas. This is a very broad issue that needs to be addressed through careful site design and operation.
Summarising the Problems
Variability in Performance

Product gas, volume% (dry)

- Nitrogen, etc
- Carbon dioxide
- Hydrogen
- Carbon monoxide
- Methane
- Energy content

Product gas energy content, MJ/m³ (dry, STP)
Another way of looking at it...
Societal Attitude Survey

Issues raised by members of the public from the region after a discussion of the potential for UCG in the region

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<th>Prospective concerns</th>
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<td>• Better way of coal utilisation</td>
<td>• Safety</td>
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<td>• Benefits to regional community</td>
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<td>• Better alternatives</td>
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<td>• Lack of trust in politicians, scientists &amp; business</td>
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