www.csiro.au

GPO Box 1700, Canberra ACT 2601
Email: FOI@csiro.au
ABN 41 687 119 230

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): 1-5

For more information, please refer to CSIRO's FOI disclosure log at www.csiro.au/FOILog

CONFIDENTIAL – for discussion purposes only- DRAFT

s7 or s47C

[redacted]

s7 or s47C

[redacted]

Document 2

Underground Coal Gasification (UCG) in Australia

CSIRO

Cliff Mallett & Andrew Beath

Sustainable Mining Research Group

CSIRO Exploration and Mining

UCG in Australia

CSIRO Exploration and Mining

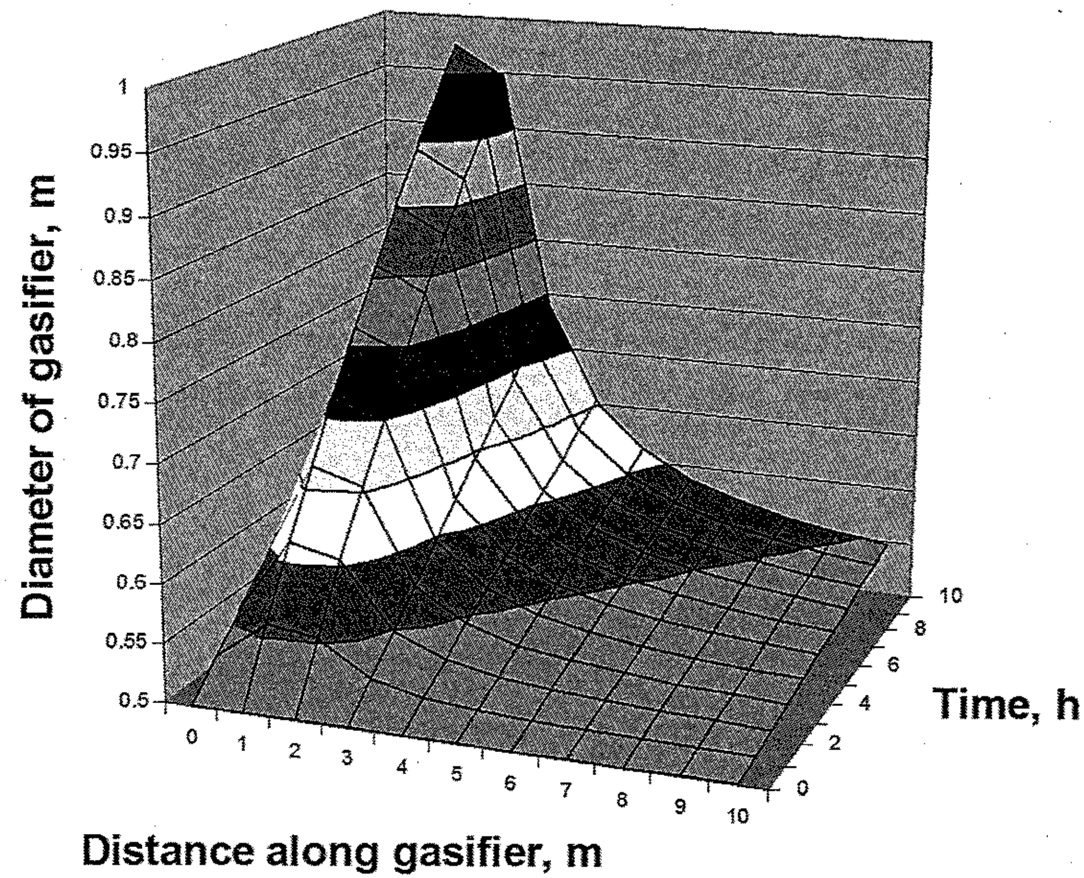
CSIRO

- Real-time UCG modelling
  - Development of a 3D modelling tool to
    - Assist in site design
    - Predict the progress of UCG cavity growth
    - Optimize product gas quality
- Process modelling
  - Design of UCG processes with reduced environmental impact
  - For example, processes with integrated carbon dioxide sequestration

UCG in Australia

CSIRO Exploration and Mining

- **Cavity growth predictions**



UCG in Australia

CSIRO Energy Technology

CSIRO

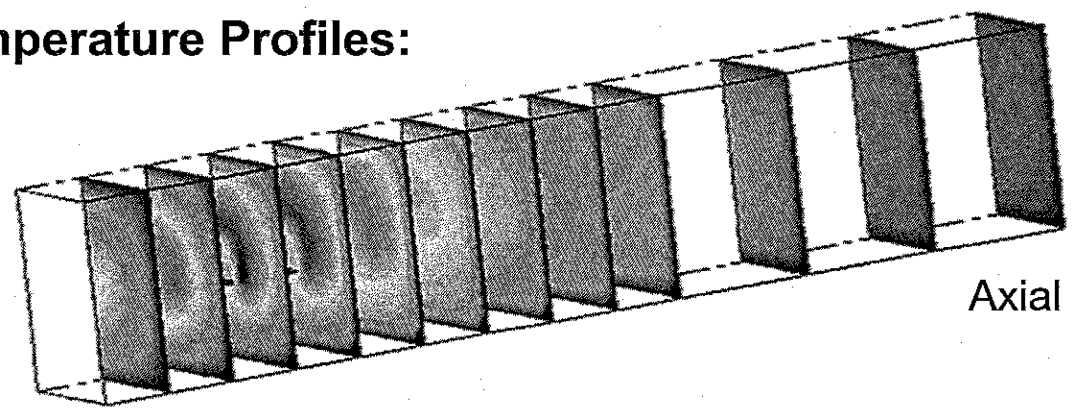
- CFD modelling of UCG
  - Detailed modelling of UCG cavity growth using a commercial fluid flow modelling package (FLUENT)
  - Includes modelling of gas flows in the gasification cavity and through porous materials

UCG in Australia

CSIRO Energy Technology

- **Example CFD model output - Temperatures**

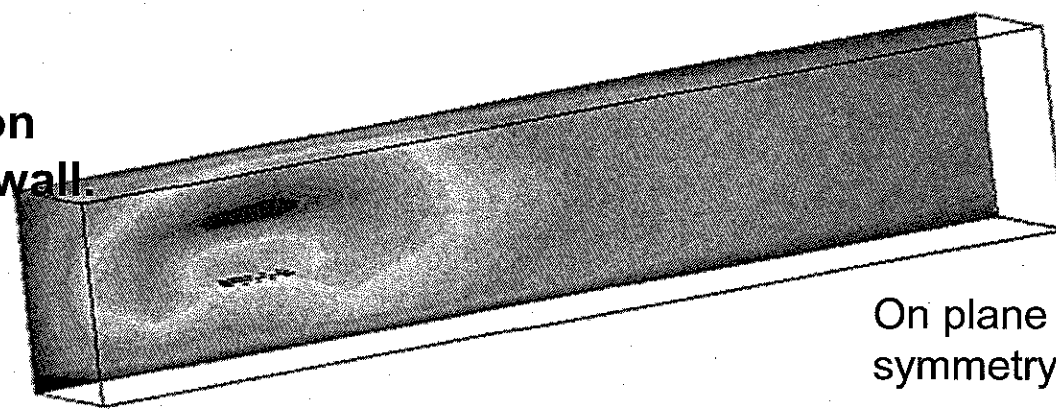
Temperature Profiles:



Max. Temp. ~1400K

Axial slices

High temperatures on cavity roof and sidewall.



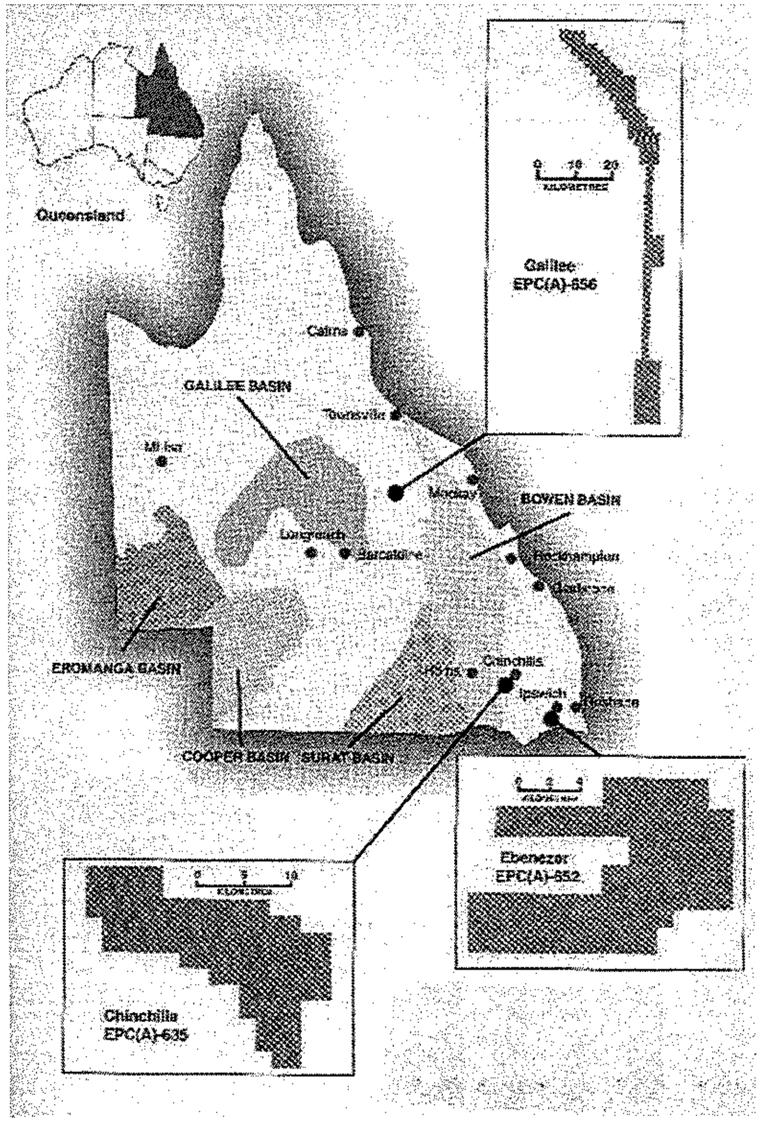
On plane of symmetry

Areas of most intense reaction and highest coal consumption

UCG in Australia

Commercial activities

- **Linc Energy**
  - Started trial in Dec 1999
  - 3-hole UCG site
  - Coal depth ~170m
  - Seam thickness 5-8m
  - Air-blown
  - Low calorific gas produced
  - Next stage a 40MW plant
  - Currently evaluating 6 sites



UCG in Australia

Concluding remarks

- Summary
  - CSIRO is currently undertaking UCG modelling research using two different approaches
  - Commercial UCG developments are advancing past preliminary trials towards a small scale demonstration

Document 3

Key note Speaker

Burl Davis is recognized world wide for work in Underground Coal Gasification Technology. He is an Expert in coal conversion technologies including, coal gasification, direct liquefaction, indirect liquefaction (Fischer-Tropsch), coal water fuels, combustion, and beneficiation. He has had almost 20 years experience with Gulf Research and Technology, and 13 years with Energy International. Over the past twenty years Mr Davis has had a major role in UCG field test programs in the U.S. and New Zealand, including Rawlins 1981, Rocky Mountain 1 , Huntly 5-spot 1993, Hanna III-IV 1977-79, Centralia Partial Seam CRIP 1983-4, Rockdale 1978-80. Mr Davis operates out of Pittsburgh PA and will be visiting CSIRO in 1999.

Location

Queensland Centre for Advanced Technologies is a CSIRO research facility for minerals, energy and associated industries, built with support of the Queensland Government. It is located in the western suburbs of Brisbane, about 40 mins from the airport. It is the site of a new coal gasification research facility operated for the Black Coal CRC.

CSIRO

Workshop

UNDERGROUND COAL GASIFICATION

ENVIRONMENTALLY FRIENDLY FUELS FROM COAL?

23 March 1999

CSIRO Queensland Centre for Advanced Technologies

2643 Moggill Rd, Pinjarra Hills, Q

A one day workshop with presentations describing the potential and developments of in situ gasification of coal world wide. The implications and commercial opportunities in Australia will be discussed. Burl Davis who has over 20 years experience in underground gasification in the US is the keynote speaker.

Registration

To: Sharyn Dawson, CSIRO, QCAT,
PO Box 883, Kenmore Q 4069
Or email s.dawson@dem.csiro.au

Cost $100 One day workshop including lunch and tea breaks

http://www.dem.csiro.au/unrestricted/workshop/

Underground Coal Gasification

Underground coal gasification holds out some tantalising potential benefits. There is an enormous coal resource available, gasification works just as well on coals which are unattractive to mining, it is deep and remote and has less surface impact than mining, it is safer than mining, and a gas energy source has advantages in use and environmental controls.

Gasification can give a range of products and recent experiments have produced up to 70% hydrogen (by volume). Is this an economic method to produce very large quantities of hydrogen and the source for new environmentally friendly hydrogen based energy systems?

Against this there have been problems in implementing commercial in situ gasification in western countries. Are there fundamental problems with the technology, or it is only a matter of bringing the right combination of factors together at the same time?

This workshop will examine the potential for UCG and its relevance to Australia's large coal deposits.

Program

9.00	Opening Address
9.05	The Potential in UCG ***Dr Cliff Mallett CSIRO***
9.15	History and Worldwide Review Coal Gasification Processes **Keynote Speaker: *Burl Davis***
10.15	Environmental Impacts in UCG
10.35	Morning tea
11.00	US Trials Parameters for Successful UCG **Keynote speaker: *Burl Davis***
12.0	Uses for Gasification Products ***CSIRO Energy Technology***
12.30	Lunch
1.15	Coal Deposit Gasification Characteristics in Australia ***Dr Joan Esterle CSIRO***
1.45	Australian Studies of Gasification technologies ***Dr David Harris***
2.30	Commercial Opportunities ***Dr Len Walker Linc Energy***
3.15	Legislative Framework ***Steve Matheson Qld DME***
3.35	Afternoon tea
4.00	**Panel Discussion:** Why is there no commercial UCG in a western country? ***Burl Davis, Len Walker, Steve Matheson, Cliff Mallett***

CSIRO

Workshop

UNDERGROUND COAL GASIFICATION

REGISTRATION

Please provide name and affiliation details as you would like them on your nametag.

(Dr/Mr/Mrs/Ms/Other – *please circle*)

....

Name

....

Organisation Affiliation:

....

Organisation/Company Name

....

Address

....

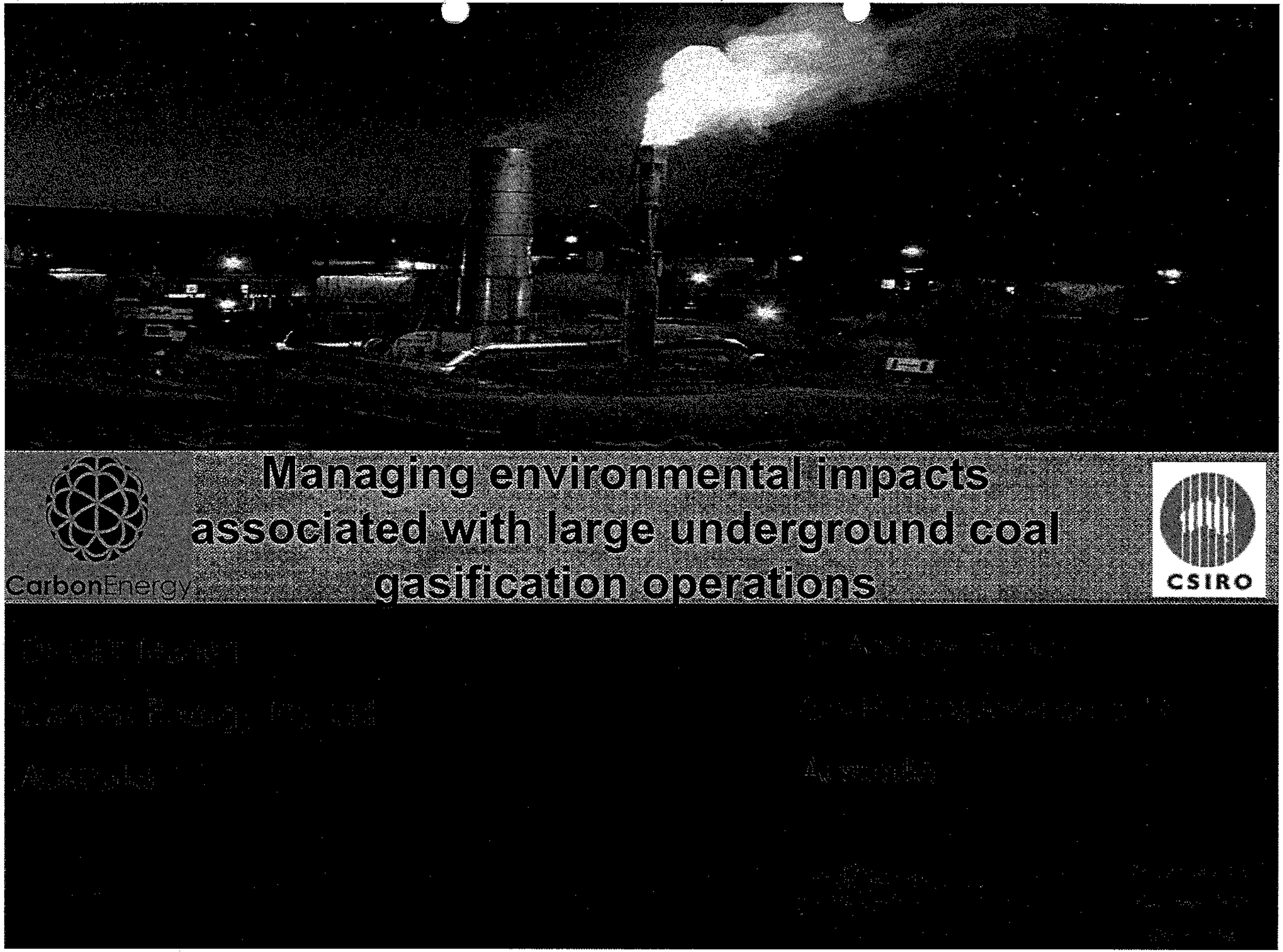
....

Phone Fax

....

Email

Return to:
Sharyn Dawson
UCG Workshop,CSIRO, PO Box 883, Kenmore Q 4069
Fax (07) 3212 4566
Enclose $100 registration or pay on the day (cheques payable to *CSIRO, Exploration and Mining*)
Register via the web site
http://www.dem.csiro.au/unrestricted/workshop/


CarbonEnergy
Managing environmental impacts associated with large underground coal gasification operations
CSIRO

CarbonEnergy

Outline

CSIRO

- Introduction
- Key aspects of UCG
- Potential environmental concerns with examples and comments
- Site selection
- Prediction of UCG behaviour
- Conclusions

CarbonEnergy

Introduction

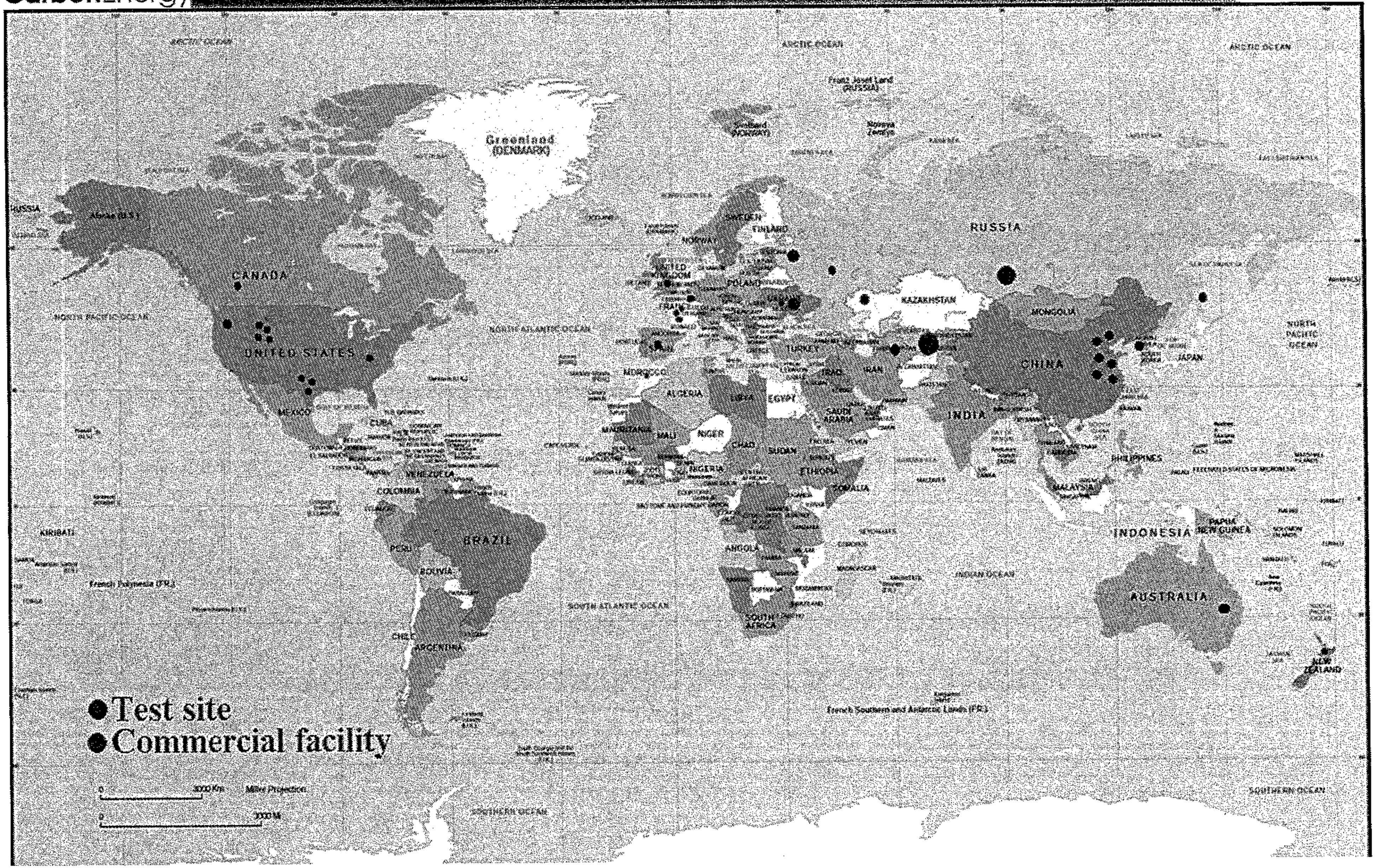
CSIRO

- Underground coal gasification has been performed at over 50 sites worldwide since the 1930s
- Operations in the former Soviet states dominate in terms of quantities of coal gasified and the range of coal seam characteristics used
- Gasification sites over 600m deep have been used in Western Europe

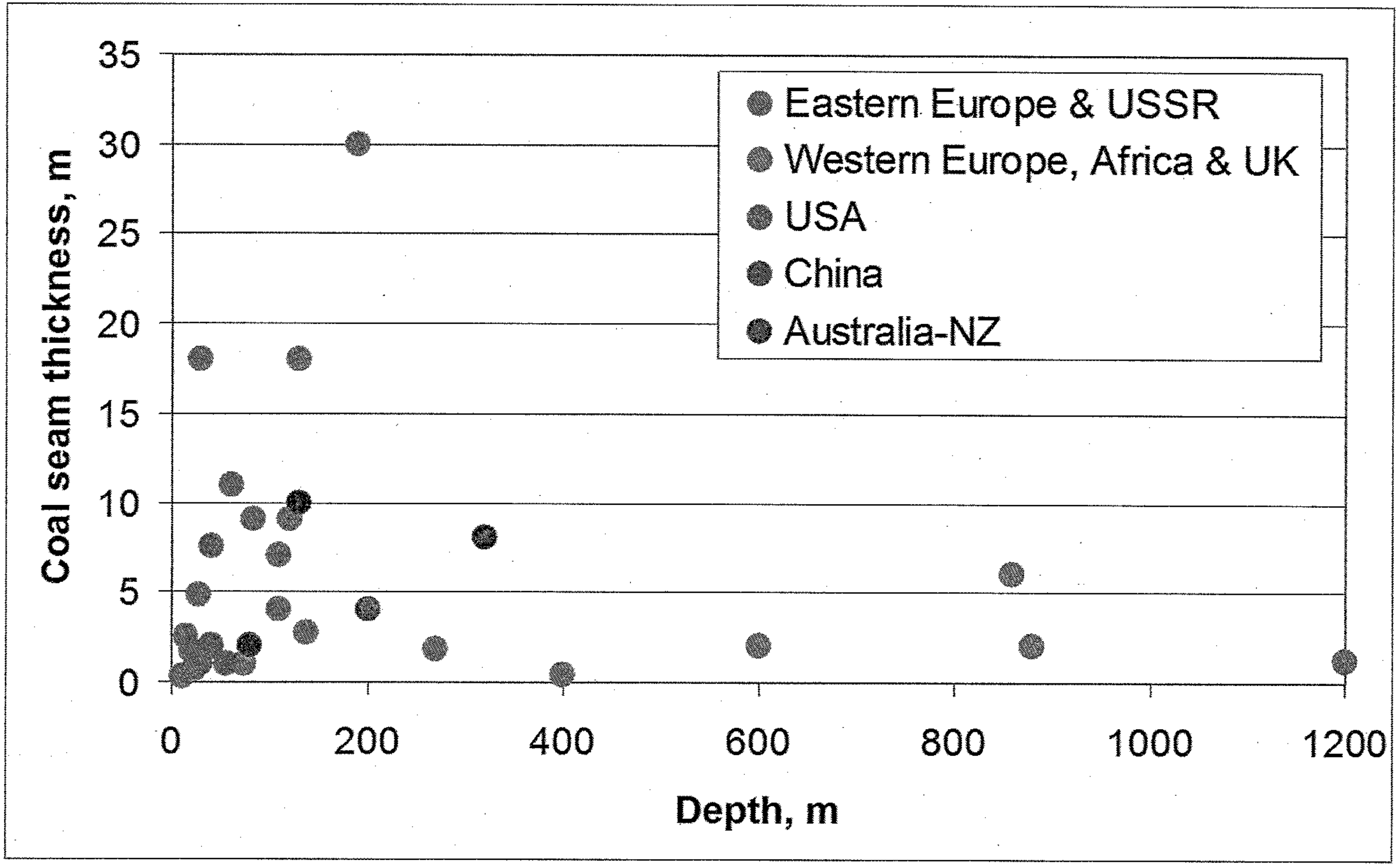
CarbonEnergy

Distribution of UCG sites

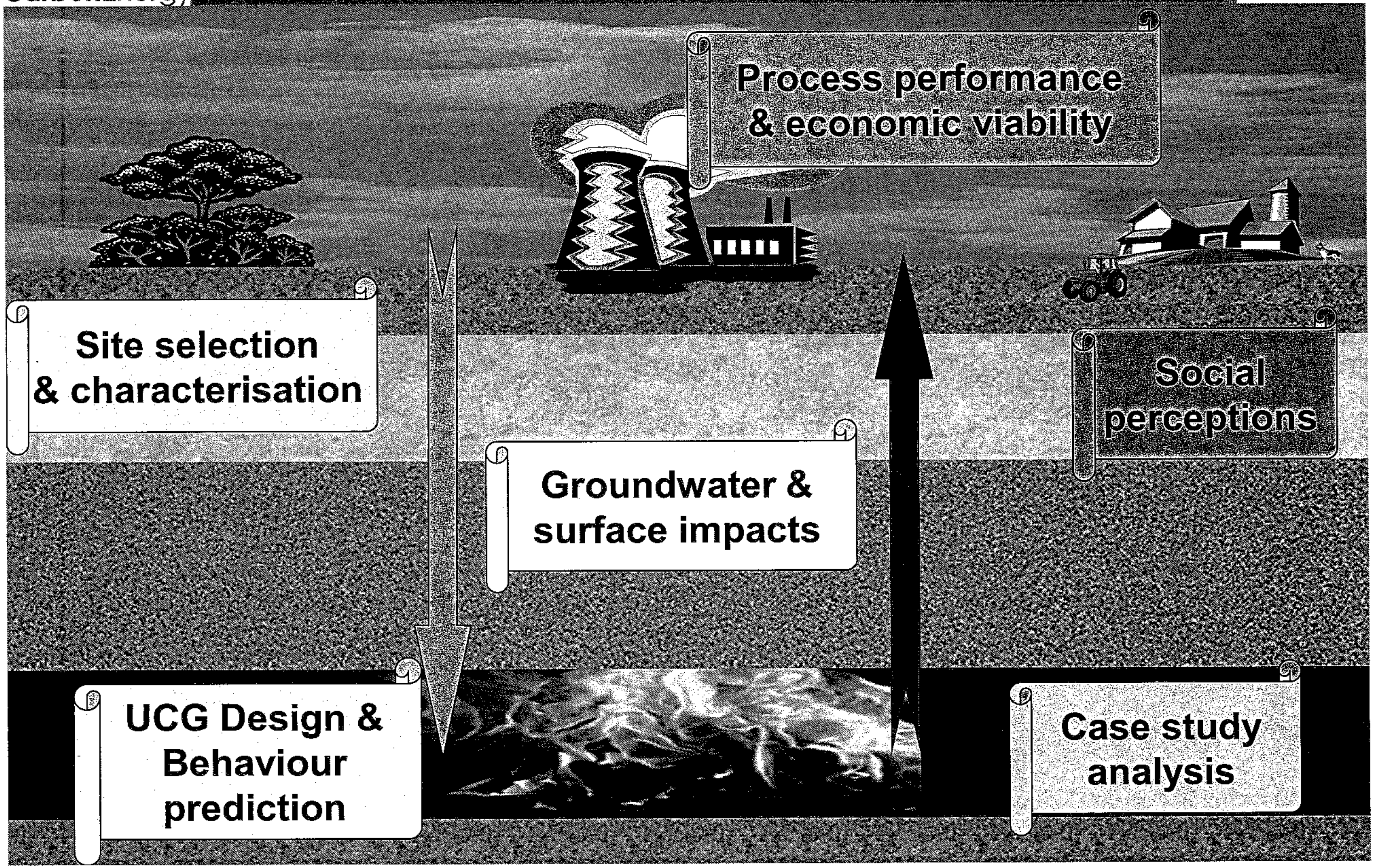
CSIRO



Site characteristics



Key aspects of UCG



CarbonEnergy

Potential environmental concerns

CSIRO

The site characteristics have a major impact on potential environmental impacts, however the main areas of concern for large UCG operations are:

- oSubsidence
- oGroundwater depletion
- oGroundwater contamination

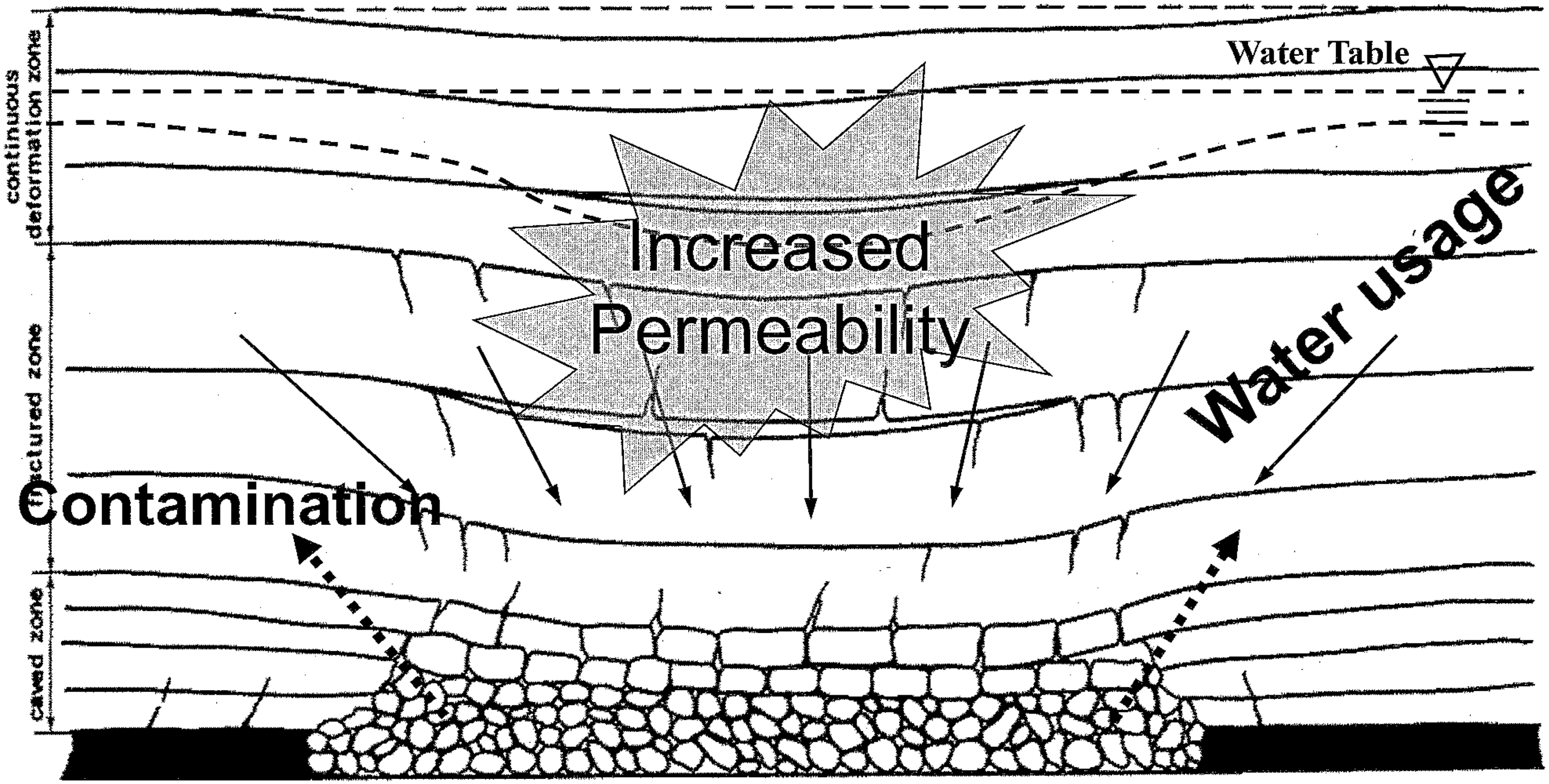
Other environmental issues, like waste water handling, can be handled using conventional equipment from existing industries

CarbonEnergy

Site Changes caused by UCG

CSIRO

Surface subsidence



Subsidence

- UCG, like any other coal extraction technique, will cause some subsidence
- The *magnitude* of this will be determined by the seam thickness, depth, site geotechnical properties and the UCG design
- The *impact* will depend on surface land use

CarbonEnergy

Subsidence - Historical

CSIRO

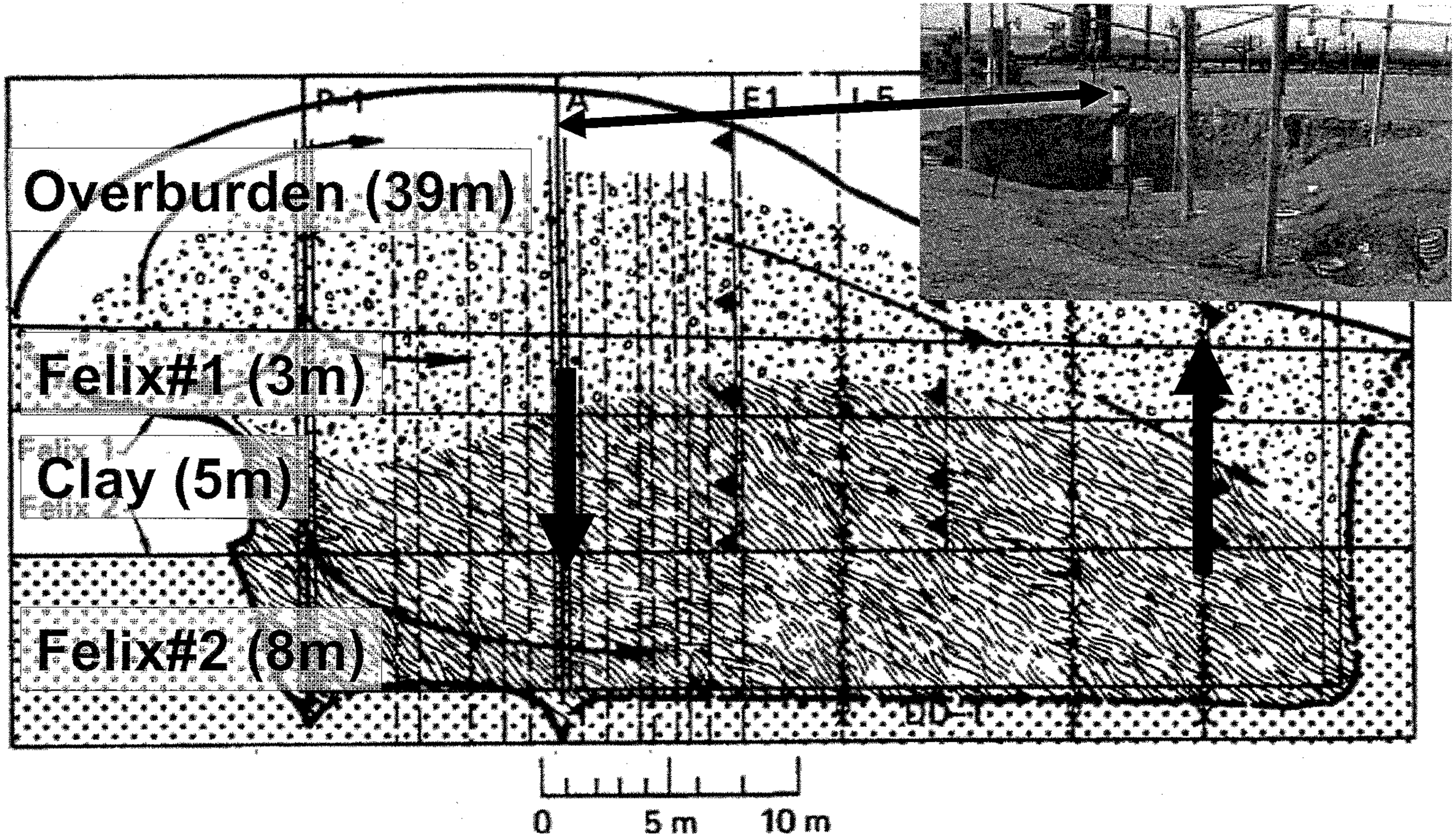
- Much of the Soviet and American experimentation took place in shallow, thick coal seams
- This minimises the cost of operation, but maximises the likely magnitude of subsidence

CarbonEnergy

Hoe Creek #3 Trial (USA, 1979)

CSIRO

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



CarbonEnergy

Linc Energy – Chinchilla (1999+)

CSIRO

- Approximately 10m of coal at 130-140m
- Low subsidence UCG technique applied
- Much more coal extracted than at Hoe Ck
- Minimal subsidence detected

Source: Blinderman & Jones, 2002 Gasification Technologies Conference

CarbonEnergy

Notes on Subsidence

CSIRO

- ❖ Subsidence can be an issue, but can be minimised through careful site selection and UCG design
- ❖ Besides environmental impact, it will also have substantial process control ramifications if at excessive levels, so must be addressed during planning

CarbonEnergy

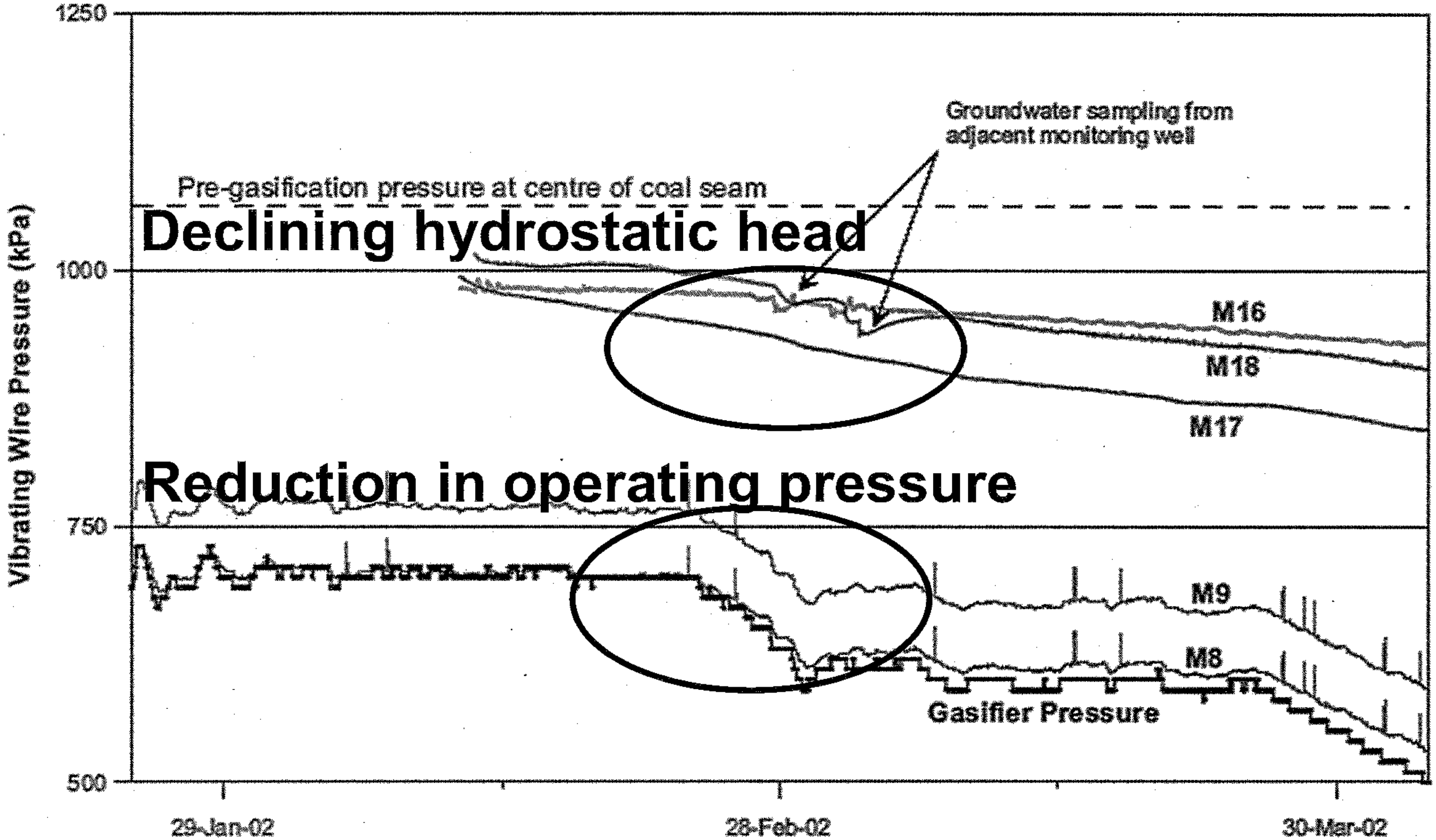
Groundwater Depletion

CSIRO

❖ **Impacts:**

- Shortages for other users of groundwater (eg. agricultural)
- Can lead to high gas losses from the UCG operation (→Contamination)
- Product gas composition changes and production pressure declines, with possible impact on the gas utilisation process

Linc Energy – Chinchilla (1999+)



Source: Blinderman & Fidler, Water in Mining 2003

CarbonEnergy

Notes on Groundwater Depletion

CSIRO

- Depletion is site dependent but should be less than for other resource utilisation methods (eg. Coal Bed Methane or Underground Mining) when performed on a similar scale
- Plant size will have a large impact and this may be a limiting factor in specifying the plant design

CarbonEnergy

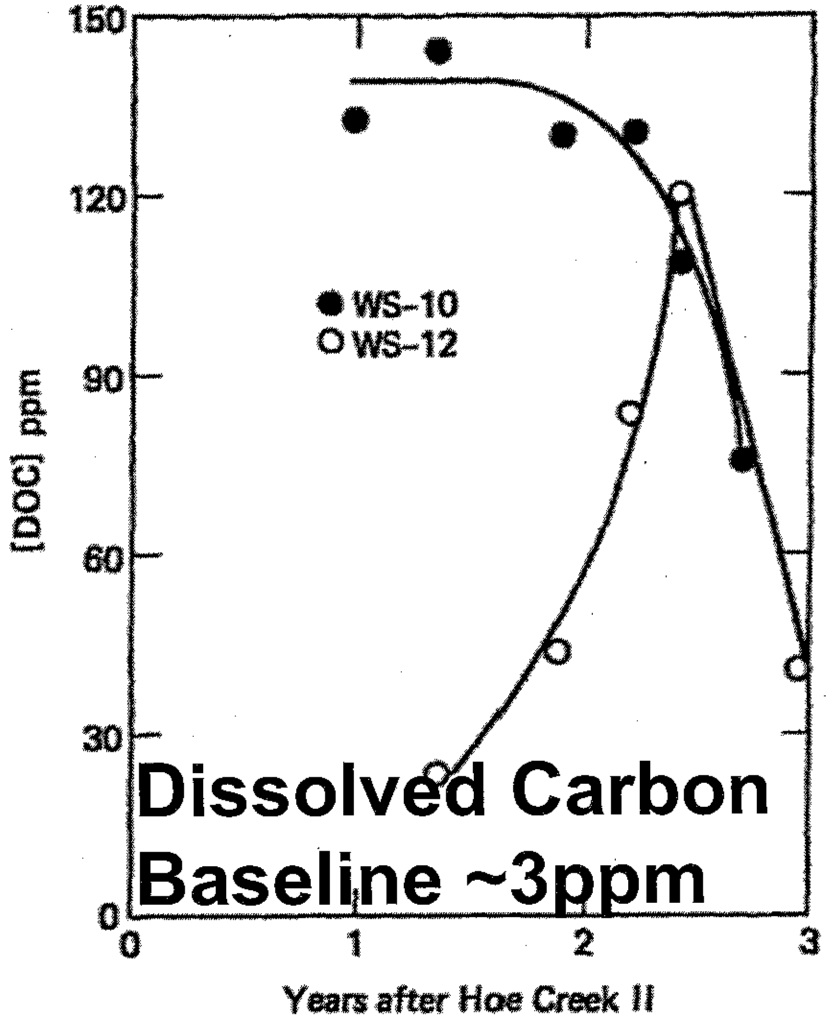
Groundwater Contamination

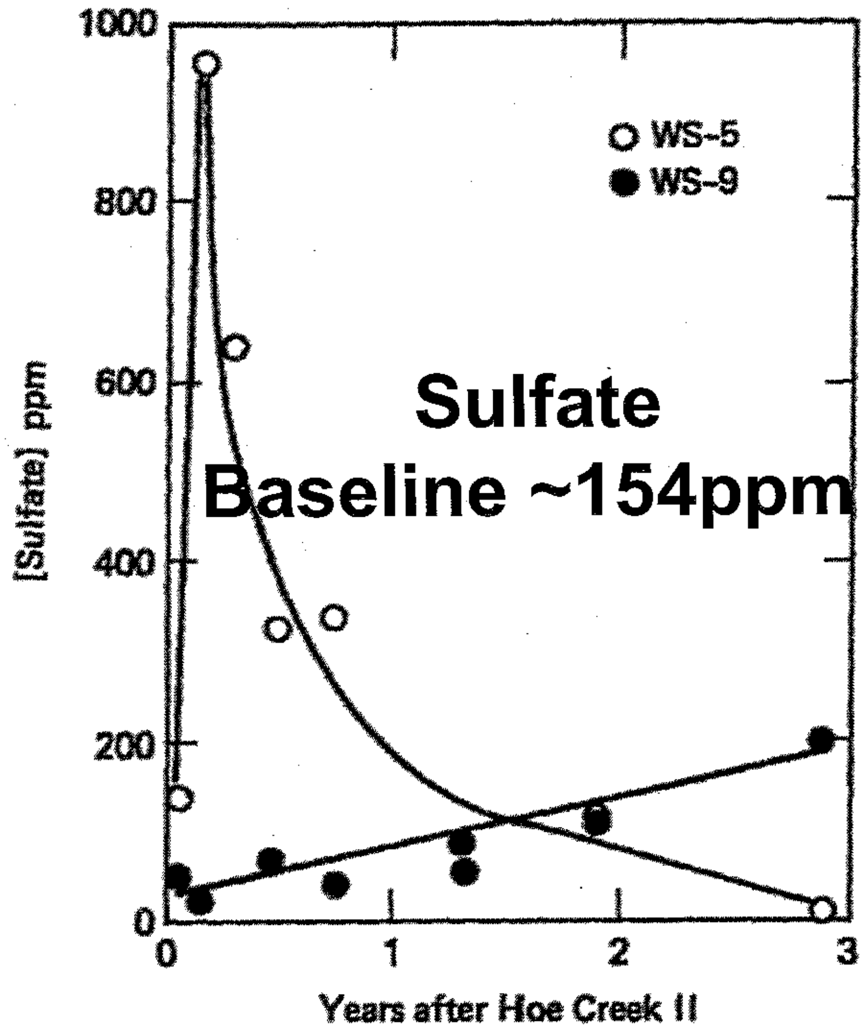
CSIRO

- ❖Benzene and other organics have been found in groundwater near two UCG sites in the USA
- ❖Organic contamination is linked to high operating pressures and was avoided in subsequent US trials
- ❖Soviet testing identified elevated salt concentrations around a large UCG site after closure, but these rapidly decreased to background levels

Hoe Creek II (USA, 1977)

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





CarbonEnergy

CSIRO

CarbonEnergy

Hoe Creek site (USA, 1973-2003)

CSIRO

- Contamination was noted in 1977, but did not exceed the limits for livestock watering
- The US government committed to cleaning up old DOE sites in 1991
- Clean-up started in 1995 and continued intermittently until 2003
- Contaminant limits were set by Wyoming State as "Not Detectable" due to the lack of a site environmental licence and full background testing prior to the trials

CarbonEnergy

Hoe Creek site (USA, 1973-2003)

CSIRO

- Initially, the groundwater was extracted and filtered through activated carbon
- Then combined air-sparging and bio-remediation was performed
- Later, only air-sparging was used

Hoe Creek II, October 2002

CarbonEnergy

Notes on Groundwater Contamination

CSIRO

- ❖A significant issue for UCG that requires strict operating methodologies and site selection
- ❖Impact most readily reduced by avoiding good water aquifers
- ❖Modelling of organics very complex and requires detailed assessment of geochemical properties at the site

CarbonEnergy

Managing Environmental Impact

CSIRO

The most important factors in minimising impact are

- oSelection of a suitable site
- oDesign of the plant
- oOperation within applicable guidelines

To do this it is necessary to be able to predict the behaviour of the UCG plant at specific sites

CarbonEnergy

Site selection criteria

CSIRO

- It is possible to set a series of guidelines that simplify decision making when selecting UCG sites
- Several proposed sets of criteria have been developed in different countries, such as the UK, USA and Australia, all with a bias towards local conditions

CarbonEnergy

Our site criteria 1

CSIRO

- ❖Seam thickness >5 m
- ❖Coal ash <40% (air dried basis)
- ❖Seam dip <20°
- ❖Seam depth 200-400 m
- ❖Minimal faulting and no dips/sills
- ❖Roof thermally stable with minimal permeability, preferably structured to encourage even caving

CarbonEnergy

Our site criteria 2

CSIRO

- Hydraulic head >200 m
- Adjacent aquifers contain poor quality water and are of minimal permeability

Other notes:

- Limited human activities in vicinity
- No waterways overlying the site
- Subsidence must be acceptable at location
- Coal resource size suitable for long term operation

CarbonEnergy

Site selection summary

CSIRO

All sets of criteria are based around:

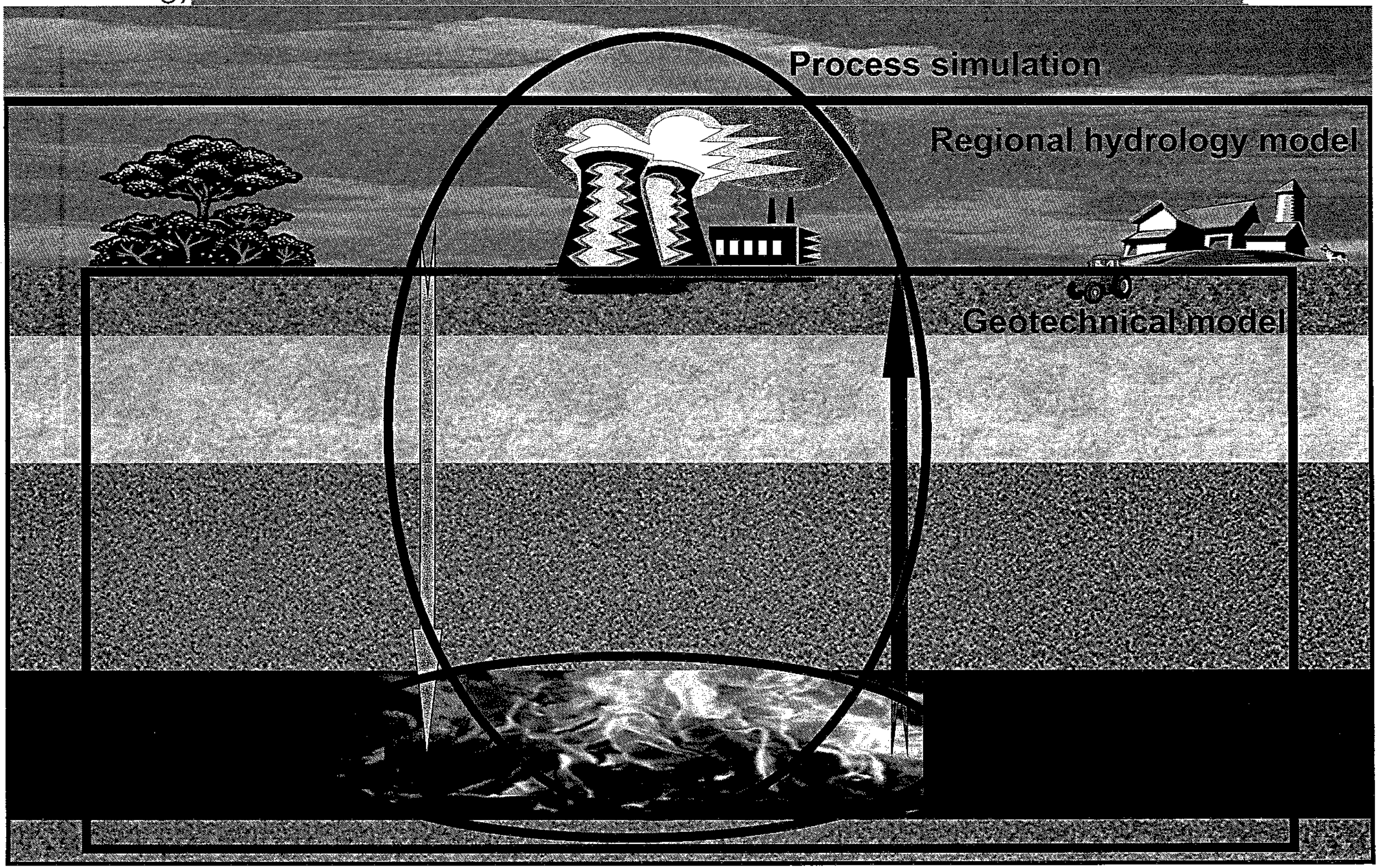
- ❖Establishing that it is an economic resource of suitable size
- ❖Geological conditions are suitable for consistent coal removal
- ❖Environmental impacts are acceptable

A comprehensive analysis will still have to be performed to ensure that the site is suitable, but use of simple criteria can eliminate unsuitable sites quickly

Prediction of UCG behaviour

- A comprehensive approach to modelling is required to adequately predict the behaviour of UCG.
- This needs to consider not only the gasification process, but also the interactions with the geological and hydrological environment at the site
- A suite of models is required for this, rather than a single model.

Modelling suite for UCG



CarbonEnergy

Comments on Modelling Suite

CSIRO

- The modelling suite is a combination of custom UCG models, specialised ground deformation models and generally available hydrological models

- It has been validated against experimental data and demonstrated to be capable of predicting the environmental impacts of UCG operations at specific sites

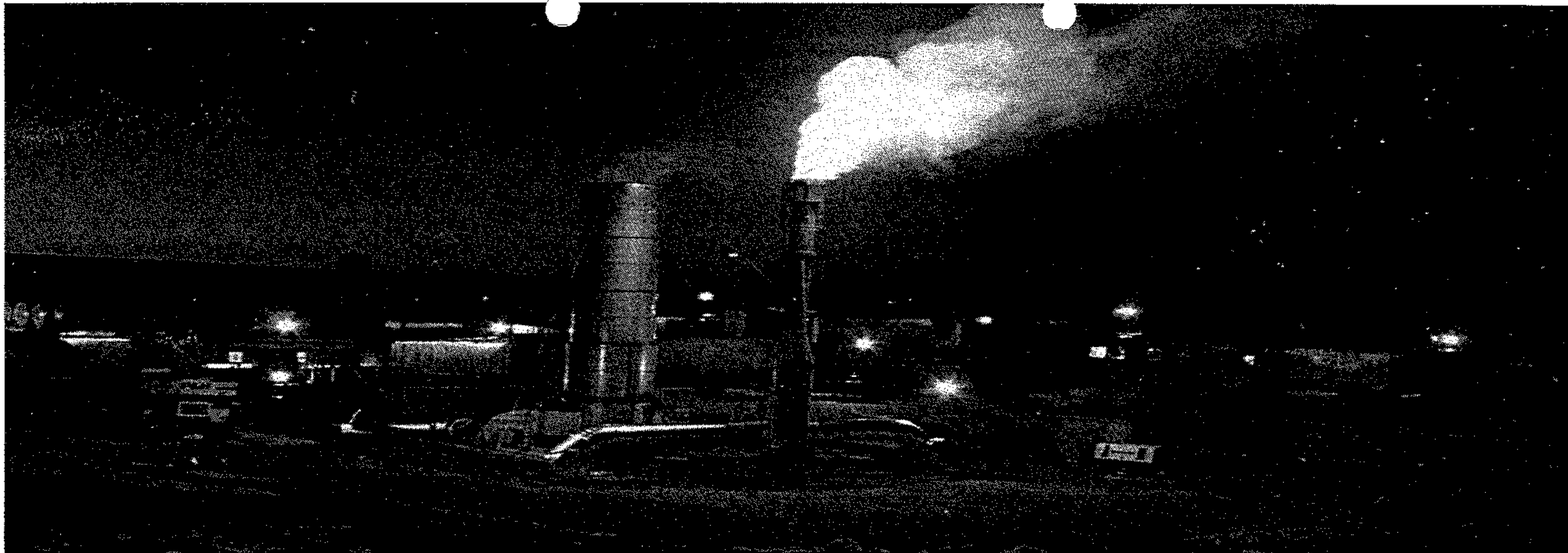
- More information on this is contained in a and presentation in the main Petrotech2007 conference

CarbonEnergy

Conclusions

CSIRO

- Environmental impacts are largely determined by the combination of site characteristics, gasifier design and the operating conditions.
- Generic criteria can be specified to assist in site selection, however, comprehensive modelling of UCG at a specific site is required to verify that the operation will be environmentally acceptable

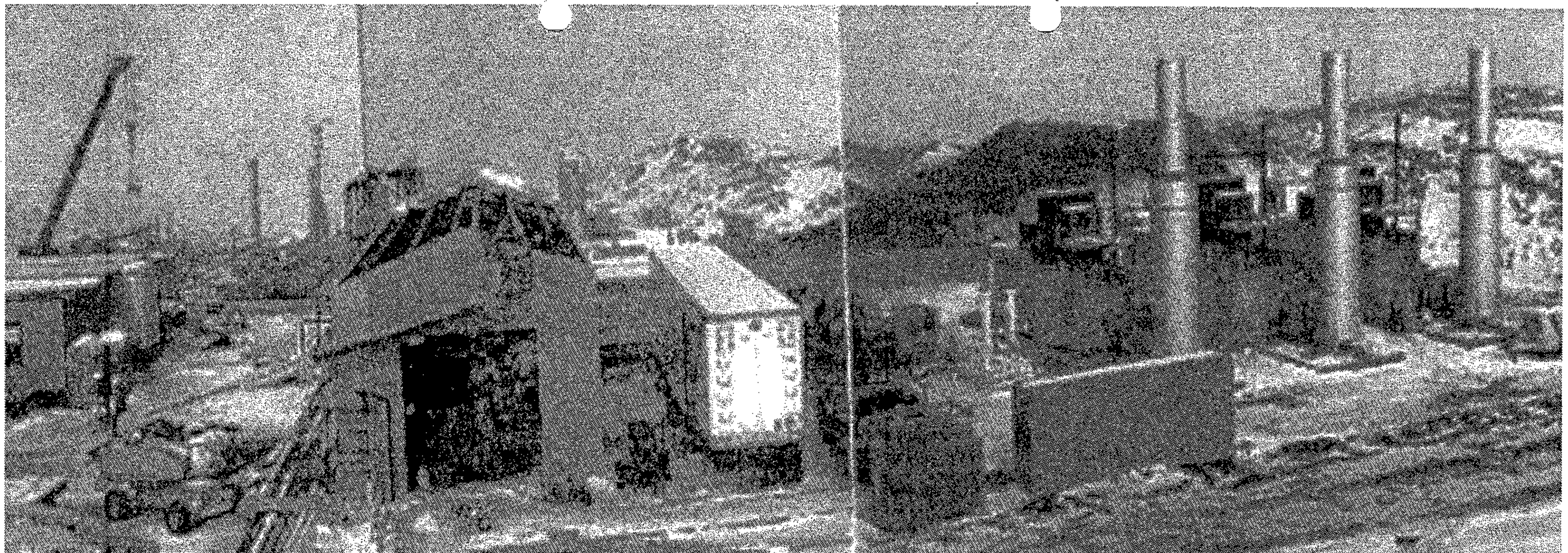


CarbonEnergy

The End

CSIRO

Document 5



Simulating cavity growth, gas production and associated processing for underground coal gasification

CSIRO

CarbonEnergy

[redacted]

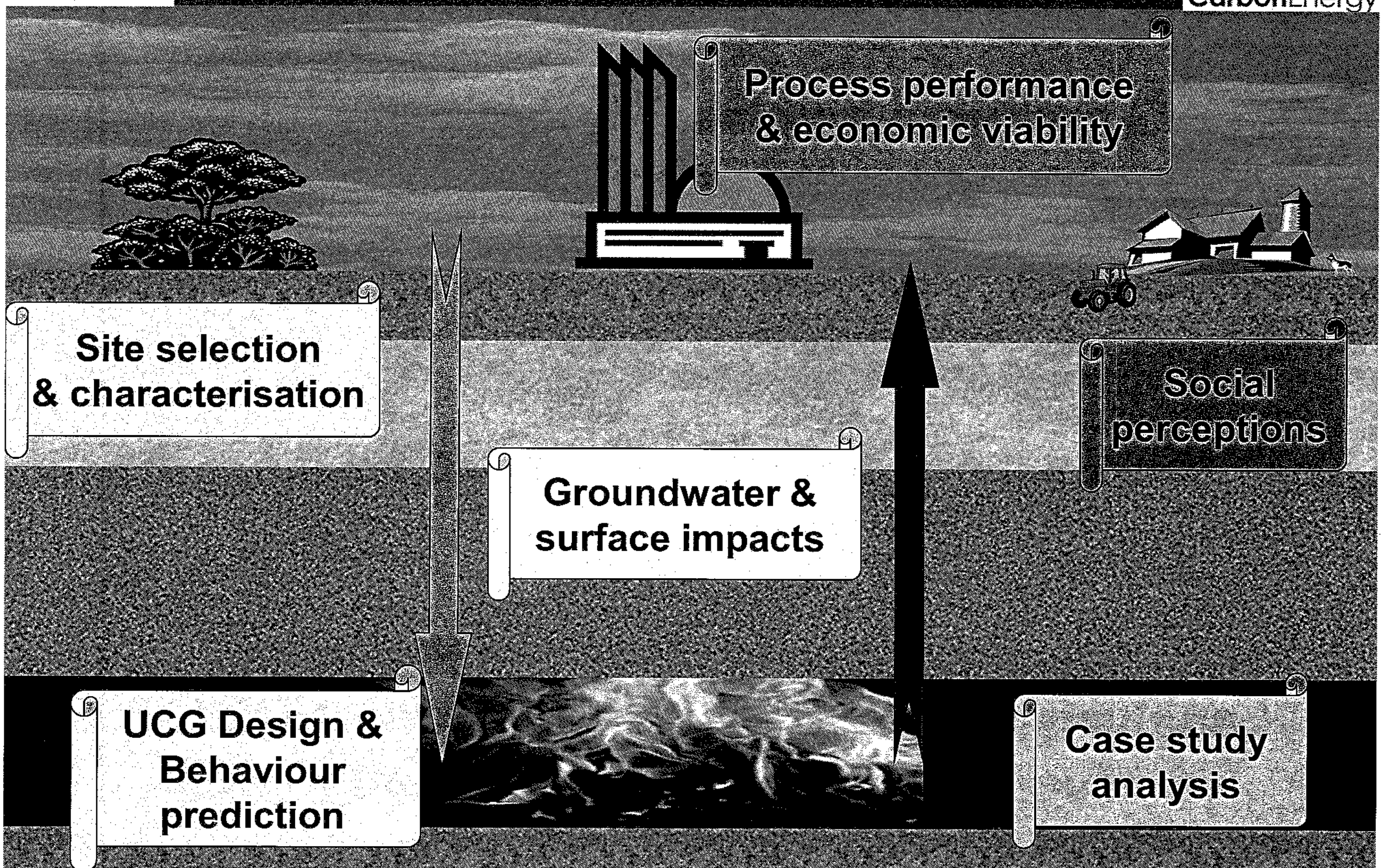
CSIRO

Introduction

CarbonEnergy

- Underground coal gasification (UCG) has been performed at over 50 sites worldwide since the 1930s
- Operations in the former Soviet states dominate in terms of quantities of coal gasified and the range of coal seam characteristics used
- Improvements in drilling, remote sensing, control systems and modelling capabilities have led to increased interest in the technology in recent years as a low cost alternative for fuel and synthesis gas

Key aspects of UCG



CSIRO

Modelling of UCG processes

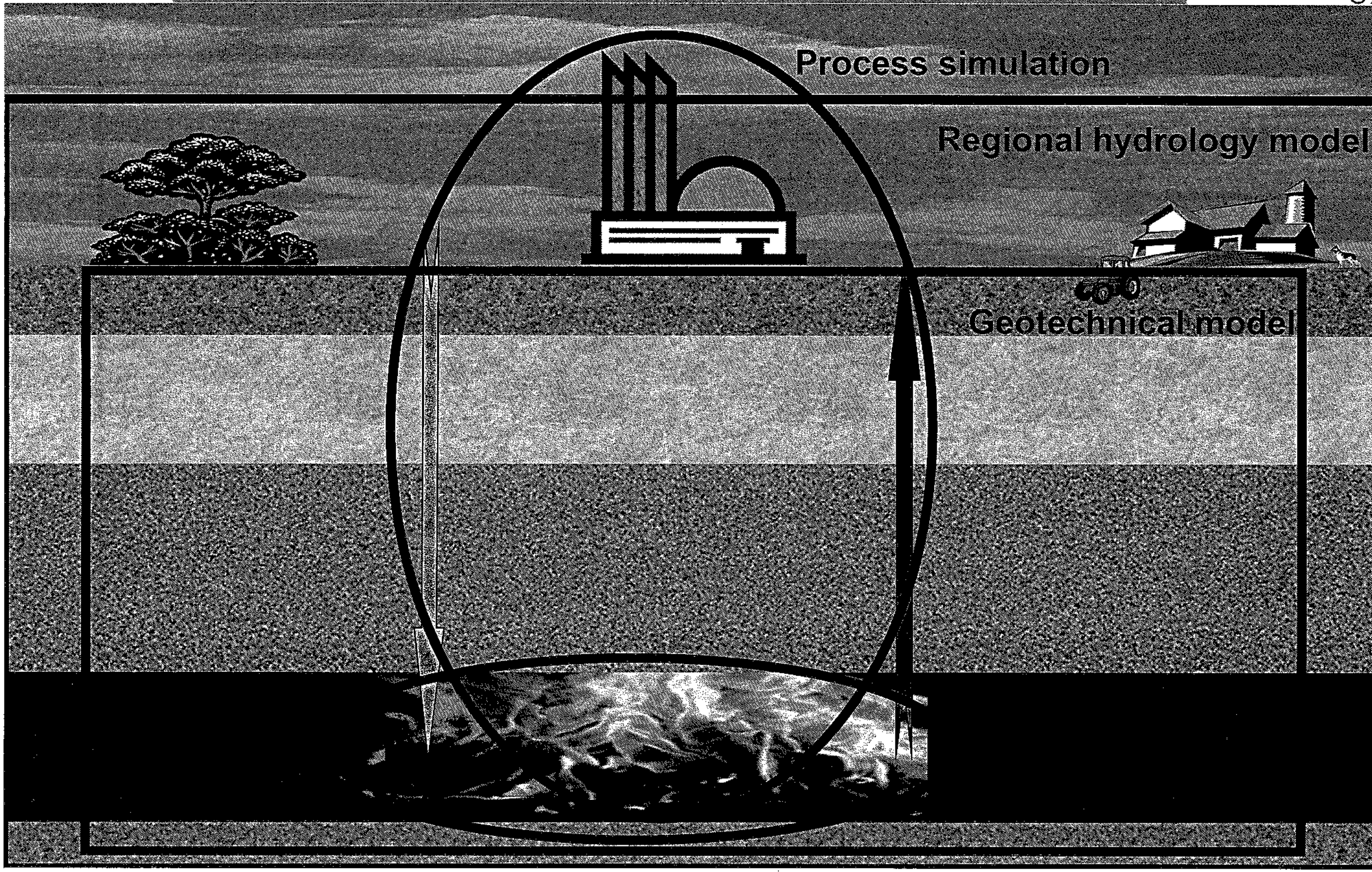
CarbonEnergy

UCG research involves analysis of a complex system of interacting:

- oGeological factors
- oGasification process
- oSurface and groundwater impacts
- oPublic perceptions

Most published models are limited to an analysis of only a part of the process, but we have taken a comprehensive approach.

Modelling suite for UCG



CSIRO

Demonstration via a Case Study

CarbonEnergy

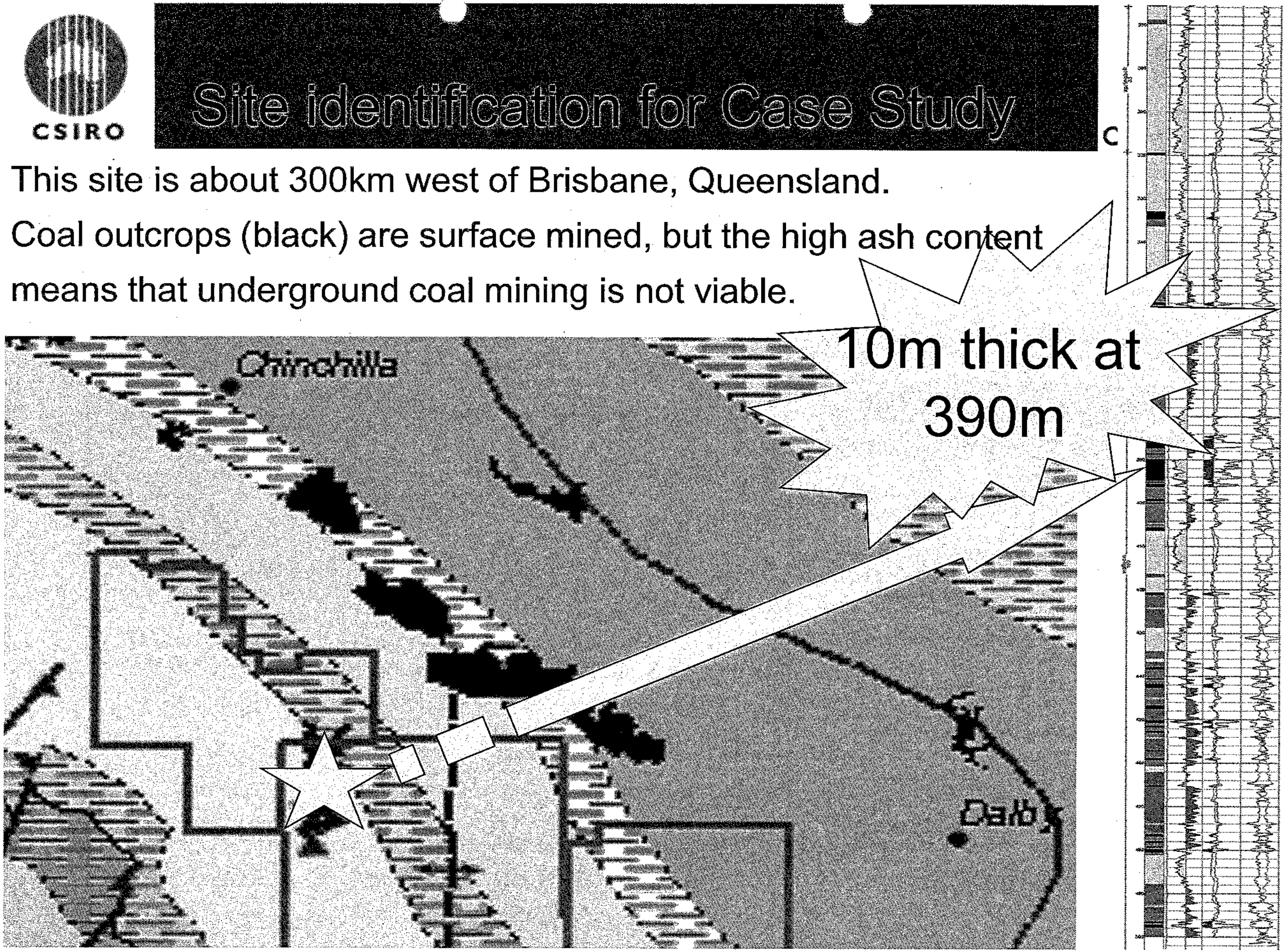
- A case study is required to demonstrate the analysis of operational and environmental performance of a commercial scale UCG plant at any specific site
- A plant size with nominal production of 10,000bbl/day of synthetic liquid fuels was selected as a significant installation

CSIRO

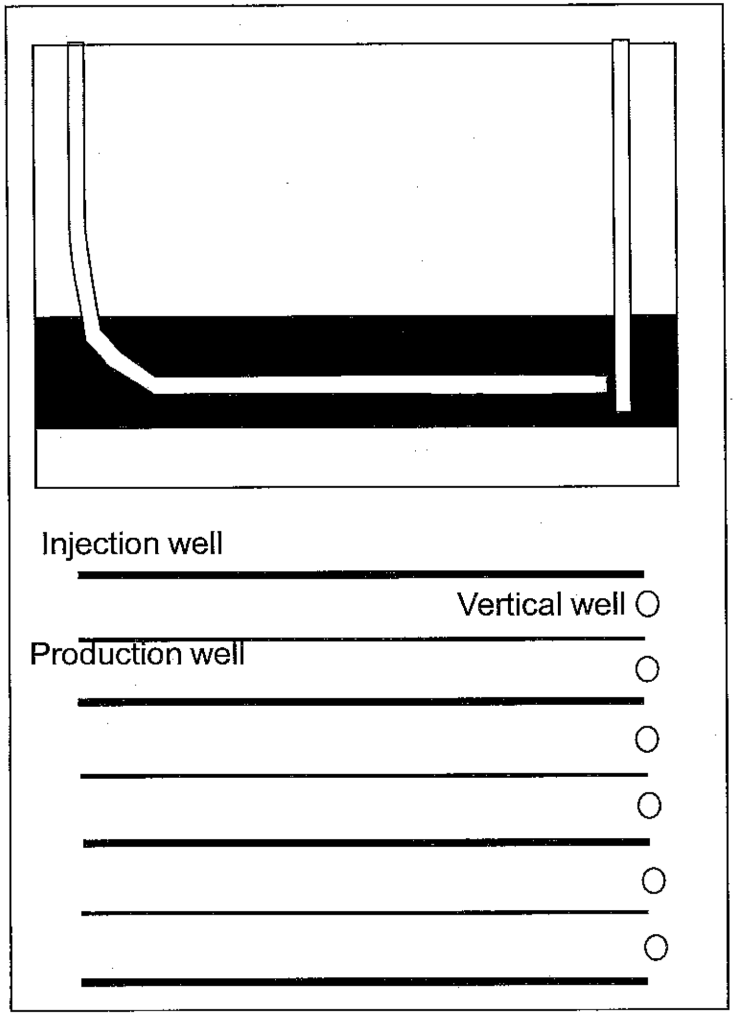
Site identification for Case Study

This site is about 300km west of Brisbane, Queensland.

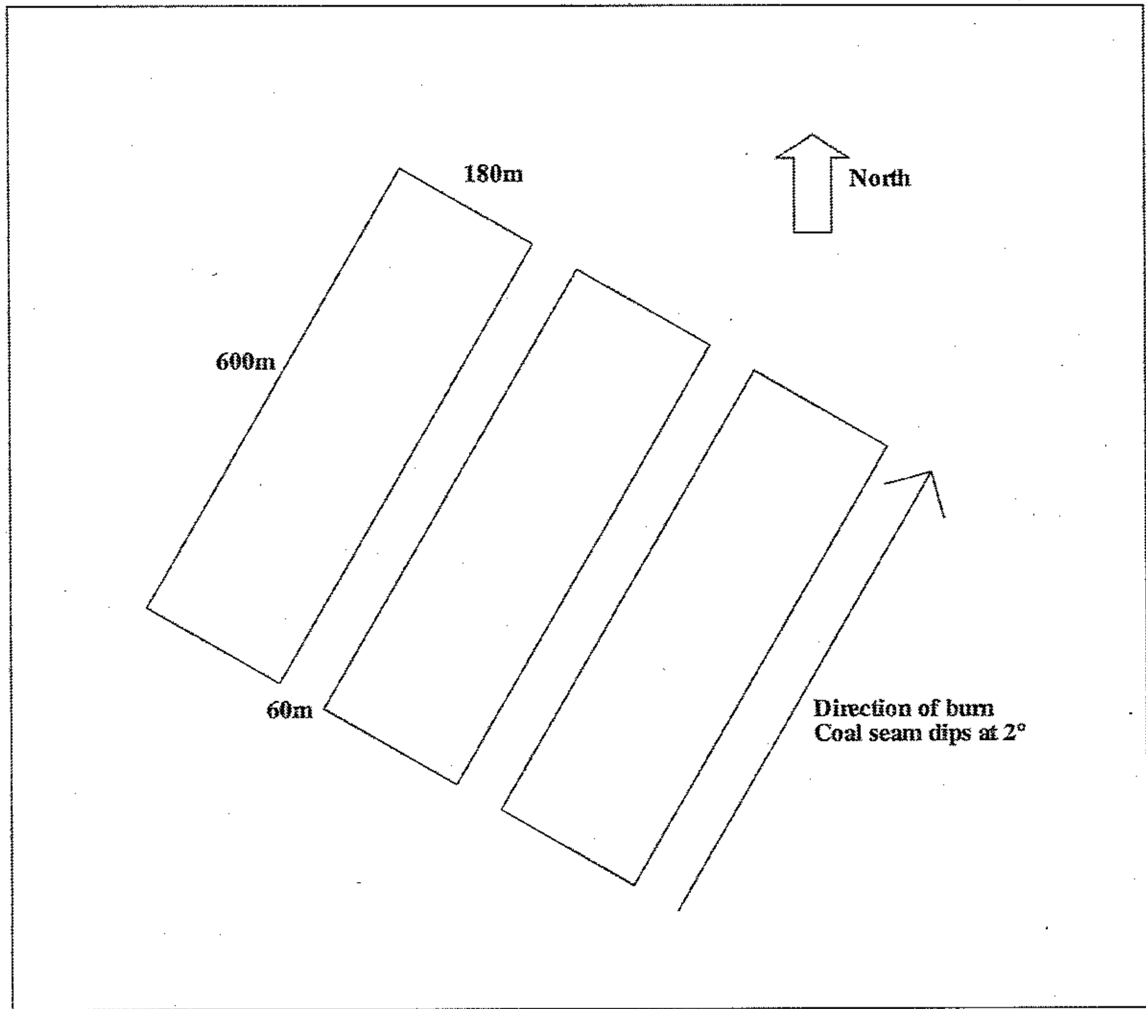
Coal outcrops (black) are surface mined, but the high ash content means that underground coal mining is not viable.



UCG design for Case Study



Module design



3 Modules as arranged in base case (Module life 2.3 years)

CSIRO

Behaviour prediction

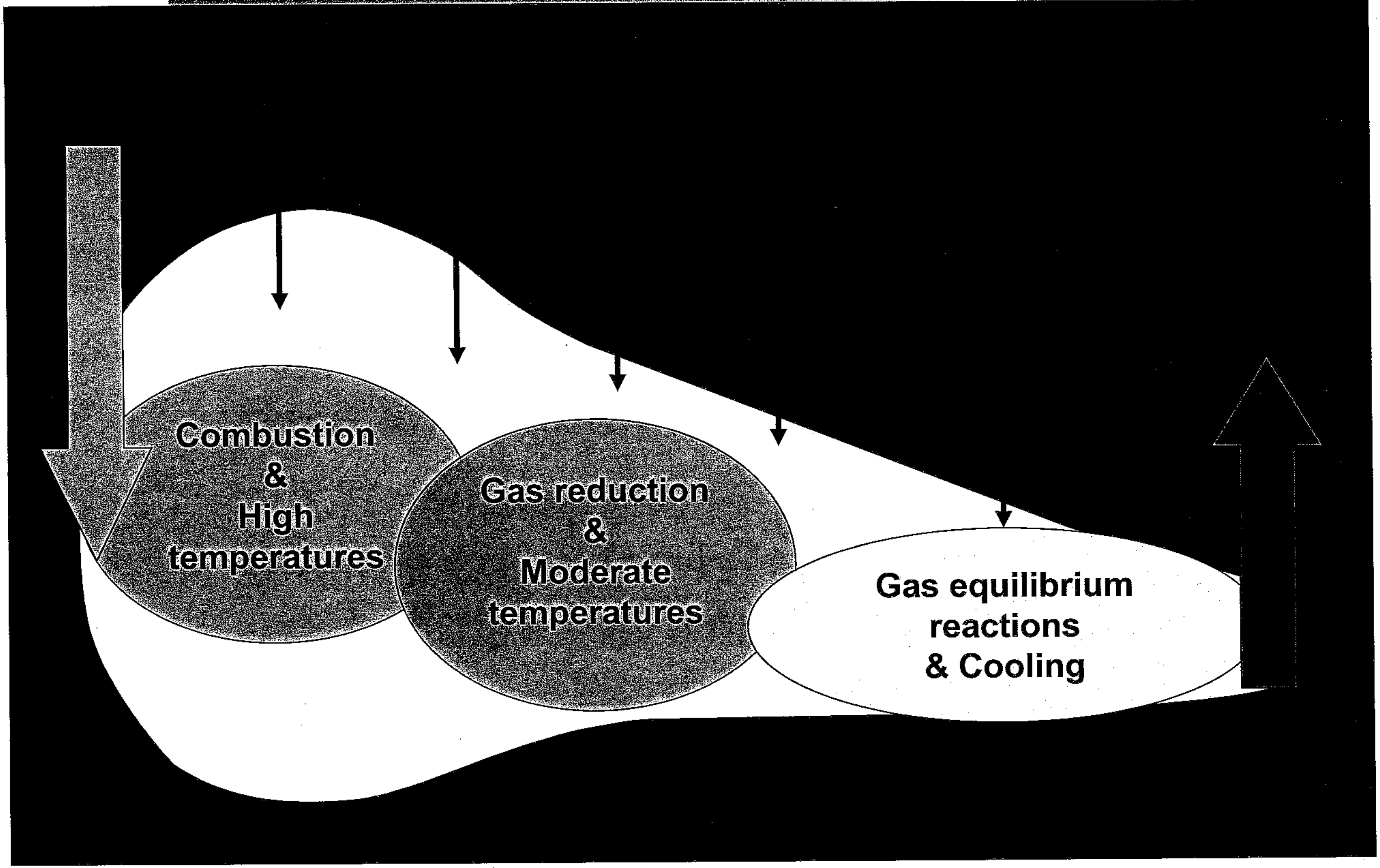
CarbonEnergy

One of the key problems with past UCG operations has been the difficulty in understanding what is happening.

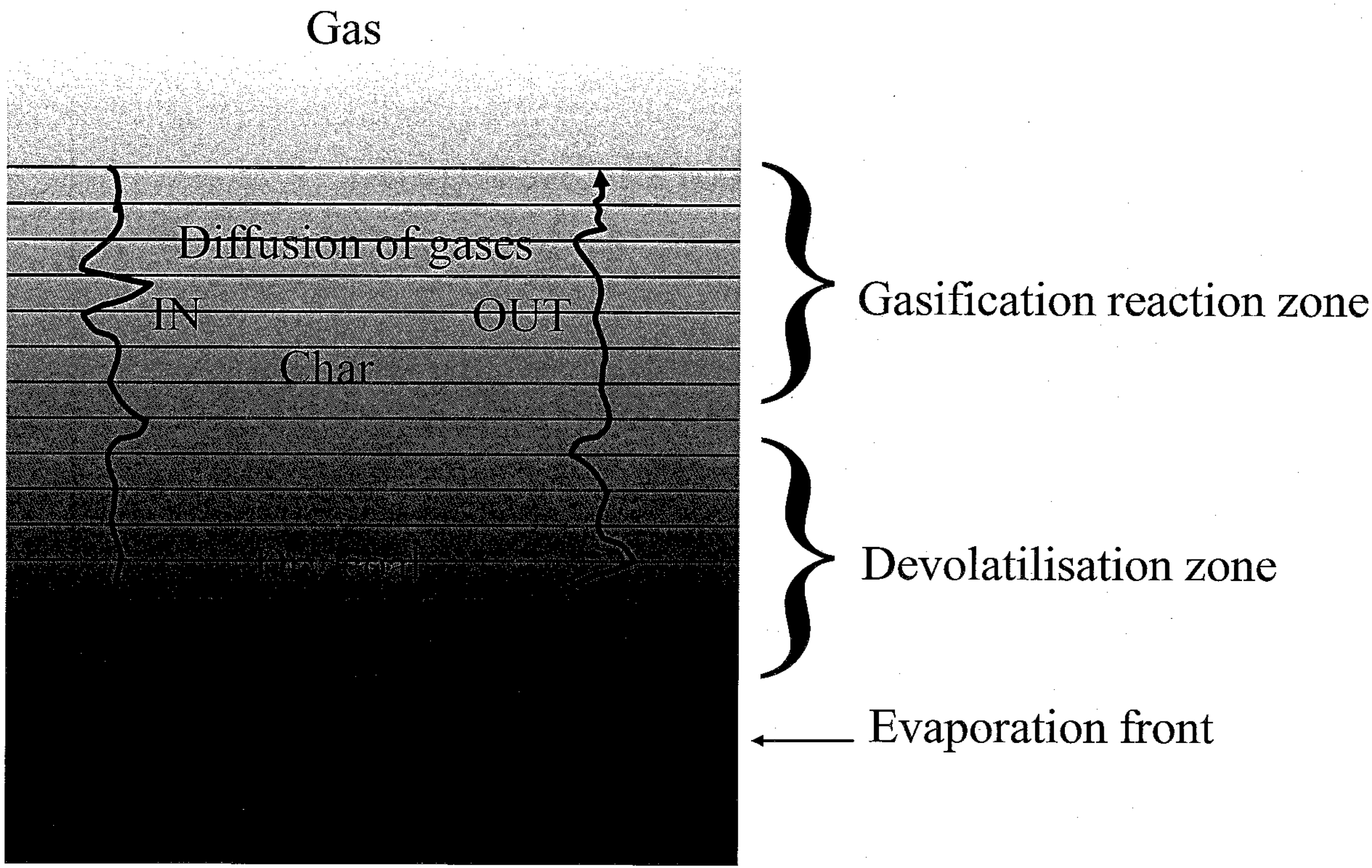
Many months of data analysis and modelling was required to interpret results from some experimental trials.

Modern computing allows the opportunity for real-time assessment of the reactor behaviour, if suitable models can be developed.

UCG reaction processes



Coal model



Gas
Diffusion of gases
IN
OUT
Char
Gasification reaction zone
Devolatilisation zone
Evaporation front

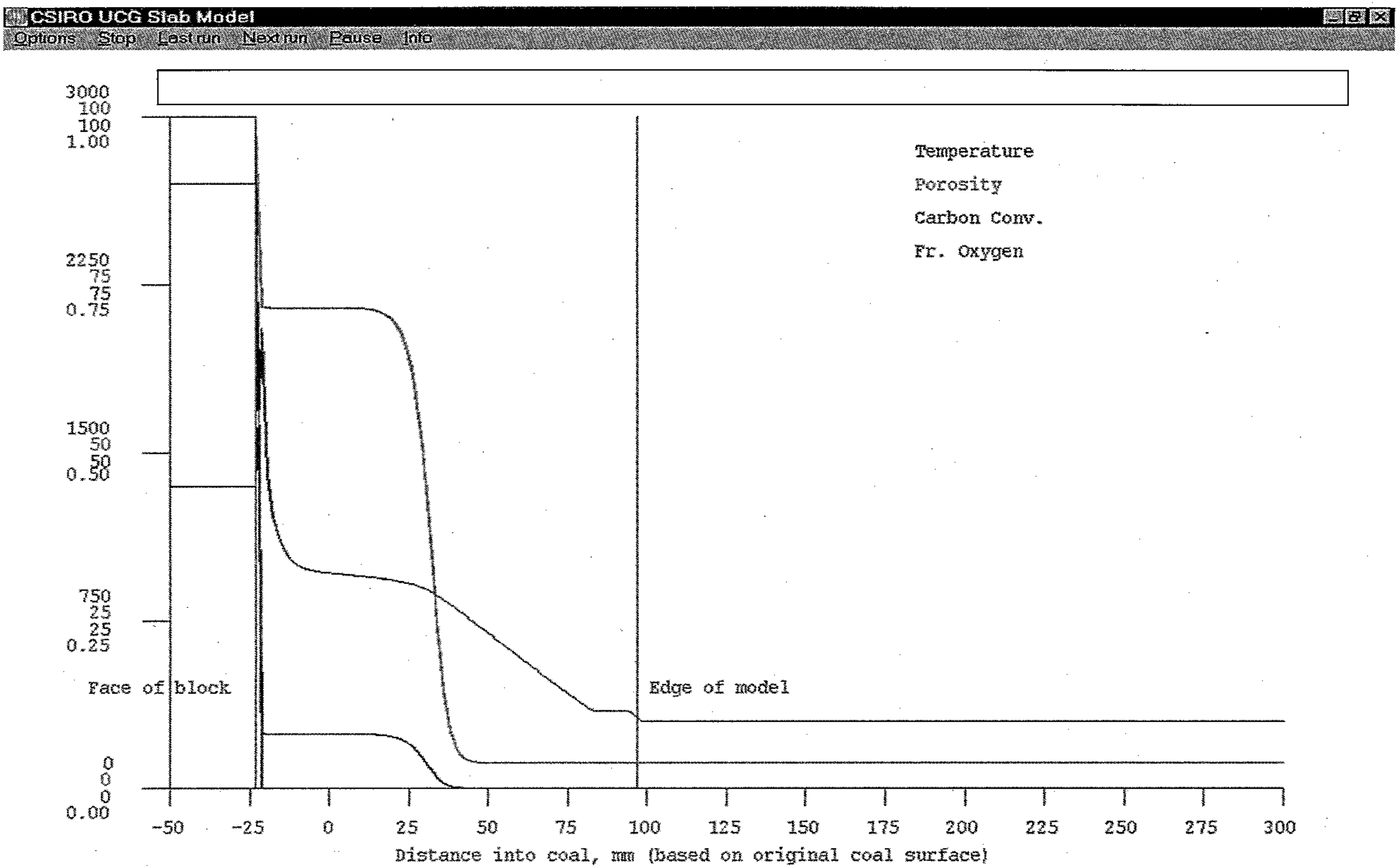
CSIRO

Elements of the Coal model

CarbonEnergy

- Coal & char reactions
- Coal/char structural changes
- Gas flow and reactions
- Water flows and evaporation
- Heat transfer

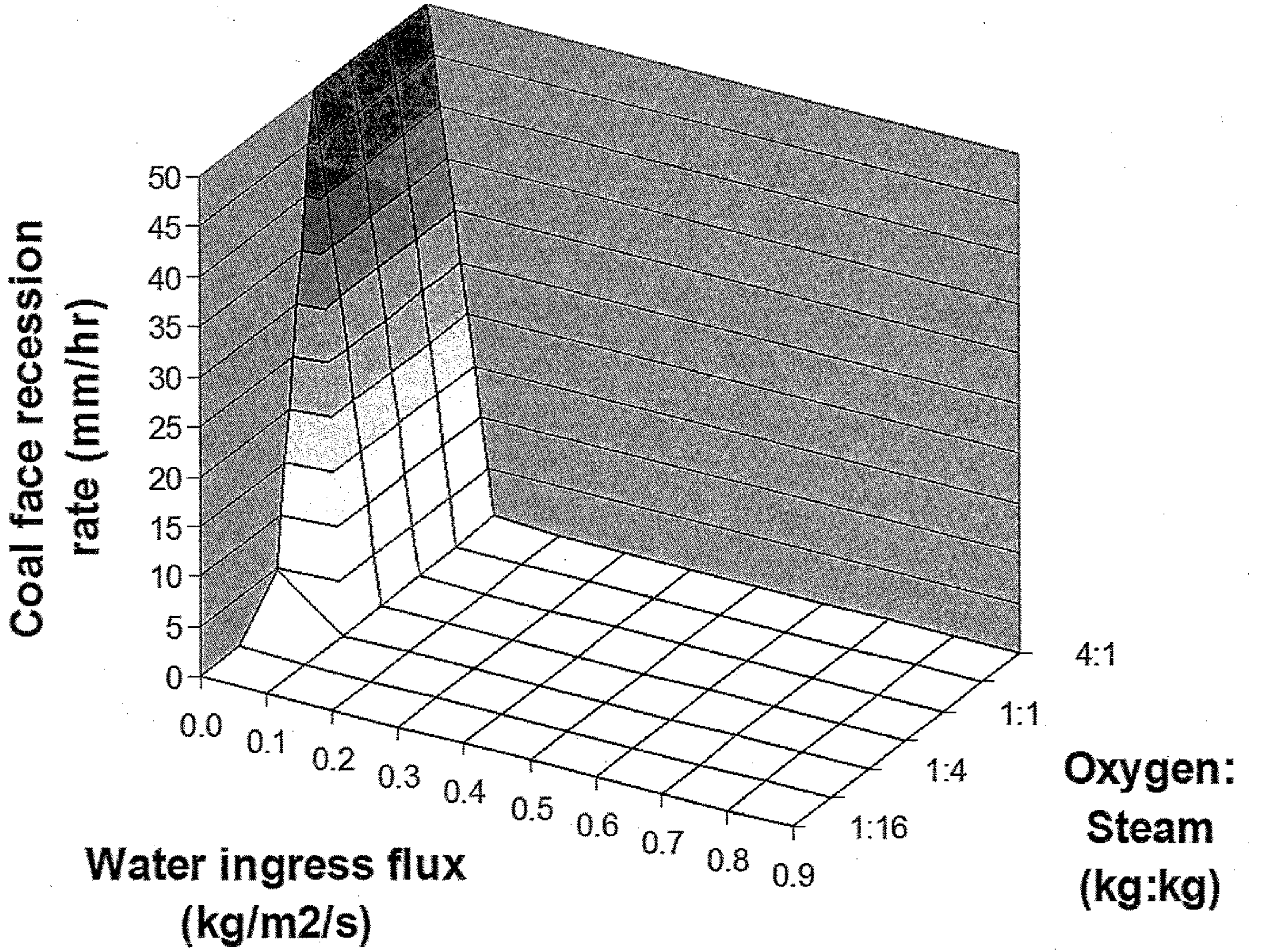
Output from coal model



CSIRO

Predictions from the coal model -Impact of reactant gas mix and water

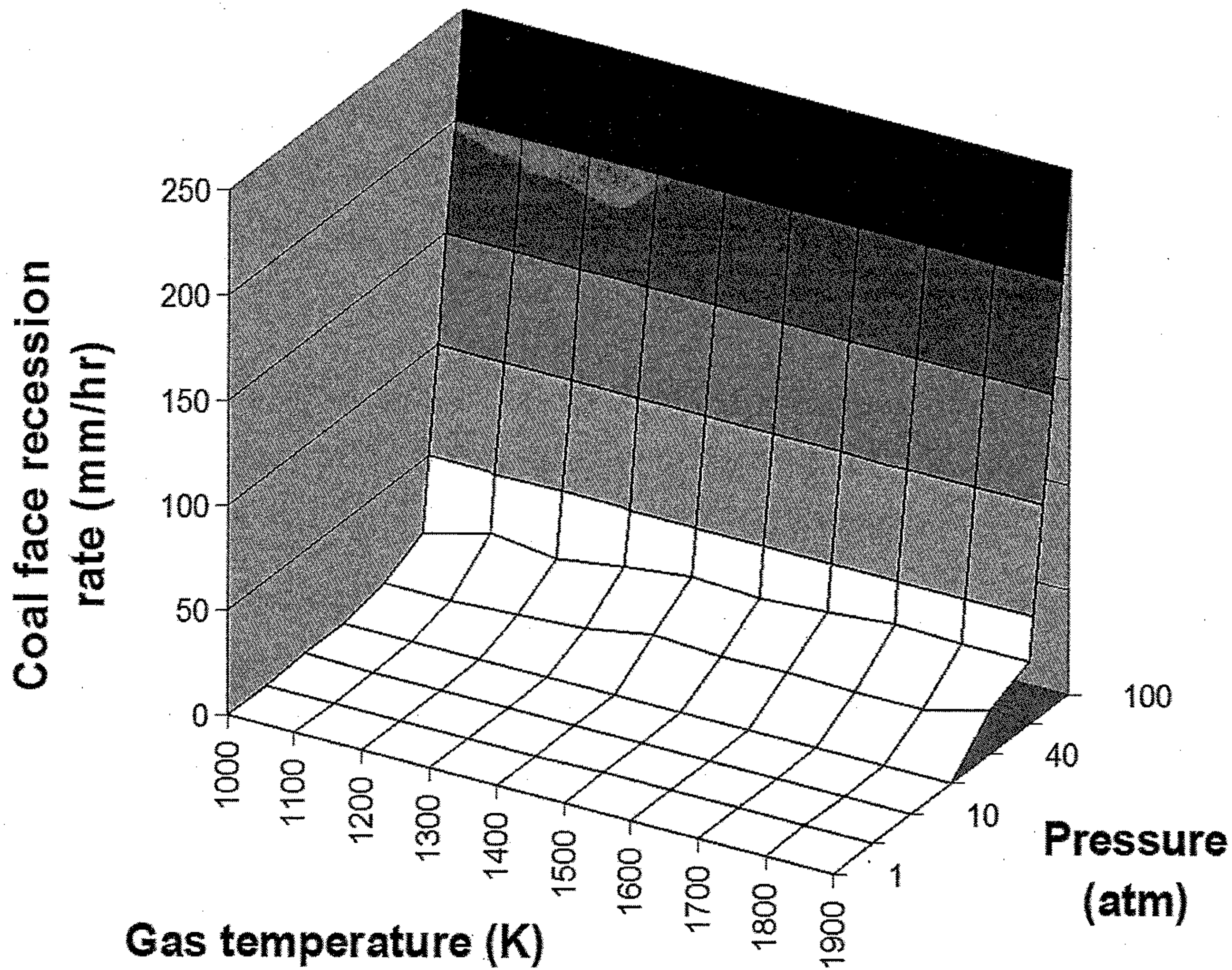
CarbonEnergy



CSIRO

Predictions from the coal model -Impact of pressure and temperature

CarbonEnergy



CSIRO

Use of the coal model

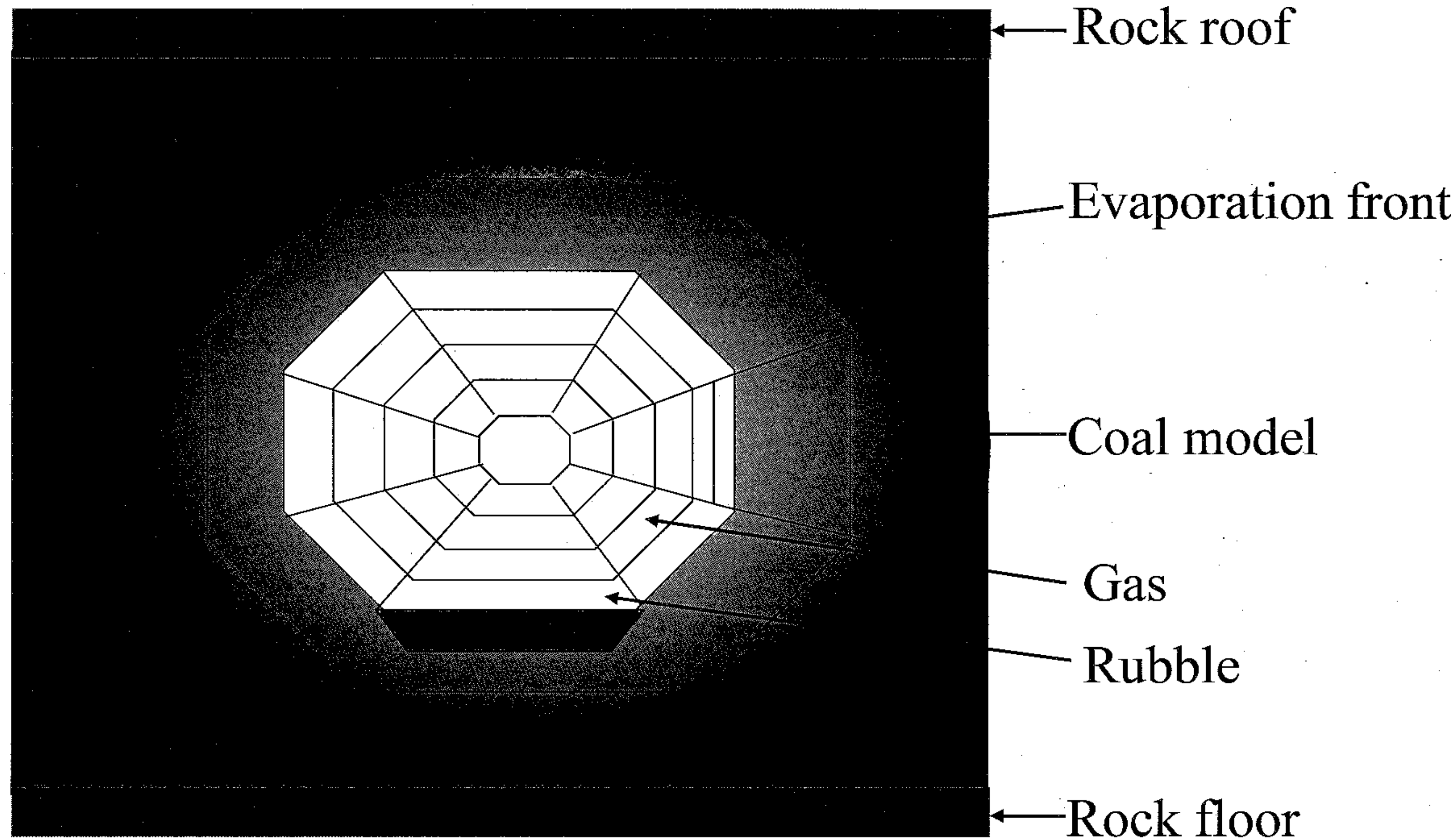
CarbonEnergy

- Does not provide standalone predictions relevant to UCG as it neglects many of the gas flow and heat transfer features of real cavities
- Makes spot predictions of coal behaviour under pseudo-steady state conditions to feed into more complex models
- Can be used to predict the general operating regimes that are desirable for efficient gasification

CSIRO

Cavity Model

CarbonEnergy



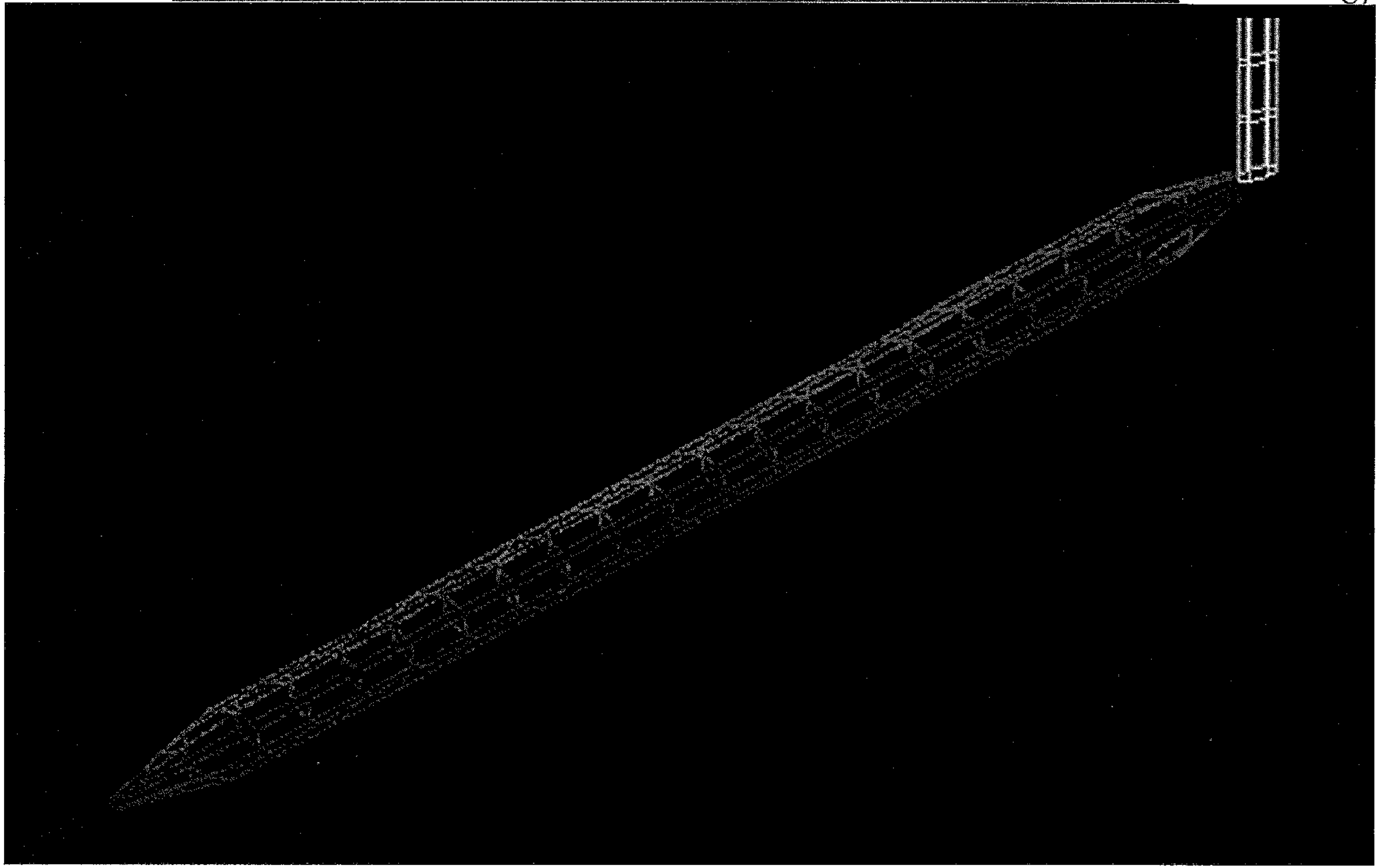
CSIRO

Elements of a cavity model

CarbonEnergy

- **Coal & char reactions**
- **Coal/char structural changes**
- **Gas flow and reactions**
- **Water flows and evaporation**
- **Heat transfer**
  - Conduction,
  - Convection
  - Radiation
- **Rock & coal breakage and collapse**
- **Resizing of the matrix with growth**

Cavity model operation



Specific gas concentration prediction from cavity model

CSIRO

Model performance

CarbonEnergy

Predicts accurately:

- o Cavity volume changes
- o Product gas composition and flow

Hindrances to model performance:

- o Requires detailed site information
- o It is difficult to accurately predict the shape of complex gasification arrangements

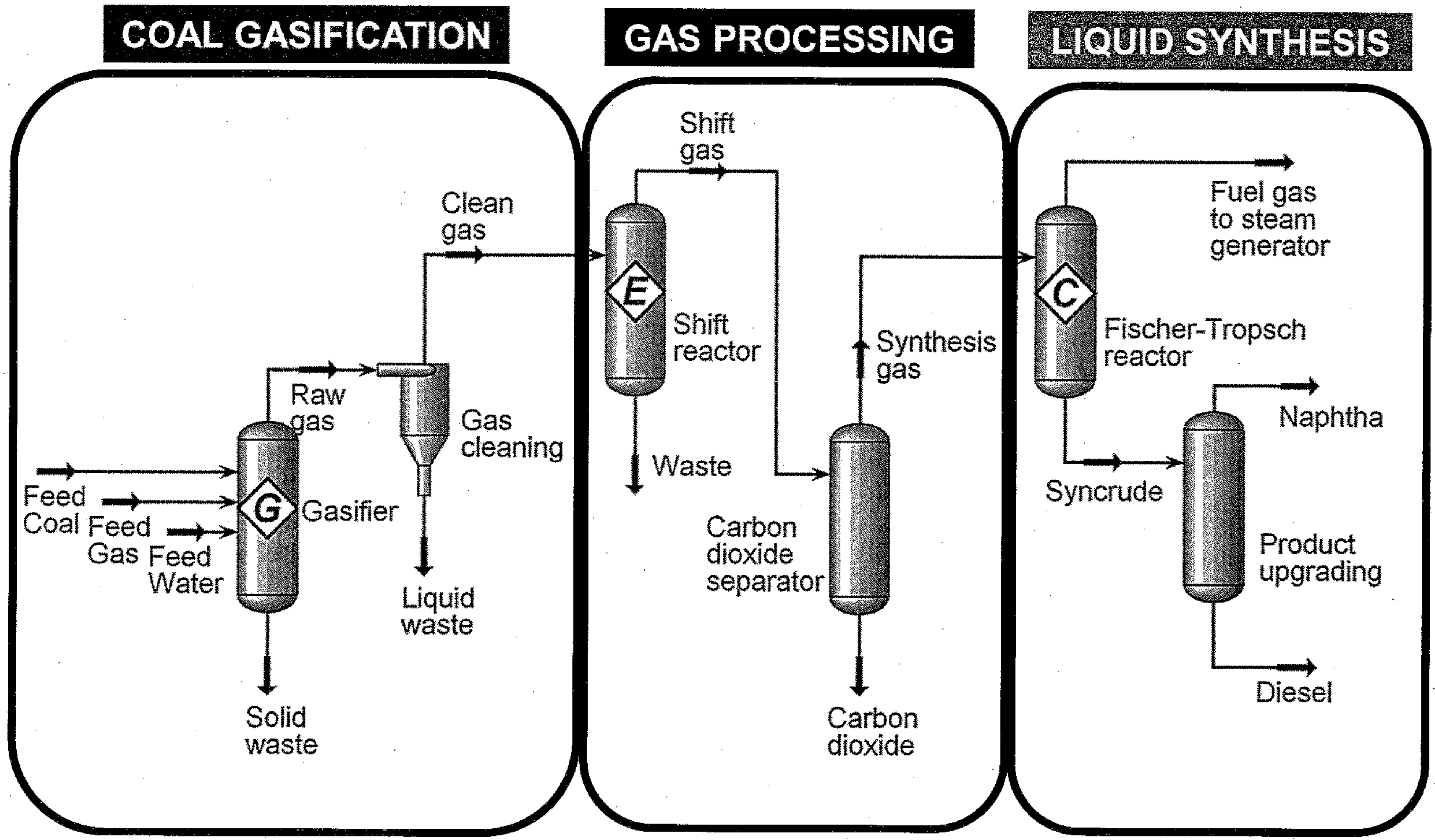
CSIRO

Process Simulation for Liquid Fuel Synthesis

CarbonEnergy

- UCG is a low cost option for providing gas for Fischer-Tropsch synthesis of liquid fuels
- This is a tempting process to consider due to the high value of the products, but the capital cost of the synthesis plant is very high

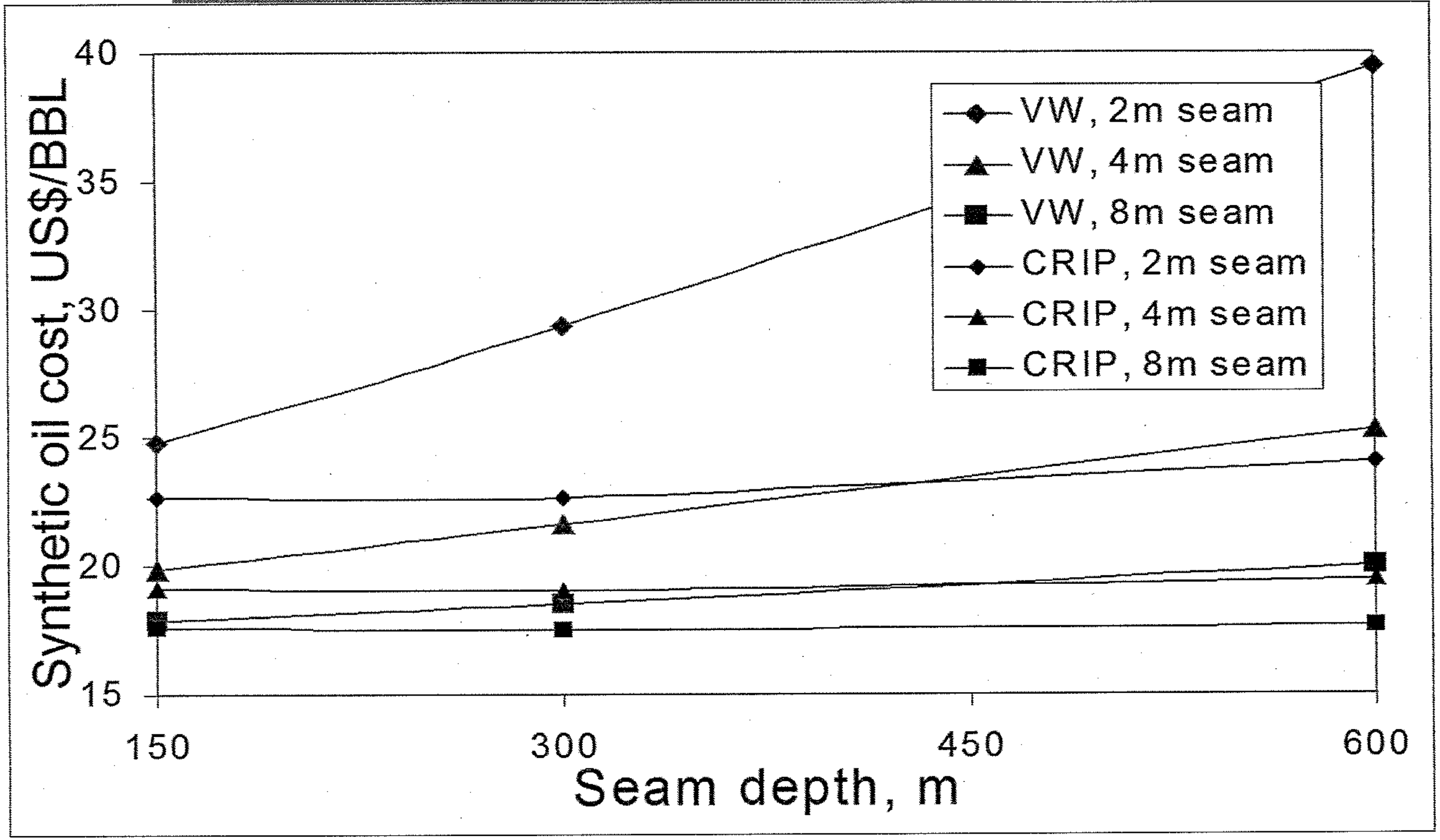
Schematic of Liquid Fuel Synthesis



CSIRO

Economics of Liquid Fuel Synthesis

CarbonEnergy



VW = Vertical Wells technology & CRIP = Generic directionally-drilled technology
Based on a 10.000 bbl/day plant

CSIRO

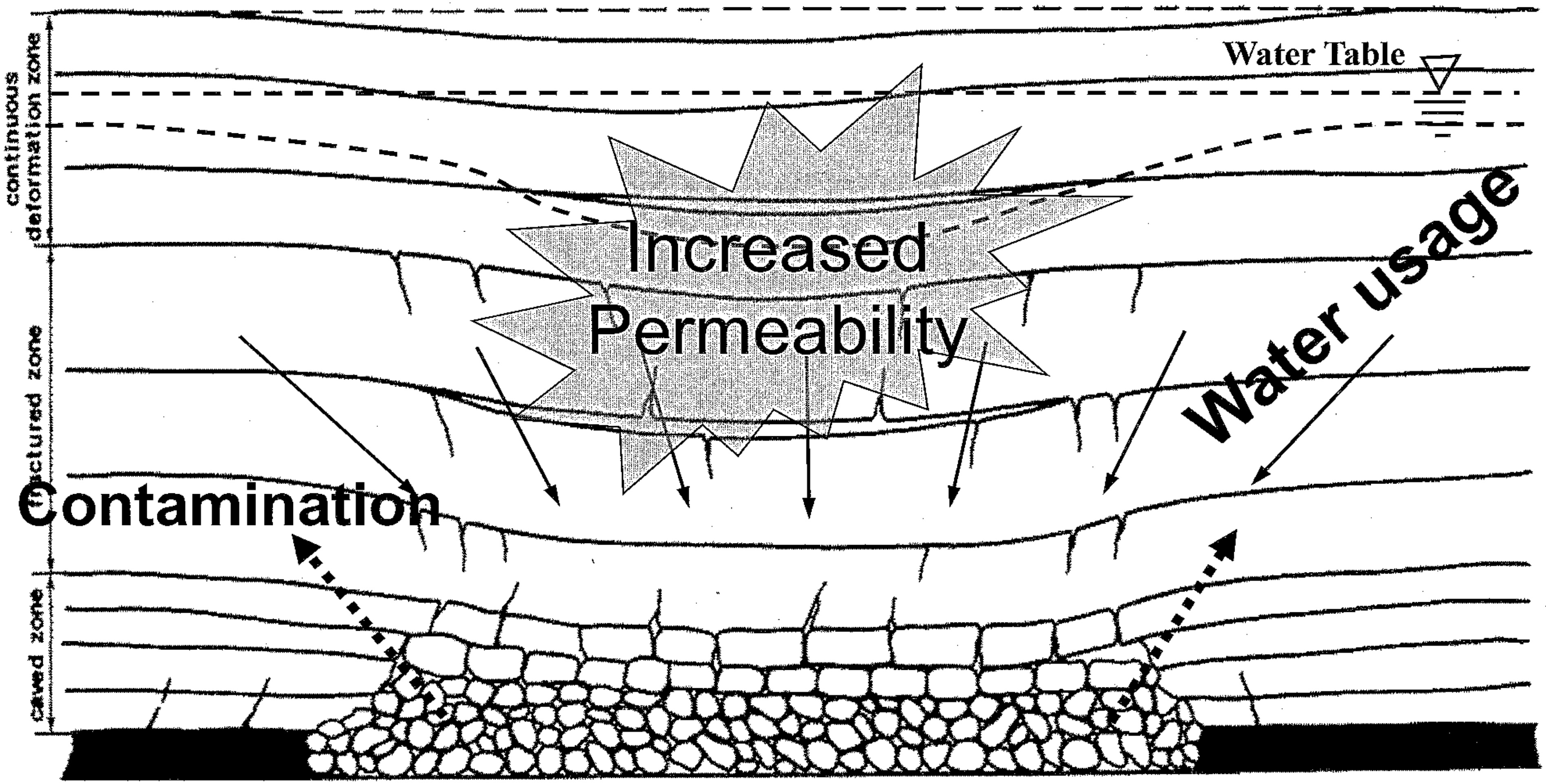
Comments on liquid synthesis

CarbonEnergy

- The gas specification for this process is much more stringent than for electricity generation and it will be difficult to convince financiers that UCG alone can supply a reliable gas feed
- Large scale UCG with gas blending can maintain constant composition, but may lead to environmental problems

Physical Site Changes

Surface subsidence



CSIRO

Physical site changes

CarbonEnergy

Specialised geotechnical and hydrological models are required to provide accurate of the physical behaviour at the site, only simplified versions are used in the other models to reduce complexity.

The physical site behaviour is important in ensuring that predictions of operational and environmental performance are accurate.

CSIRO

COSFLOW Geotechnical Model

CarbonEnergy

COSFLOW is a coupled dual porosity two phase flow model developed with a specific objective of addressing the mine issues, such as ground deformation, water flow and gas emission

- Couples rock mechanics of layered strata with one or two phase compressible fluid flow
- Cosserat Continuum => efficient simulation of the deformation behaviour of stratified rock
- Estimates rock fracture induced changes in hydraulic properties (e.g. permeability and porosity)
- Simulates water and gas flow through fractured rock

COSFLOW was developed by CSIRO assistance of JCOAL and NEDO of Japan

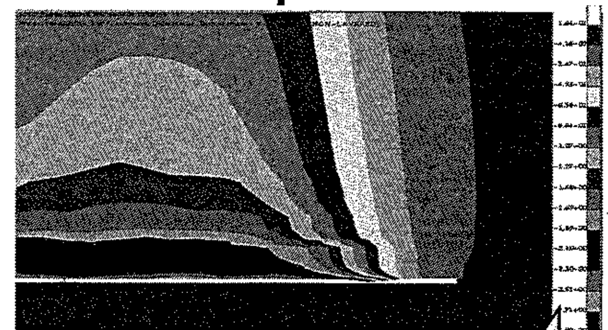
COSFLOW is a program developed By CSIRO and JCOAL & NEDO

COSFLOW Numerical Modelling

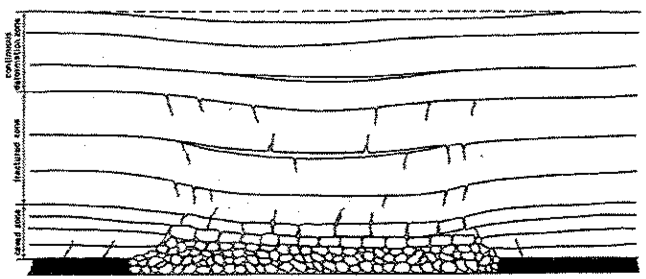
INTERACTION

Mining induced strata fracture/deformation

Vertical Displacement



Change in permeability and reservoir pressure



Caved, fractured and deformed zones

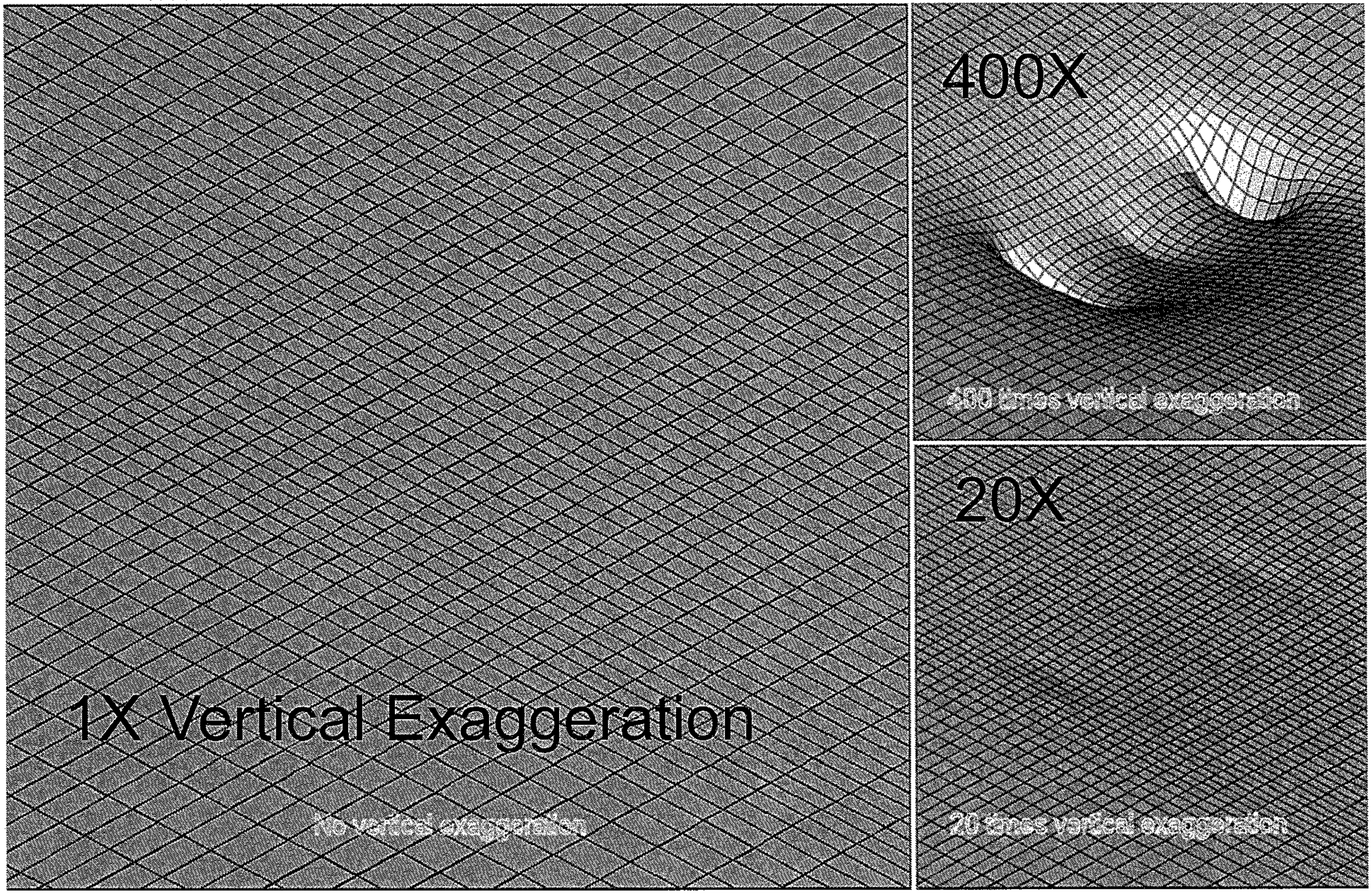
Change in effective stress

Ground water flow

Change in reservoir pressure and relative permeability

Gas diffusion and flow

Subsidence


1X Vertical Exaggeration
No vertical exaggeration
400X
400 times vertical exaggeration
20X
20 times vertical exaggeration

CSIRO

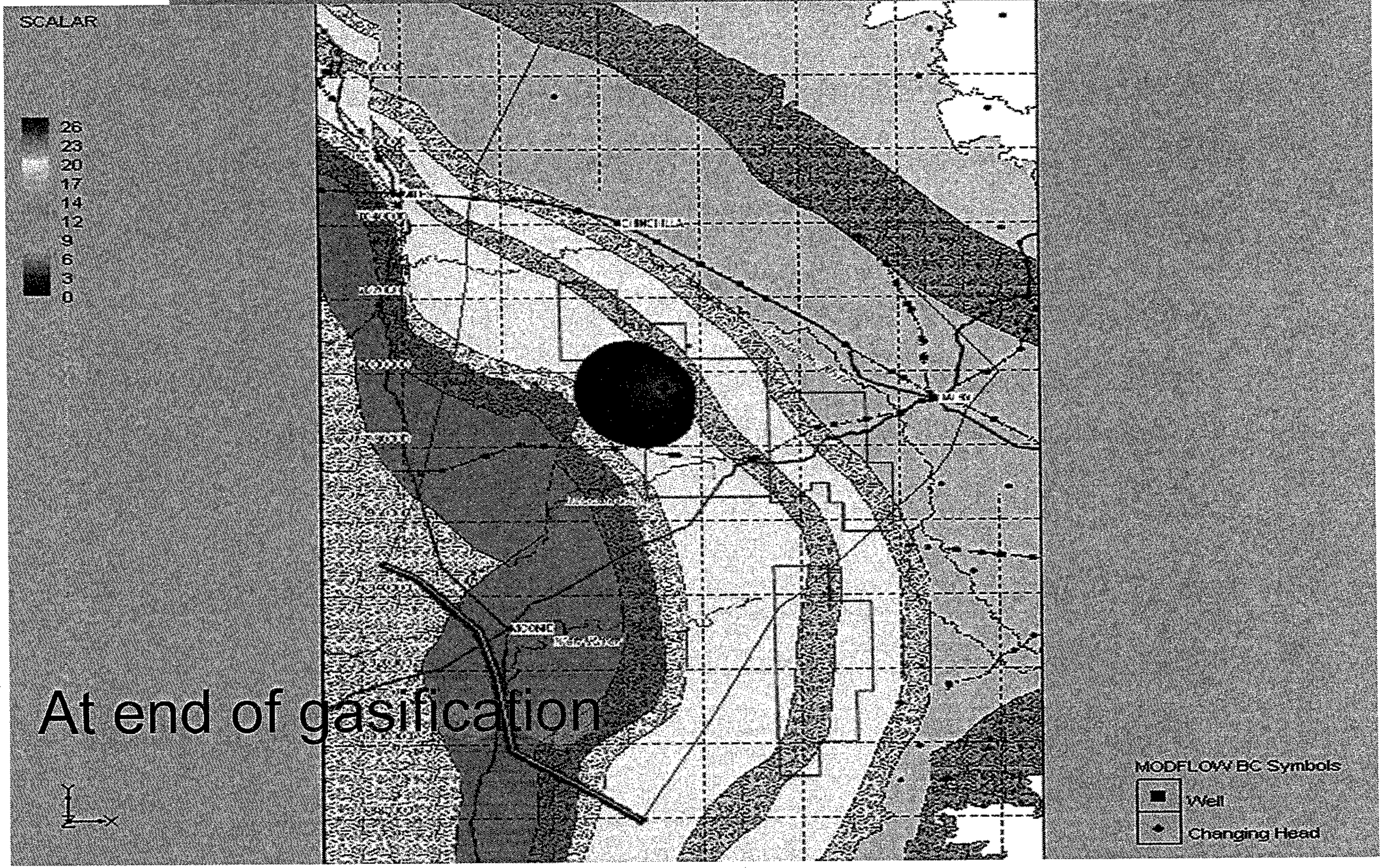
Hydrological Model

CarbonEnergy

Commonly available packages MODFLOW and MT3D are used to predict larger scale hydrological behaviour around the UCG site

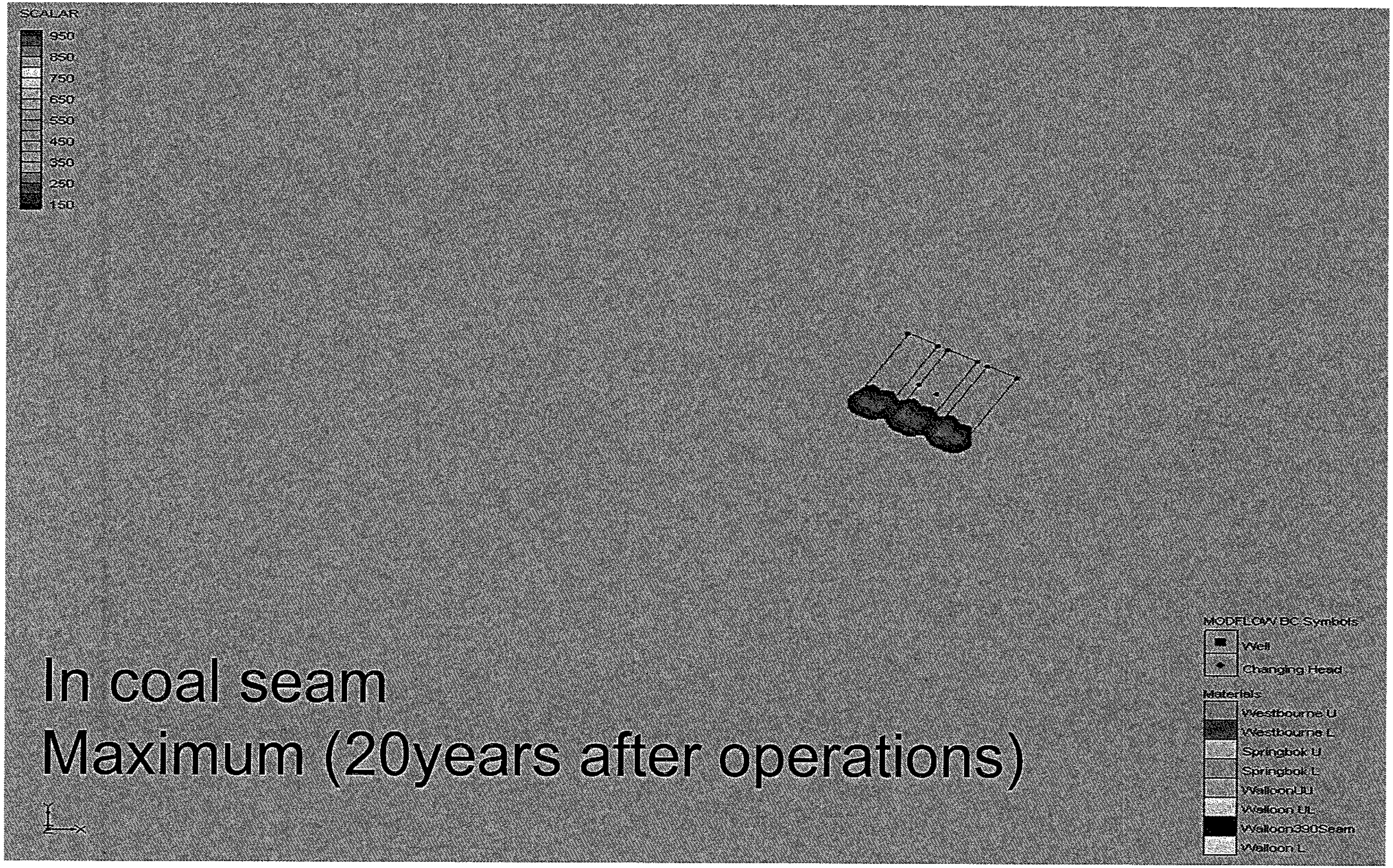
- MODFLOW simulates three-dimensional groundwater flow through a porous medium by solving the flow equation using the finite difference method.
- MT3D simulates the advection, dispersion and chemical reactions of contaminants in groundwater flow systems in either two or three dimensions.

Groundwater drawdown



At end of gasification

Salt contamination

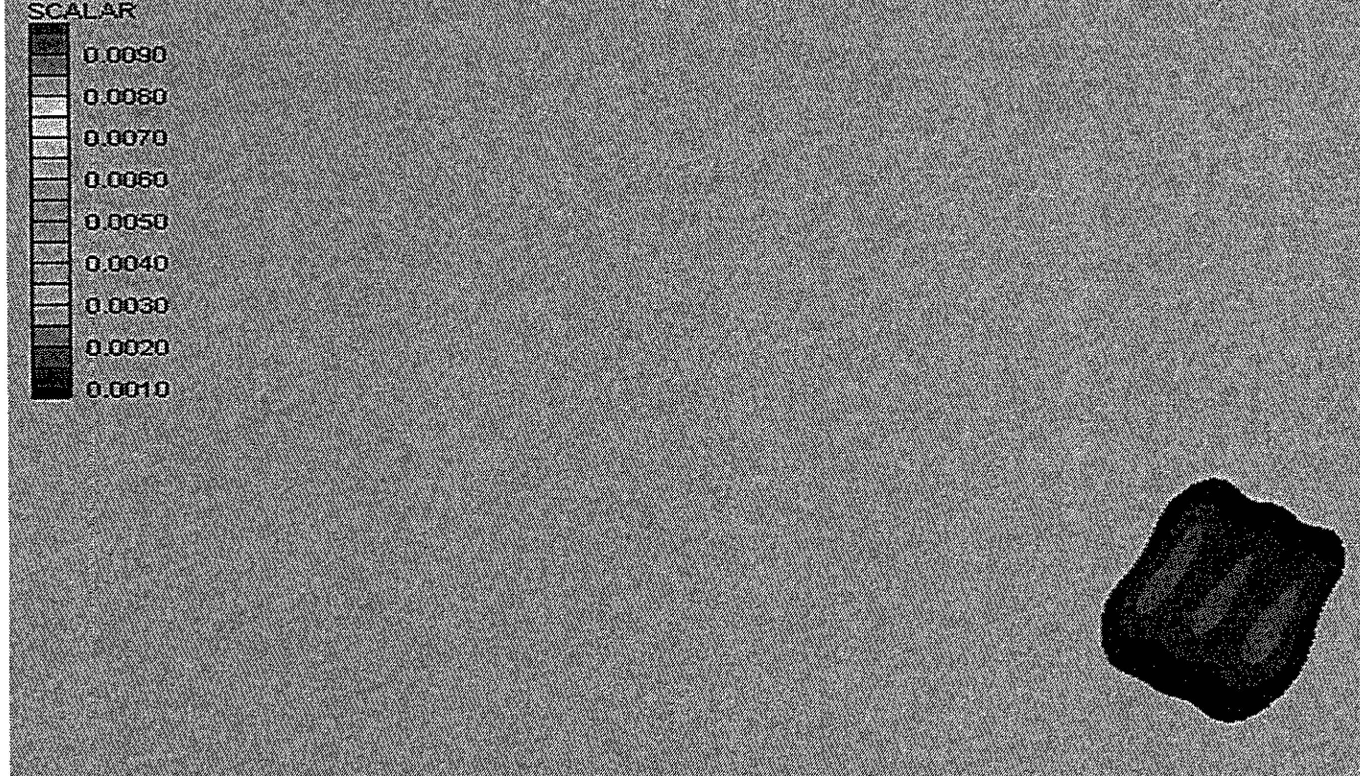


In coal seam
Maximum (20years after operations)

Benzene contamination

CSIRO

CarbonEnergy



Springbok sandstone

100years after operation

Constant release - no reaction or adsorption

CSIRO

How does this relate to other sites?

CarbonEnergy

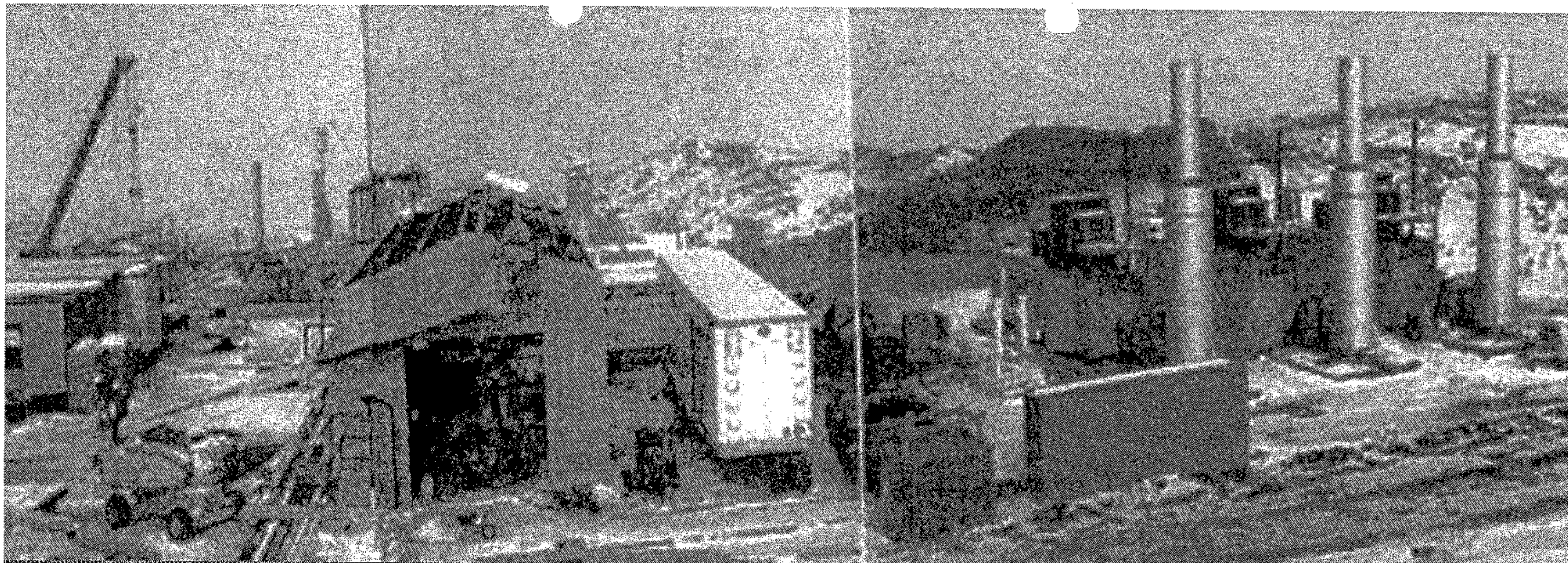
- Each site is unique, so all modelling must be repeated for the specific size of installation at the actual site
- A general finding is that it appears possible to develop and environmentally sound and operationally efficient plants at suitable sites

CSIRO

Summary

CarbonEnergy

- A comprehensive suite of models that provides predictions of all aspects of UCG based processes has been developed and demonstrated
- It is necessary to use this approach to test the performance at specific sites and to verify that the environmental performance is likely to be acceptable



CSIRO

The End

CarbonEnergy