CRF 2015 Annual Meeting and Coal Conversion Divisional seminar

UCG Developments in Wales

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- Risks/Uncertainties for UCG in Wales
- R&D - Seren project
- Field studies – Seren project
- Future directions

Mining in Wales

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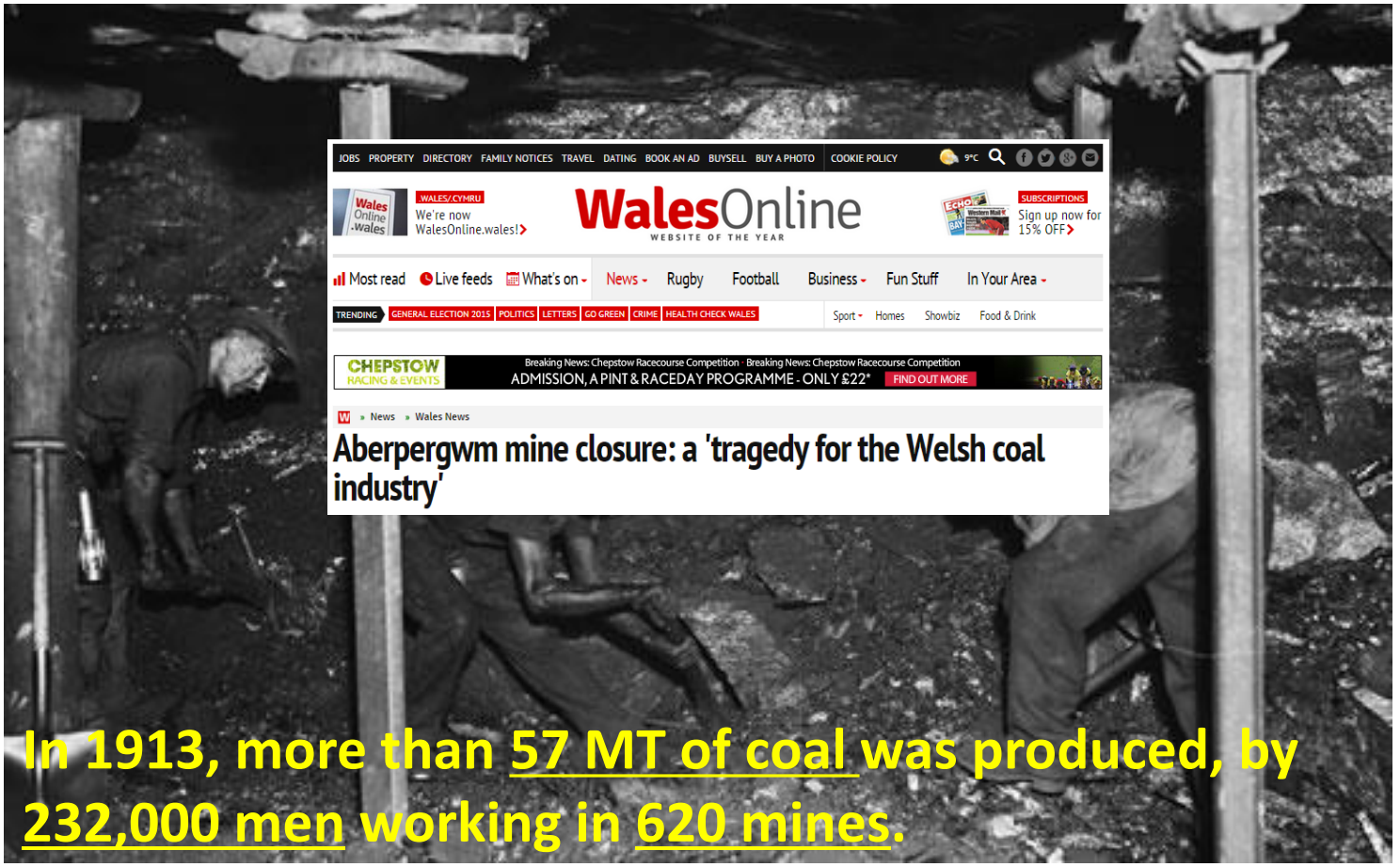
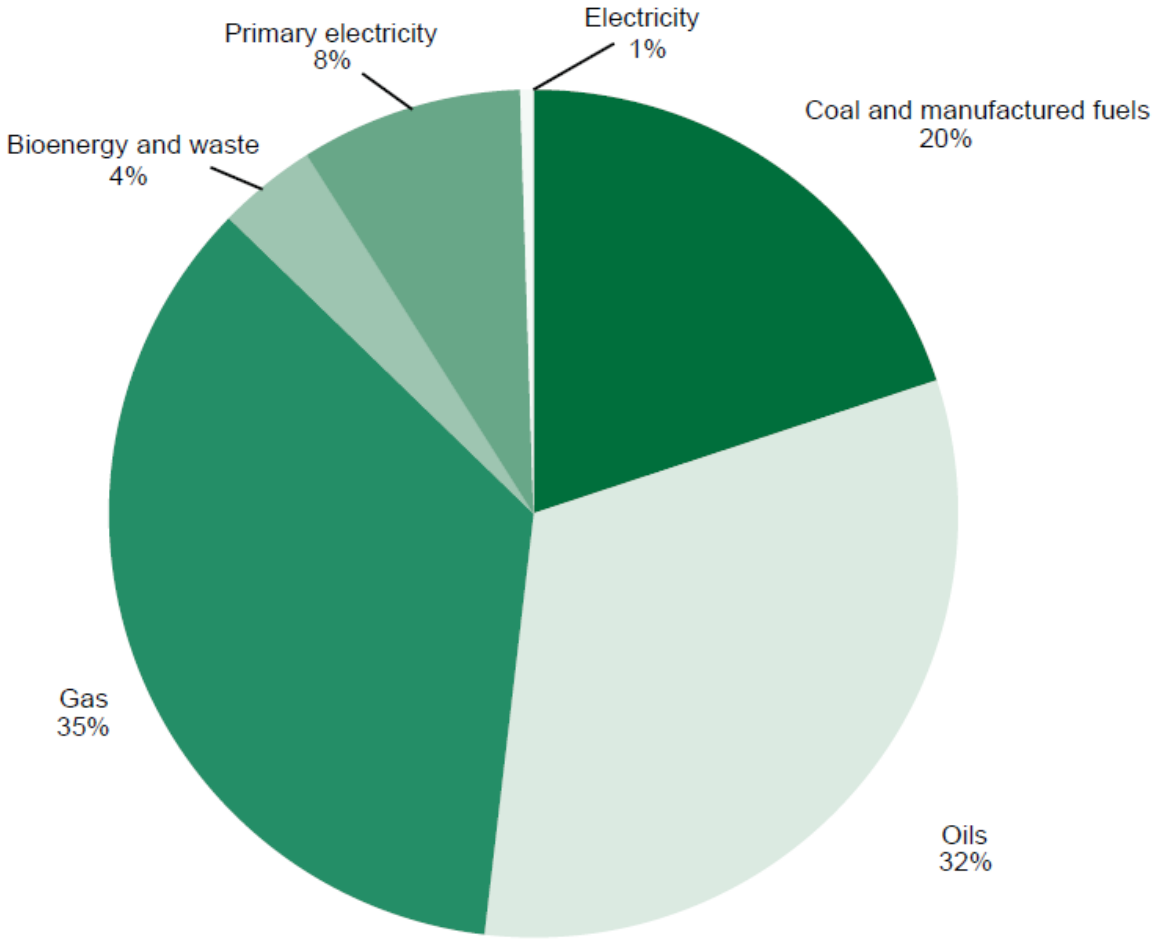
- **Mining** in Wales provided a significant source of income to the economy of Wales throughout the nineteenth century and early twentieth century. It was key to the Industrial Revolution.

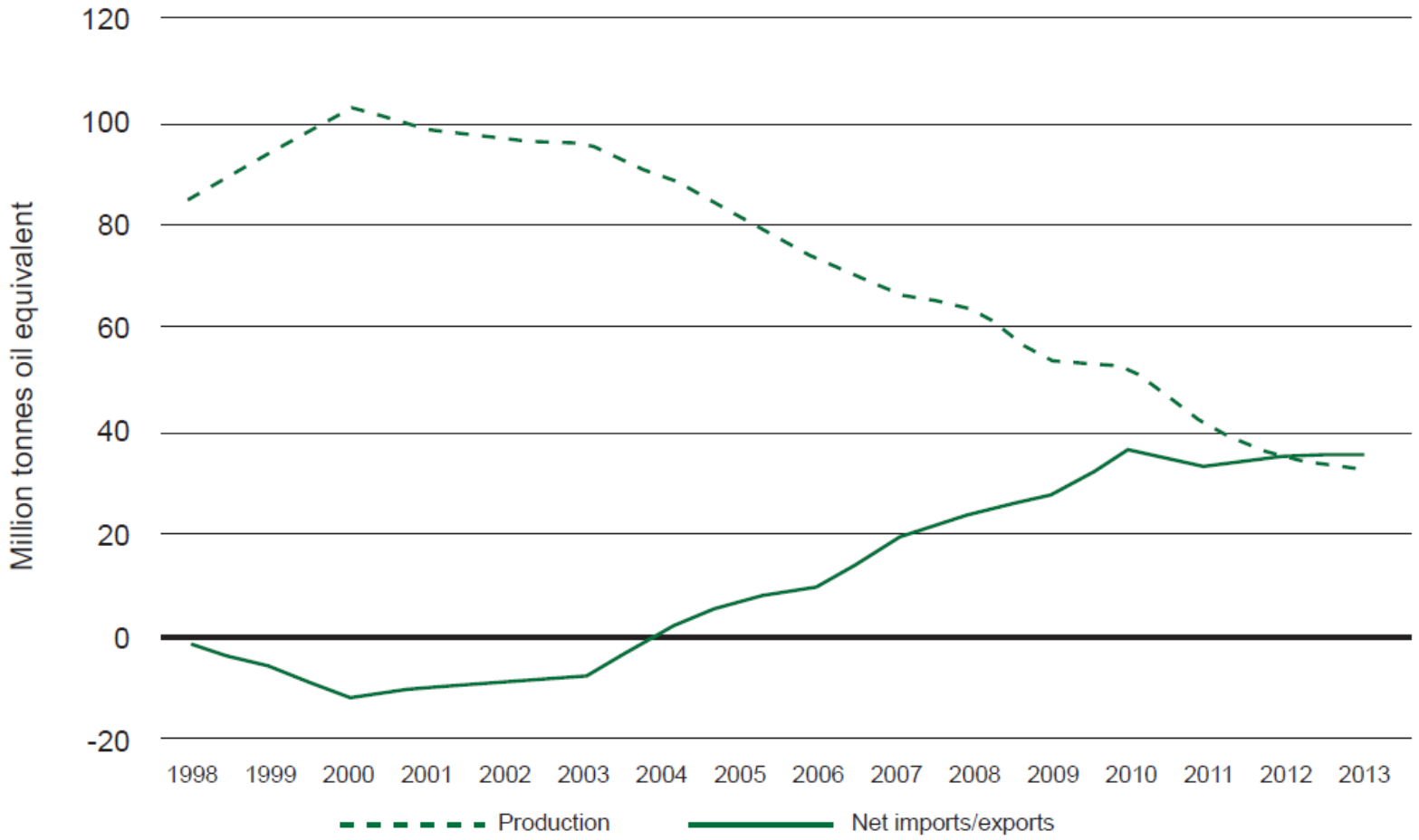


UK inland energy consumption by primary fuel in 2012



Source: Department of Energy and Climate Change

UK gas production and trade 1998 to 2013



Source: Department of Energy and Climate Change

Energy Trilemma for Electricity/Heat

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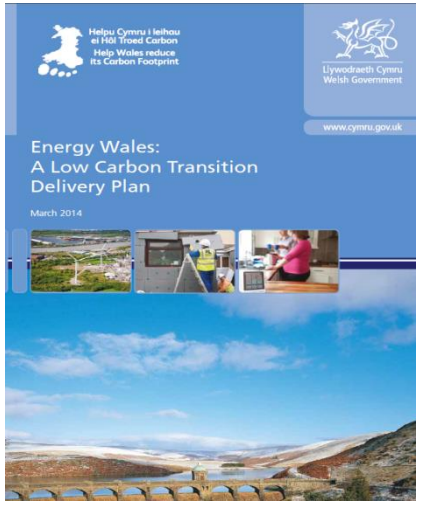
Llywodraeth Cymru
Welsh Government



Affordable energy supply

- Economic issues
- Job creation
- Local environmental impact
- Physical infrastructures
- Local v Central

Diversity and resource efficiency/smart living goals

- Public acceptability
- Project credibility
- Global influences
- Innovation opportunities

Security of energy of supply

Transition to a less carbon intensive energy mix

Percentage of electricity generated in Wales by fuel type

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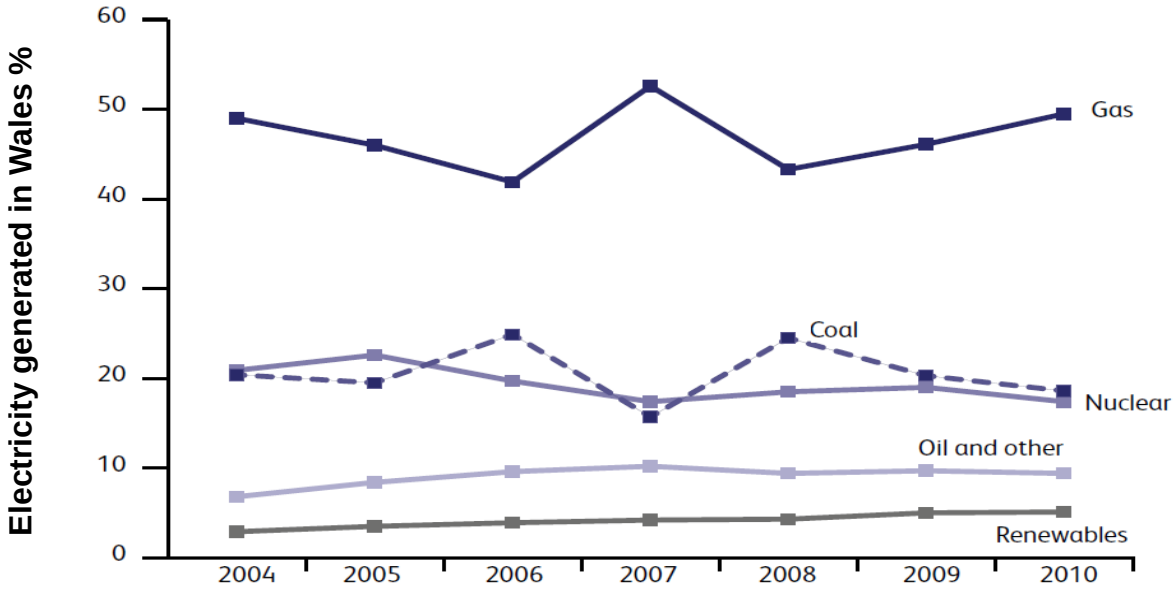
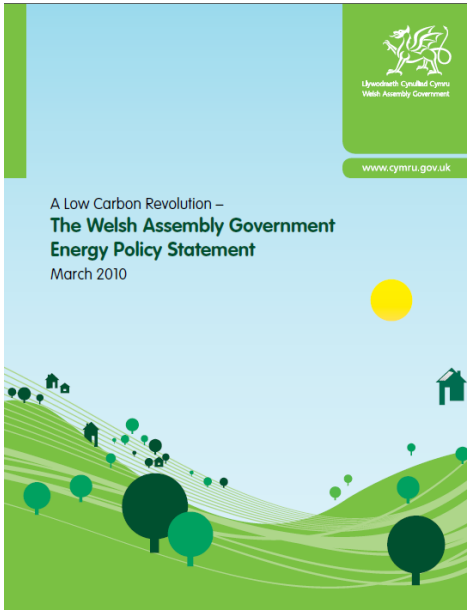
- In recent years, the UK has become increasingly dependent on gas imports
- Government forecasts that nearly 70% of the UK's gas supply will be imported by 2025.
- Gas continues to remain the dominant source, responsible for almost 50% of all electricity generated in Wales.
- Considering the growing dependence on gas supplies from countries that may be subject to political instability, it is vital to identify new sources of gas if it is to safeguard the Wales/UK's security of supply and provide economic growth in the transition to the low carbon future.





Development of innovative geo-energy solutions

ERDF
Llywodraeth Cymru
Welsh Government
Ewrop & Chymru: Buddsoddi yn eich dyfodol
Cronfa Datblygu Rhanbarthol Ewrop
Europe & Wales: Investing in your future
European Regional Development Fund

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Seren
Sustainable Earth Energy

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Developing innovative engineering technologies for commercial applications within the geo-energy themes to explore sustainable earth energy options for Wales

BGS 1835
British Geological Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

PRIFYSGOL ABERYSTWYTH UNIVERSITY

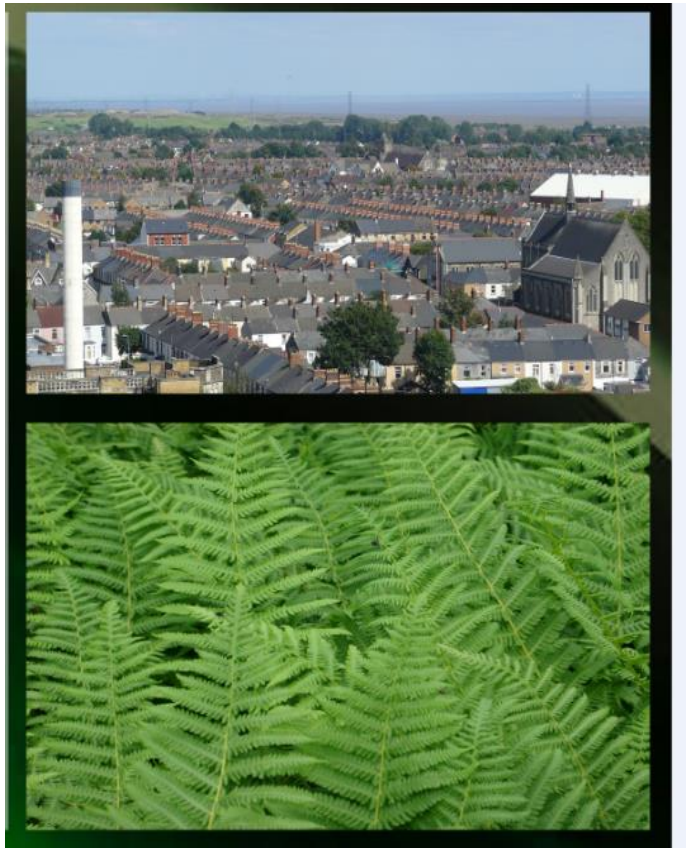
PRIFYSGOL BANGOR UNIVERSITY

WDS green energy

Cambrensis

APEX DRILLING SERVICES

AIMS OF THE PROJECT



- ***Helping to make Wales self sufficient in Energy.***
  - *Identify ground energy options*
  - *Renewable and sustainable energy mapping*
- ***Address economic renewal strategy for Wales.***
  - *Creating new companies and jobs in Wales*
  - *Building technical capacity*
  - *Renewable and sustainable energy mapping*
- **Promote cross cutting themes:**
  - *Environmental Sustainability*
  - *Equal Opportunities*

Sustainable Earth Energy

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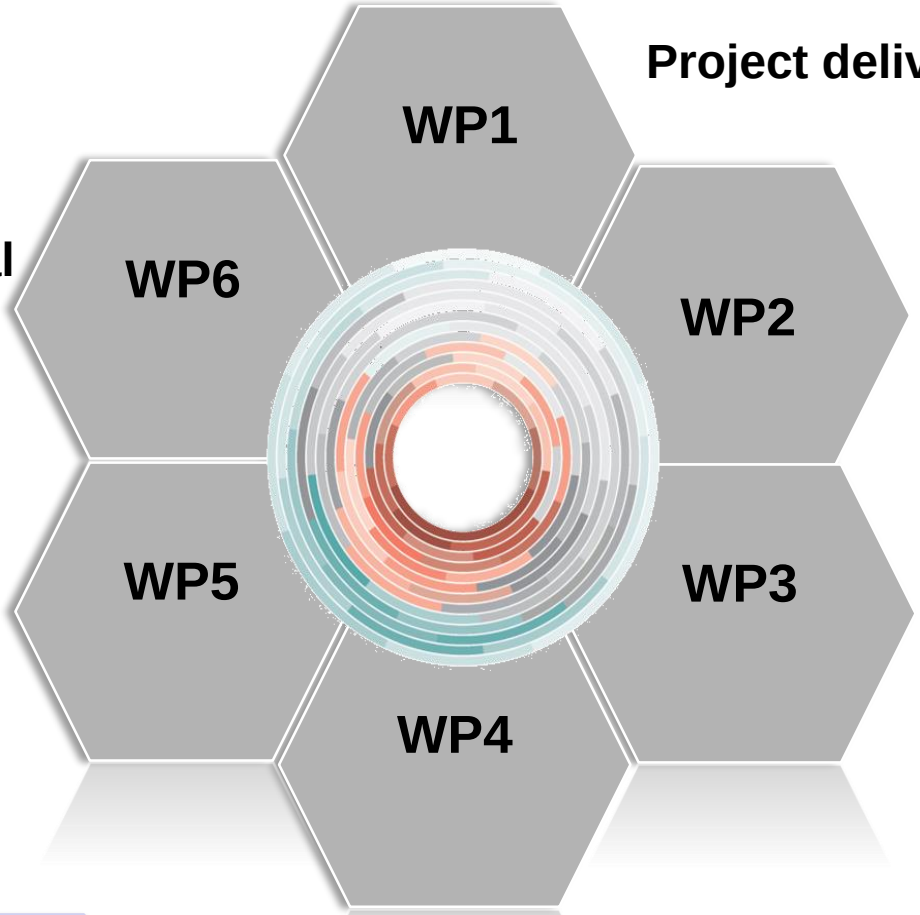
Seren
Sustainable Earth Energy



Project delivery

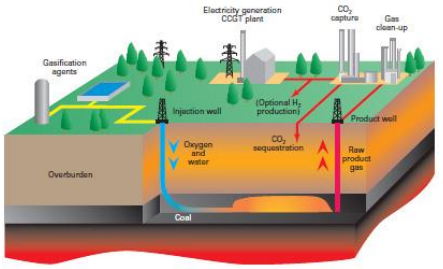
Advanced Computational Modelling

Cambrensis

Ground Source Heat

WDS green energy

Geoinformatic



Underground Coal Gasification

Carbon Sequestration in Coal and Soil

Cost	Start Date	End Date
£10.14m	Sep 2010	Jun 2015

BGS 1835 British Geological Survey
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Prifysgol Aberystwyth University

Prifysgol Bangor University

Value chain of Underground Coal Gasification

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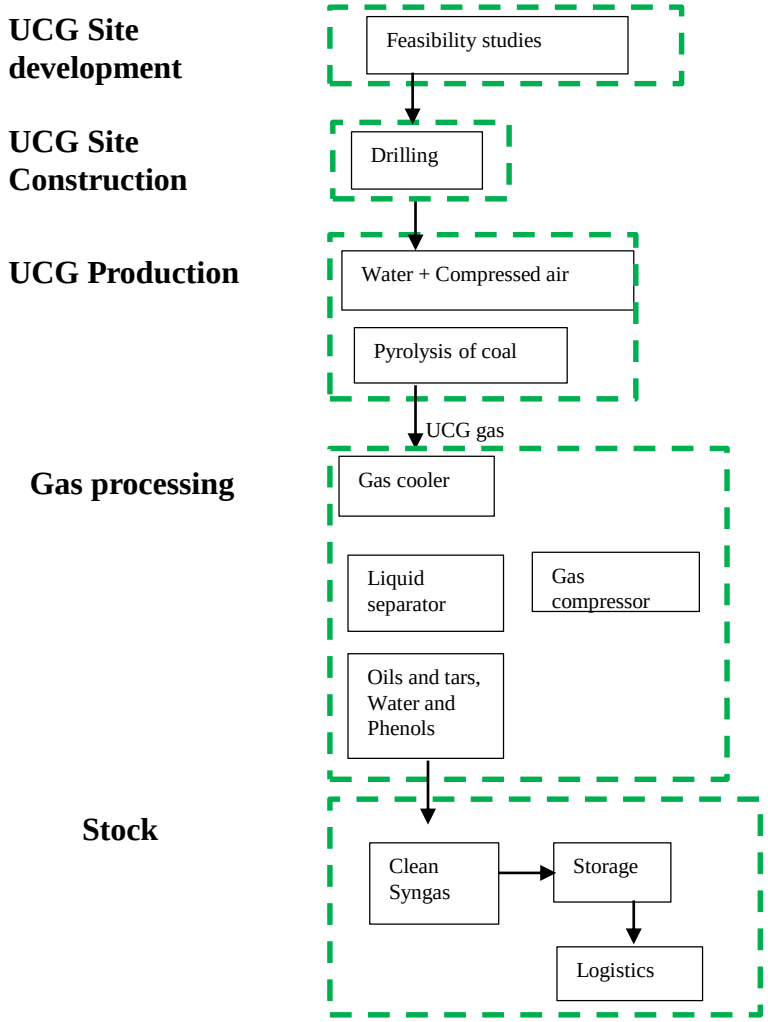
Business opportunities from the value chain in Wales

UCG could provide business opportunities for:

a) Entrepreneurs;
b) Equipment and machineries manufacturers;
c) Raw materials suppliers; and
d) Those in the service sector.
e) UCG syngas end users i.e. electricity generation, chemical manufacturing, iron and steel production, gas to liquids



Major challenges we had to face:

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- Increase low carbon energy security and reduce/sequester CO_2 emissions for Wales
- Increase job opportunities (especially high tech jobs) in general and better job security in the high energy consumption sectors and
- Create a “knowledge dam” for Underground Coal Gasification

Where	**Site Selection** • Geology • Source proximity • Proximity to settlements • Resource potential	**Desk study** **Exploration** • **Drilling** • **Geophysics** **Land use** **Market analysis**
How	**Experimentation** • Rate of injection of oxidants • Calorific Value • Gas composition	**Laboratory investigation** **Sample collection** **Data analysis** **Numerical modelling**
When	**Engagement** • Licensing • Environmental Impact • Public Acceptance/ engagement	**Seminars** **Workshops** **Training courses** **Public consultants**

Opportunities of UCG in Wales

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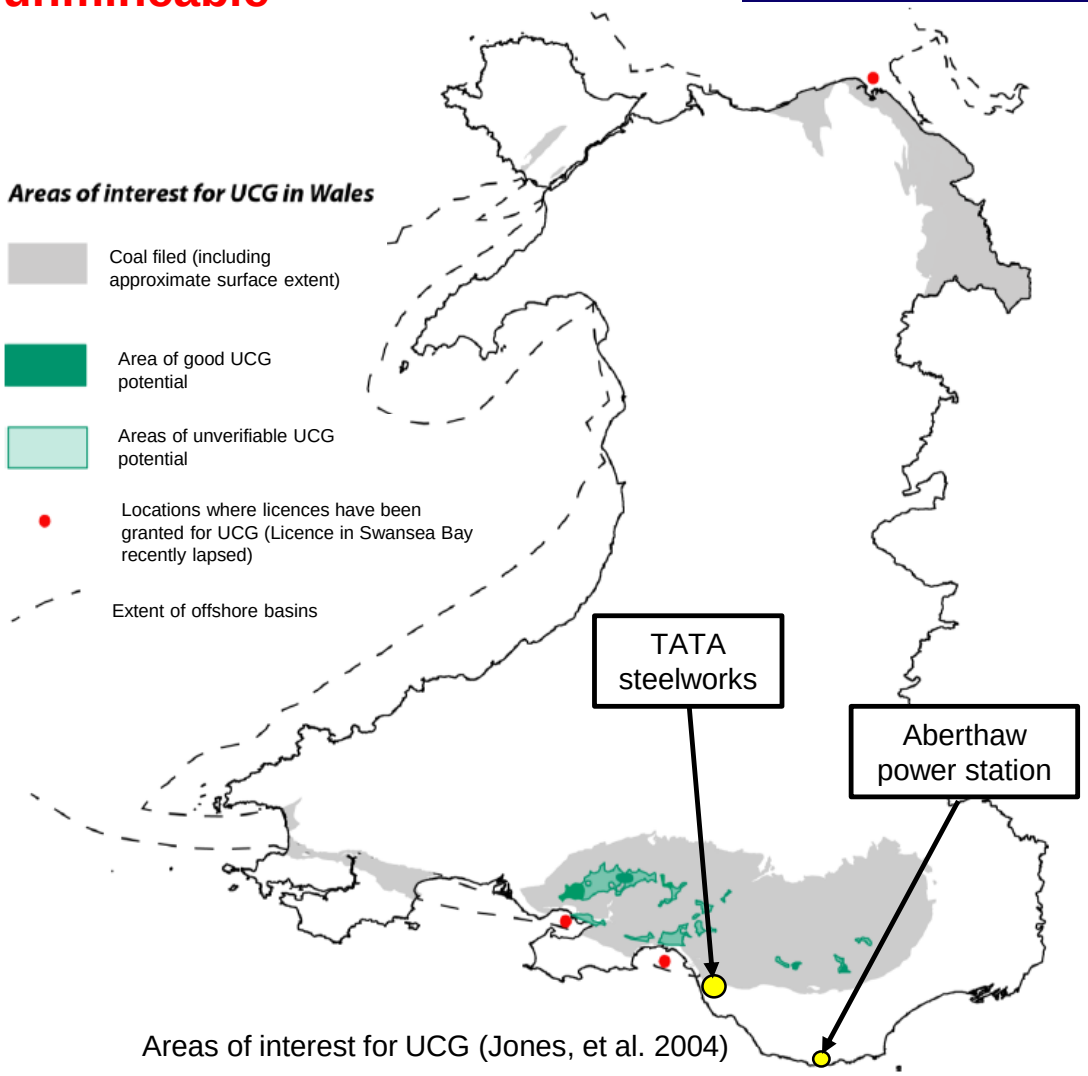
Potential for undertaking UCG into unmineable coal beds in Wales.

- The South Wales Coalfield, is one of the largest (90 x 25 miles) coalfields in UK.
- Coals are present below 1,200 m in large areas of the coal field (Llanelli and Port Talbot) which are not economical to be mined using conventional methods.
- Coal seams are thick and with a variation of coal rank across the coalfield.
- Some of the largest UCG end users are located on the South Wales Coalfield while others nearby.
- UCG Licences have been granted



Areas of interest for UCG (Jones, et al. 2004)

Opportunities of UCG in Wales

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Area of UK	"Good" UCG resource (MT)	Power output over 40 years (MW)	UCG as Nat Gas (BCM)
Eastern N/E England	6,824	11,900	681
Lancs/Dee	4,770	14,100	476
Wales	220	730*	22
Scotland	171	567	17
Total	16,784	26,730	1,676

Variation of coal rank across the South Wales Coalfield

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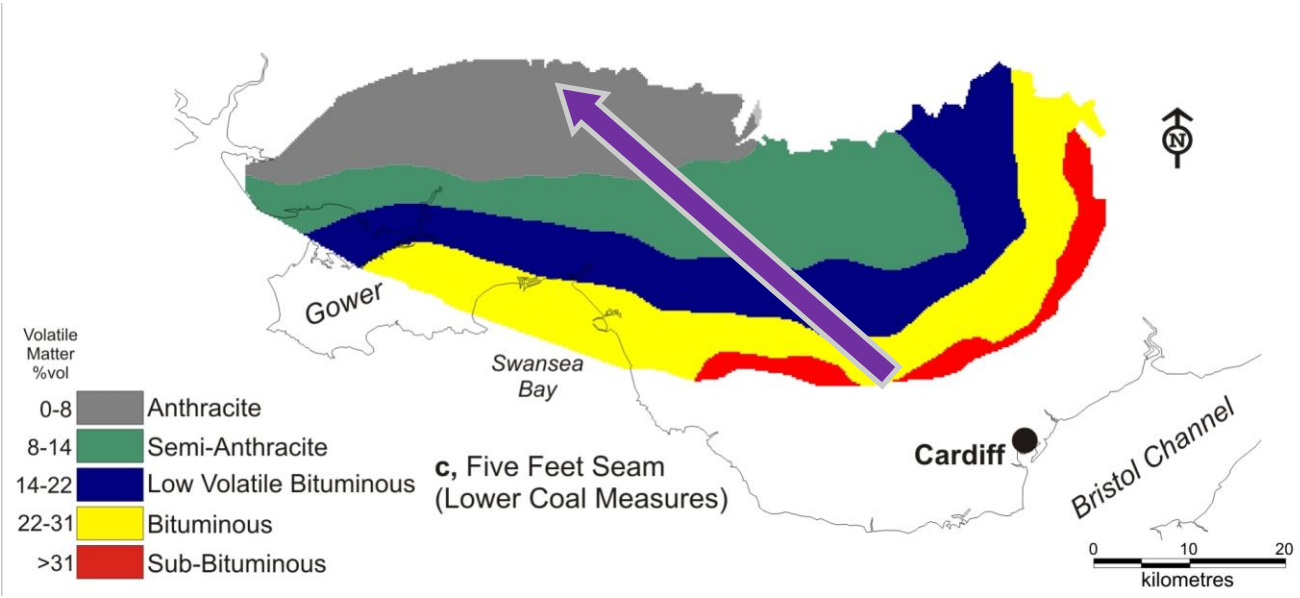
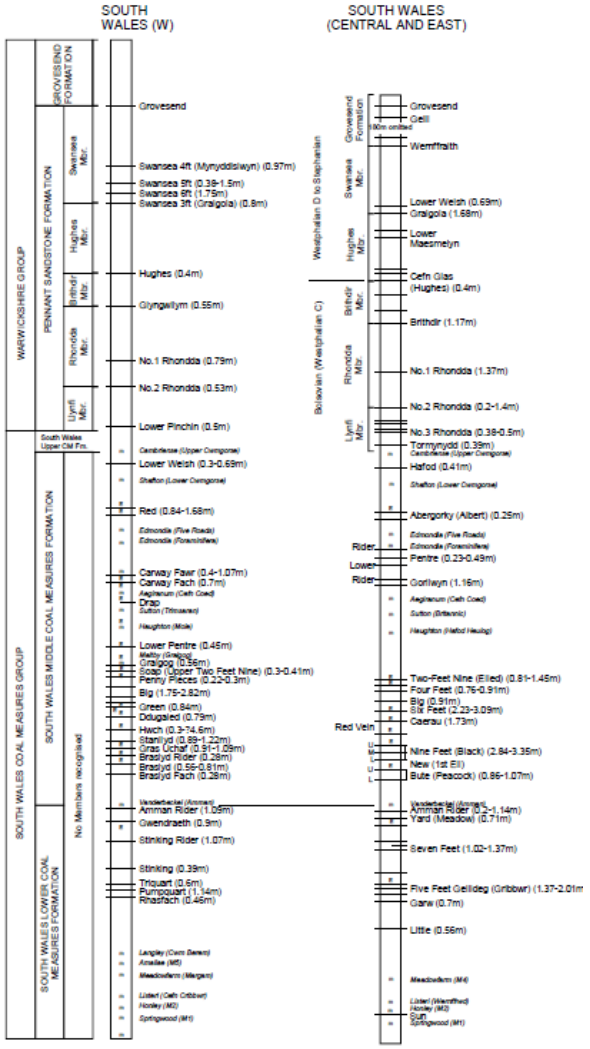
- Seams that meet criteria for UCG include (Jones 2004):

West → Big Vein
West → Nine Feet

South East → Upper seven feet
South East → Six feet



c, Five Feet Seam (Lower Coal Measures)



UCG SYNGAS composition and end uses

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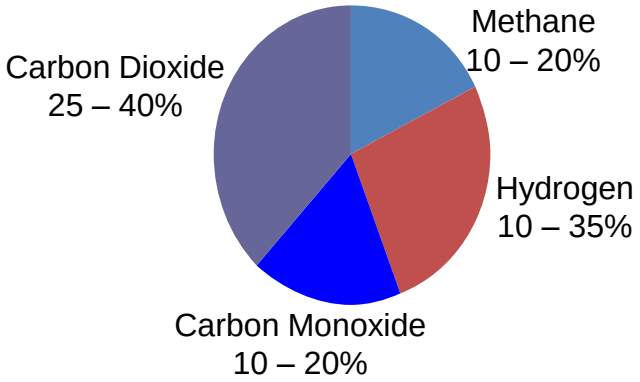
Composition

- Syngas produced during UCG is primarily composed of methane, hydrogen, carbon monoxide and carbon dioxide
- Unprocessed syngas undergoes treatment to remove water, sulphur, carbon dioxide and other waste products
  - Treatments are well understood due to surface-level coal gasification

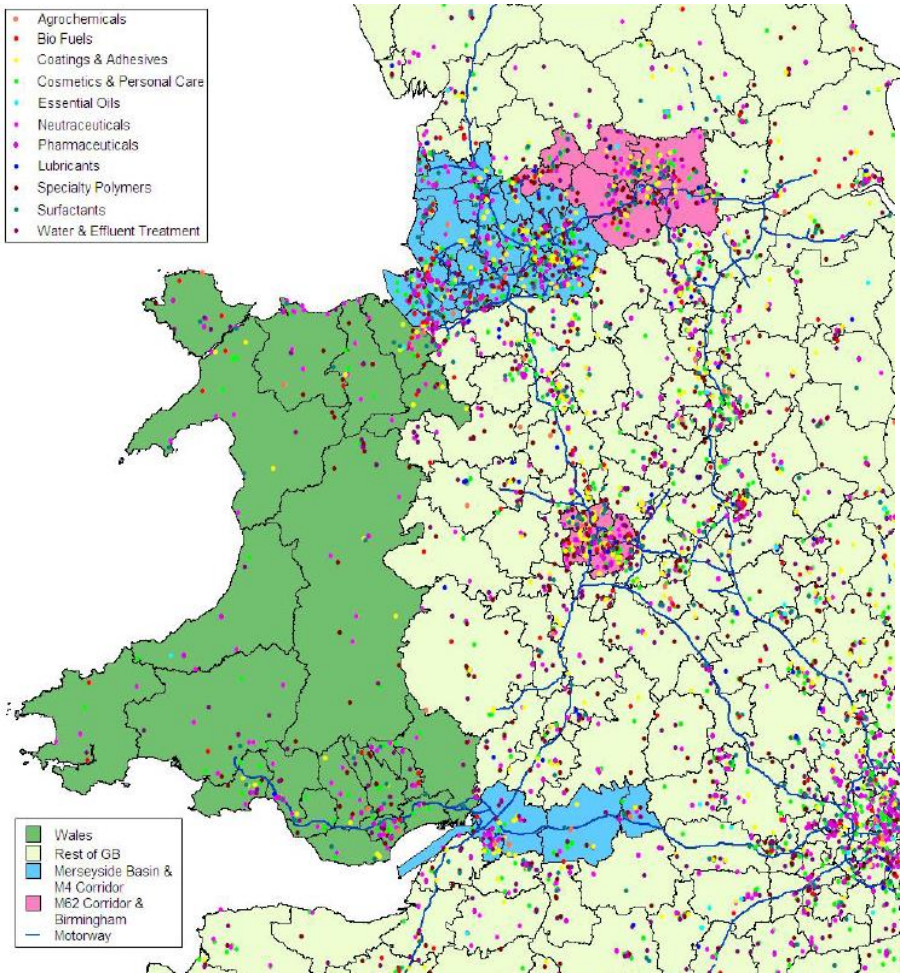


End Uses

UCG Syngas

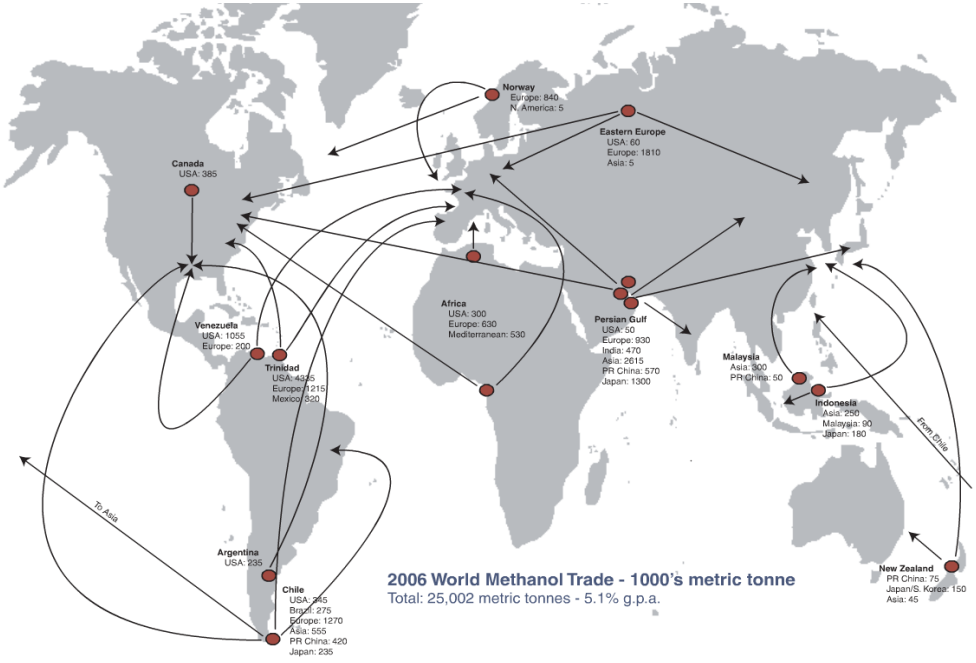
- **Electricity Generation**
  - Supply to adjacent power stations is often the optimal use
  - Using syngas directly avoids energy loss from conversion processes
- **Chemical Manufacturing**
  - High hydrogen content means ammonia can be created
    - Key input in fertiliser production
- **Iron and Steel Production**
  - Syngas can be used as a reduction agent in iron and steel production
- **Gas-to-liquids**
  - Production of fuels such as gasoline, diesel and methanol

Chemical companies



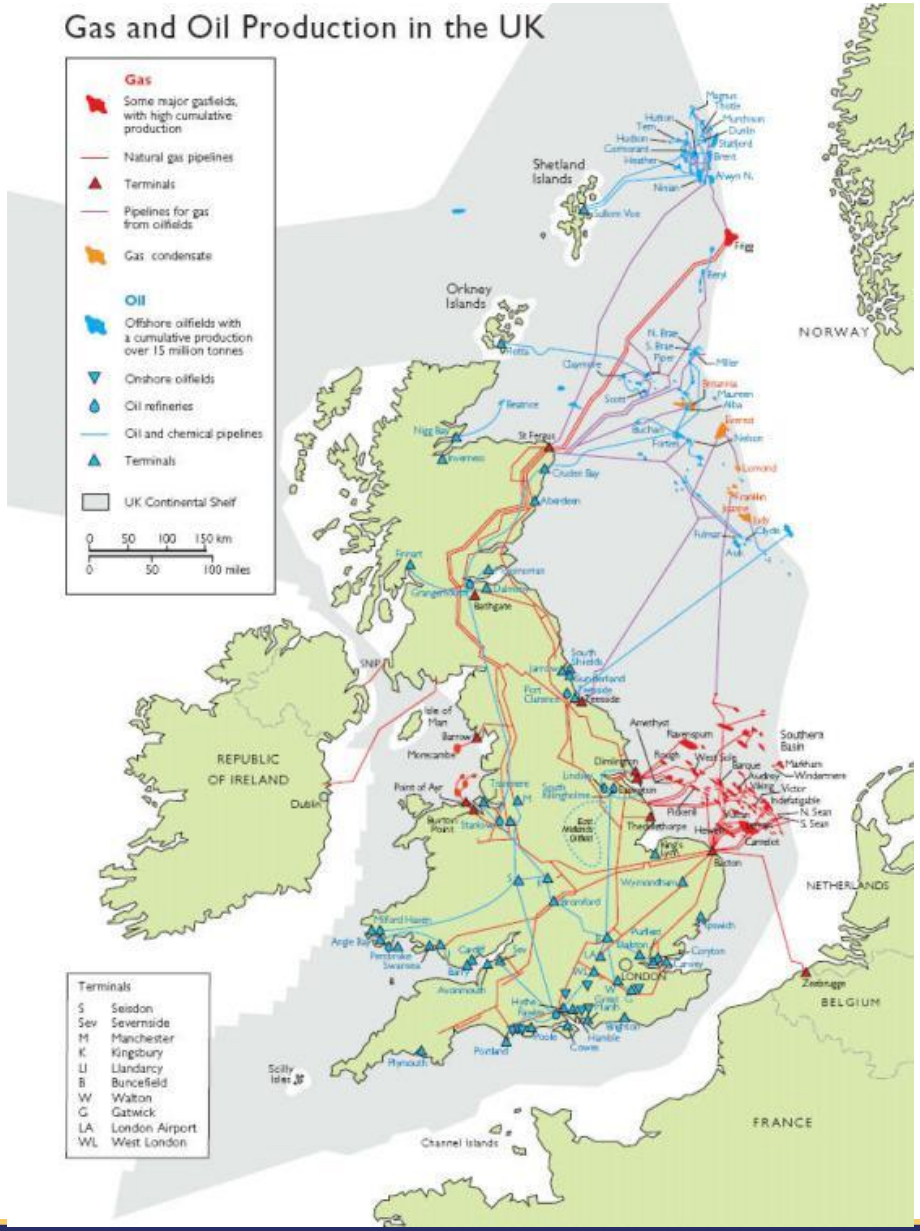
Geographical Distribution of Chemical Companies.

Source: The Biorefining Opportunities in Wales.



World Methanol Trade

Gas and Oil Production in the UK



Deep UCG licences (S Wales Coalfield)

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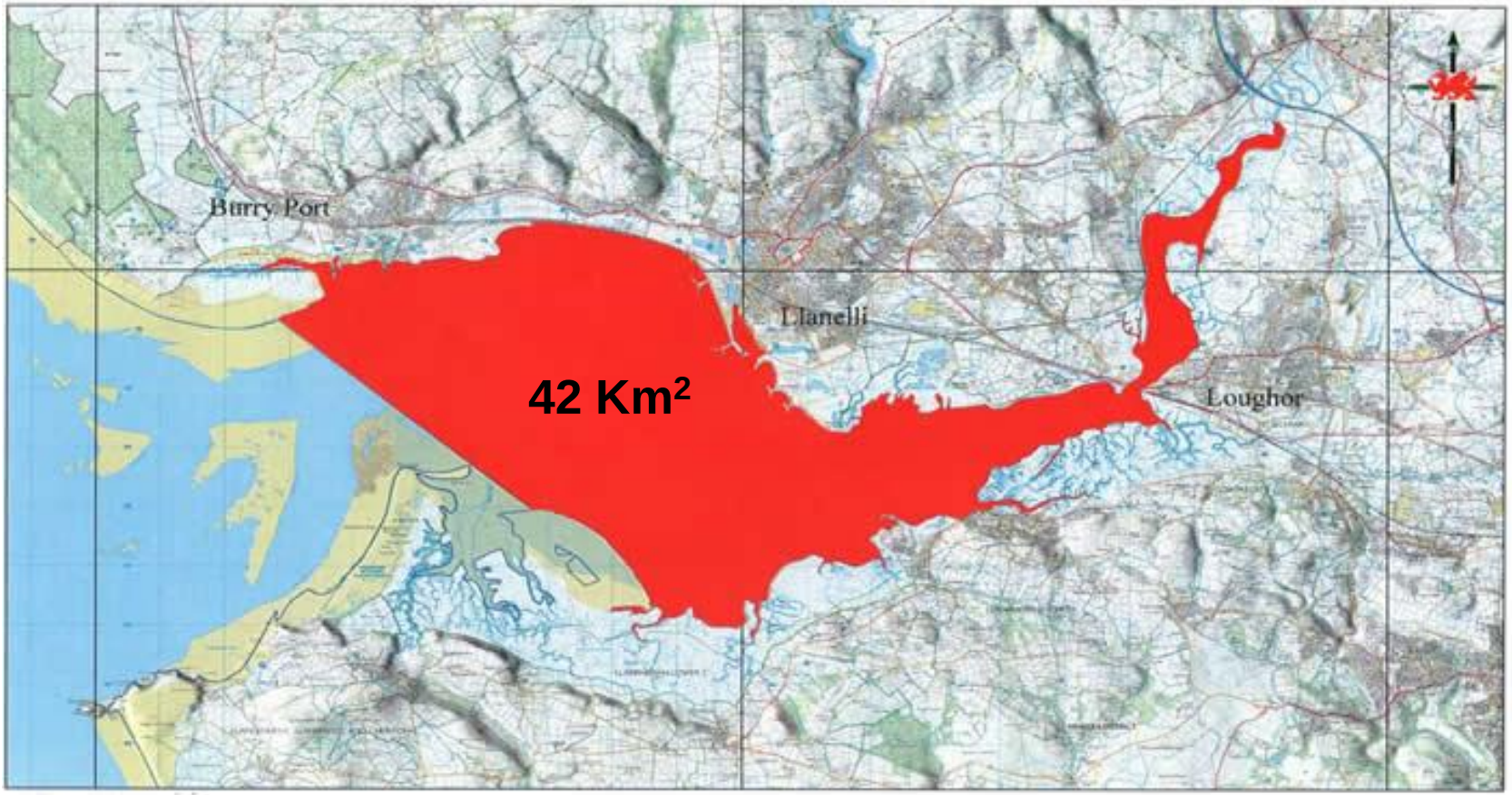
- Cluff Natural Resources hold a licence in the Loughor Estuary (South Wales) consisting of a licence area of 42 Km^2 (in which 28 Km^2 are offshore)



Deep UCG licences (S Wales Coalfield)

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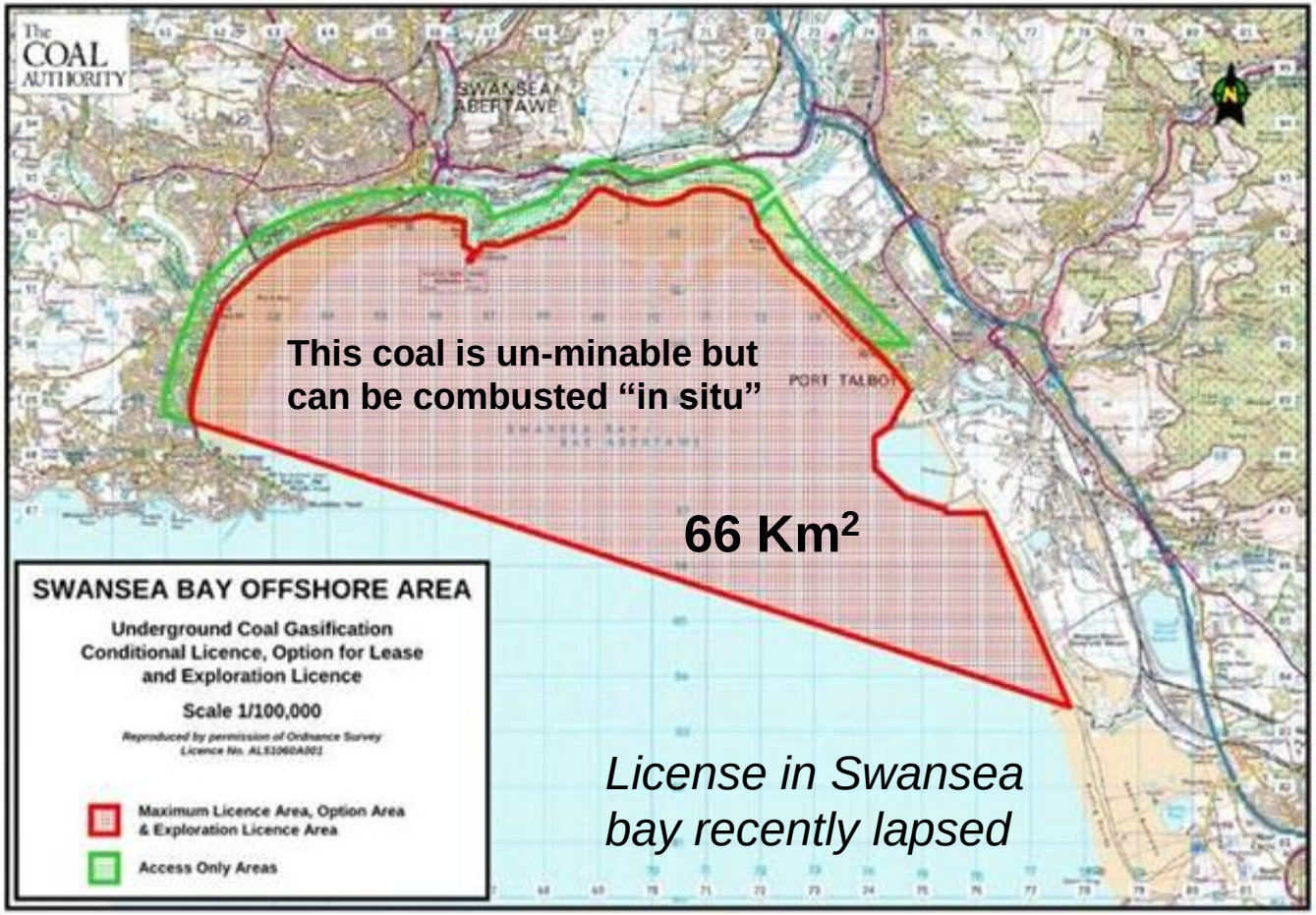
- **Clean Coal Ltd held offshore conditional UCG licences in Swansea bay**



Estimated minimum coal reserve of 200 MT

This resource could produce 0.5GW energy production for 20-30 years.

Risks and Uncertainty

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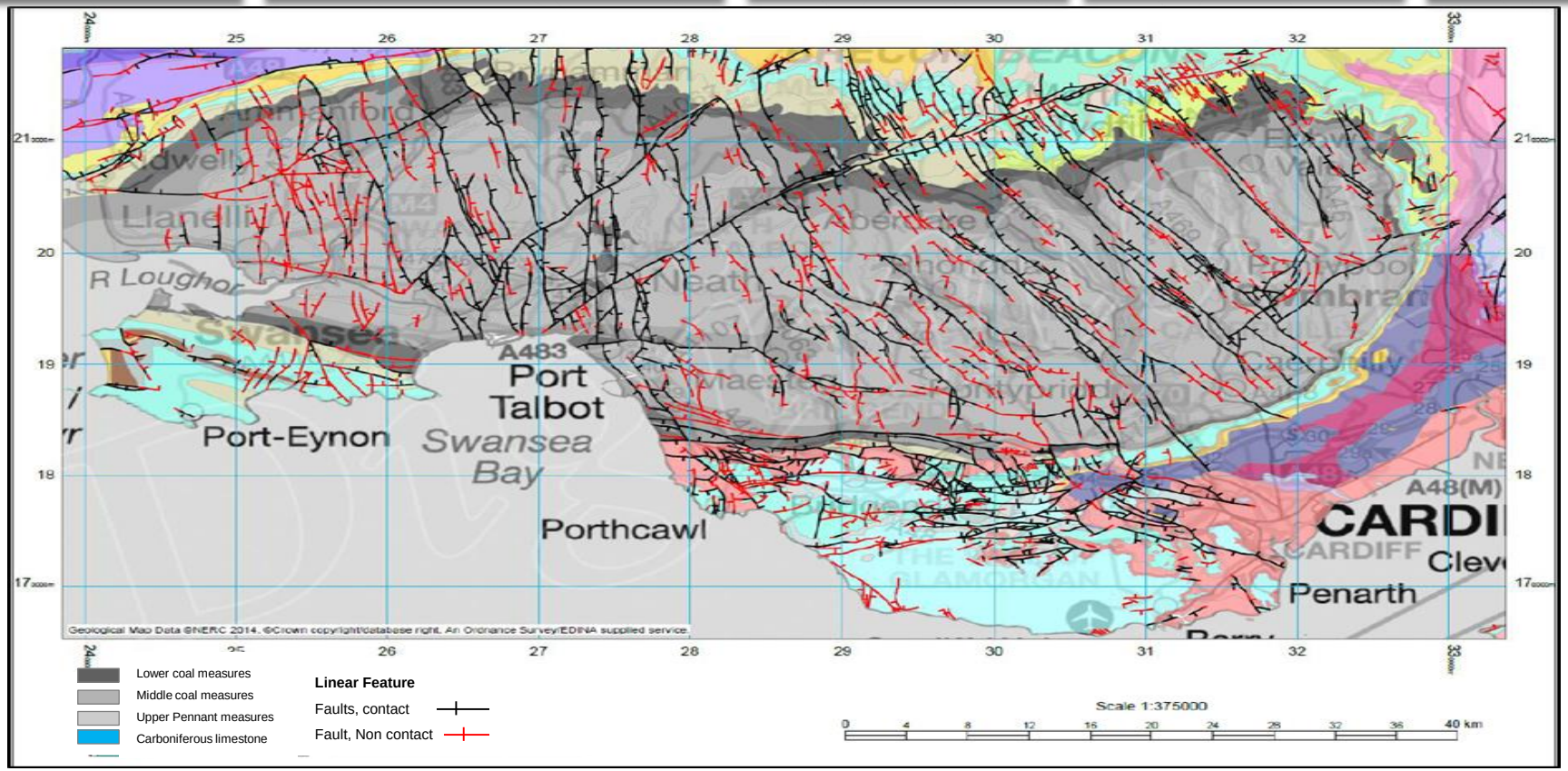
- The potential of UCG in the South Wales Coalfield is restricted by **heavy faulting**

Subsidence	Atmospheric emissions from harmful combustible products	Leakage of gases/pollutants into aquifers	Groundwater quenching the reaction	Continuity of the coal seam



Risks and Uncertainty

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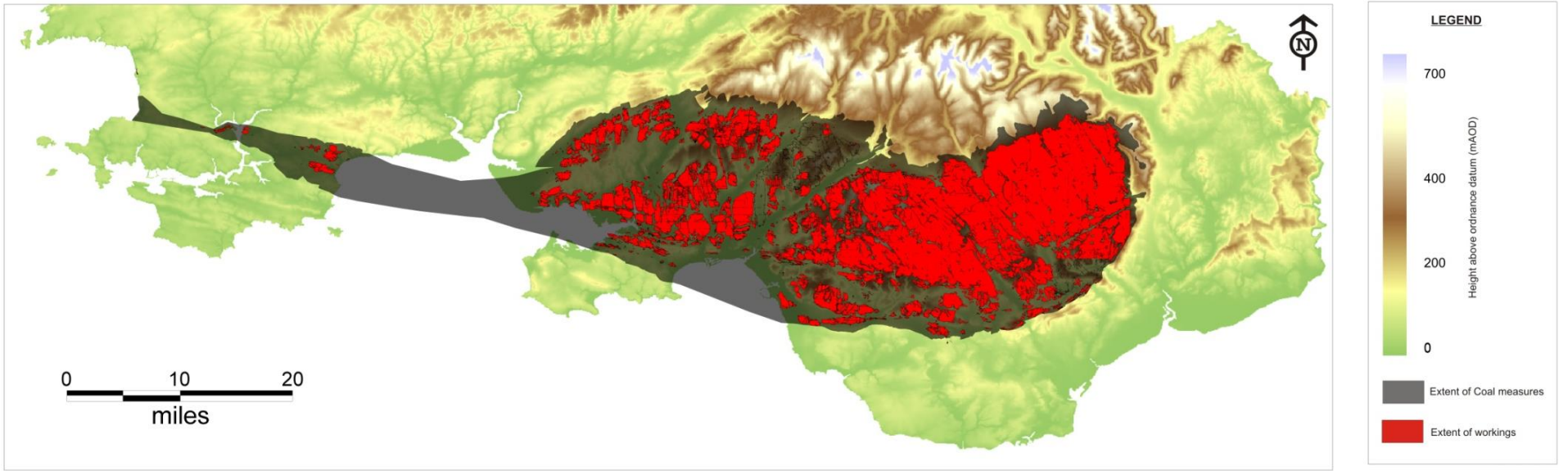
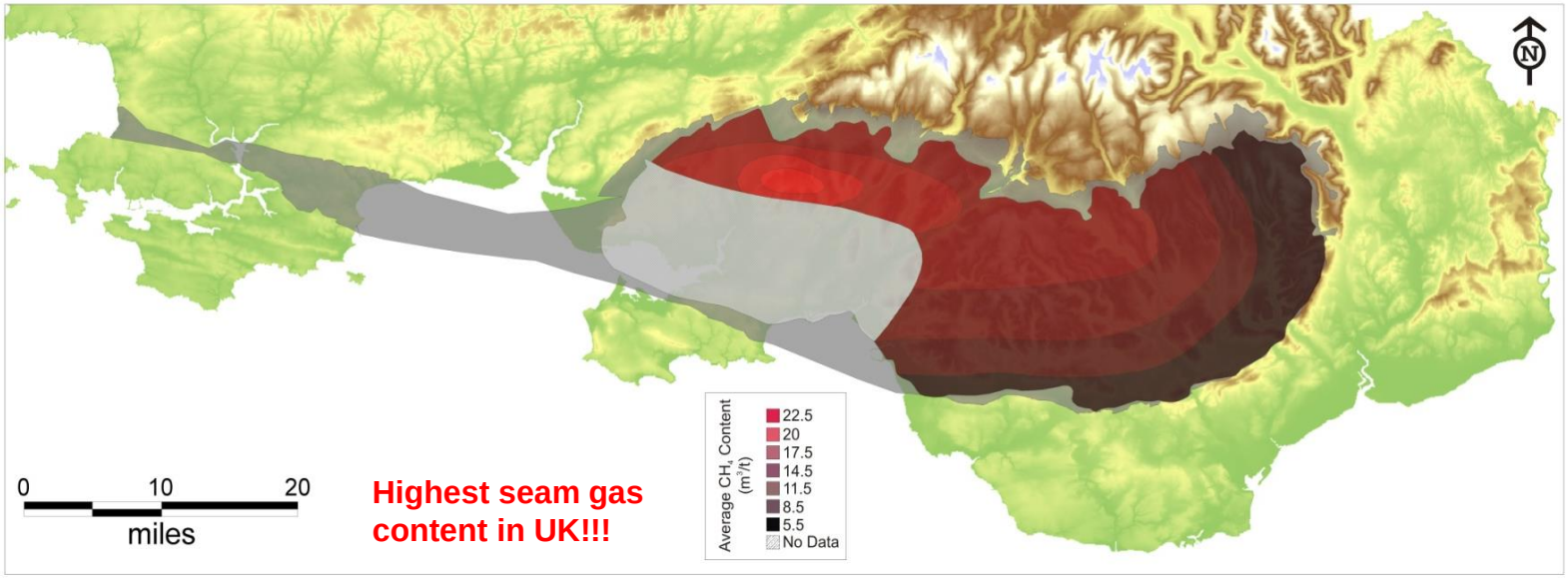
- The potential of UCG in the South Wales Coalfield is restricted by the **extent of former underground mining that has taken place.**
  - Less coal to be utilised
  - Problems with drilling processes - 5% of wells drilled fail on day one.
- Although there are minimal exploration risks as the presence and quality of the coal have already been established from the comprehensive coal mining database that is available, **there are areas within the coalfield are not classified yet.**



UCG against CBM

- UCG produces a gas of medium CV with a heating value of about 30 % that of CBM.
- If air, rather than O_2 is used as a partial oxidant , then a lower CV product gas is produced with heating value of about 10% of CBM.
- However, with UCG typically 75% of the energy value of the affected coal is produced as useful energy at surface, whereas with CBM is much lower (depends on permeability, fracking etc)



PEDLs in South Wales

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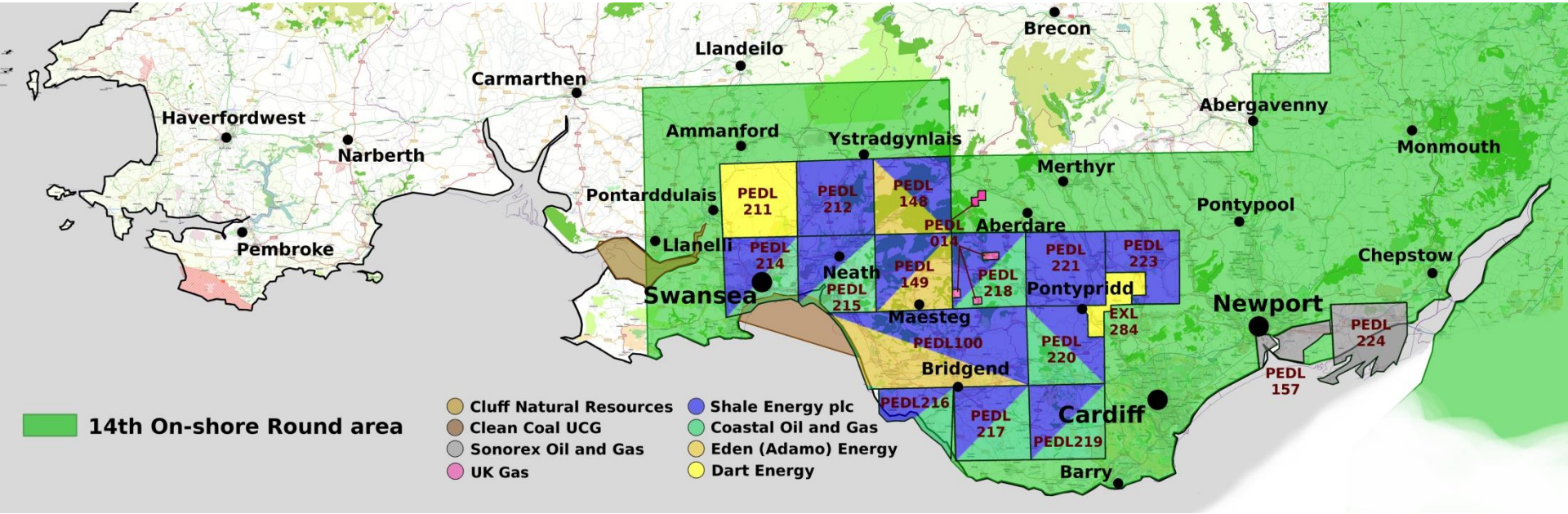
- Areas that have been awarded PEDLs in South Wales



Public perception

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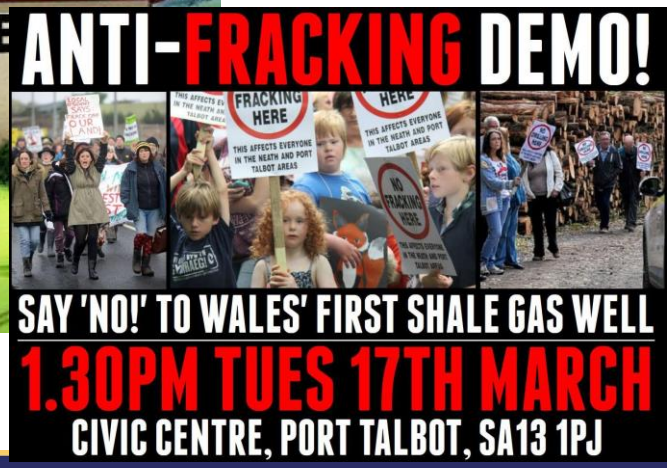
Students lock-on at Swansea University fracking research campus



Regulatory and planning regime

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- **Little progress has been made on the regulatory issues associated with UCG.**
- Licensing would involve:
  - Department for Energy and Climate Change (**DECC**);
  - **Coal Authority**;
  - **Welsh Assembly** or L**ocal Authorities** to grant planning permission;
  - **Minerals Planning Authorities** (National Planning Policy Framework);
  - Natural Resources Wales (**NRW**); and the
  - **Health and Safety Executive**.

- Cardiff is in close collaboration with NRW

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Cyfoeth Naturiol Cymru
Natural Resources Wales

Products developed by SEREN

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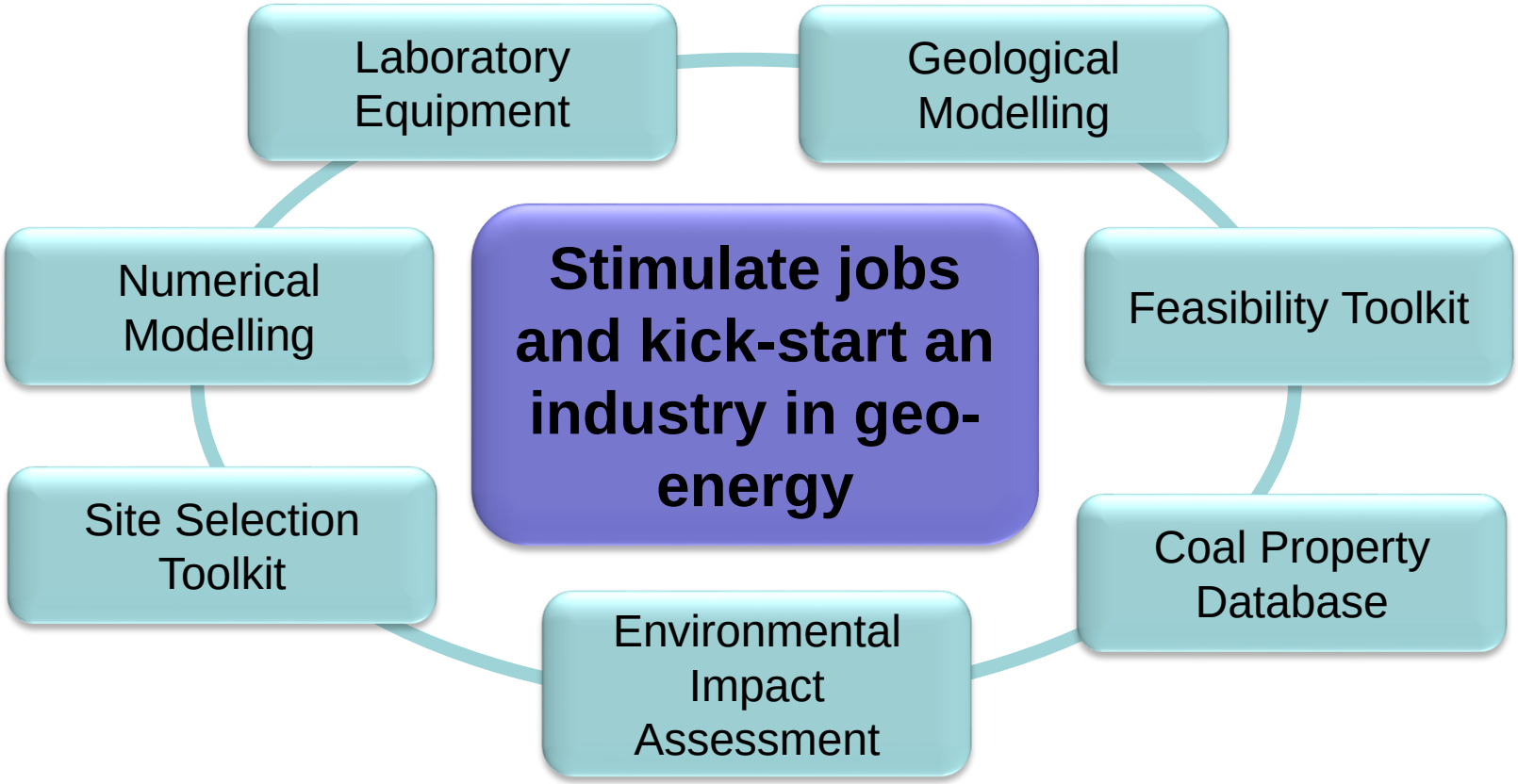
Research & Development – Products and Services – Pilot Scale Demonstrations



Geological modelling and coal resource assessment

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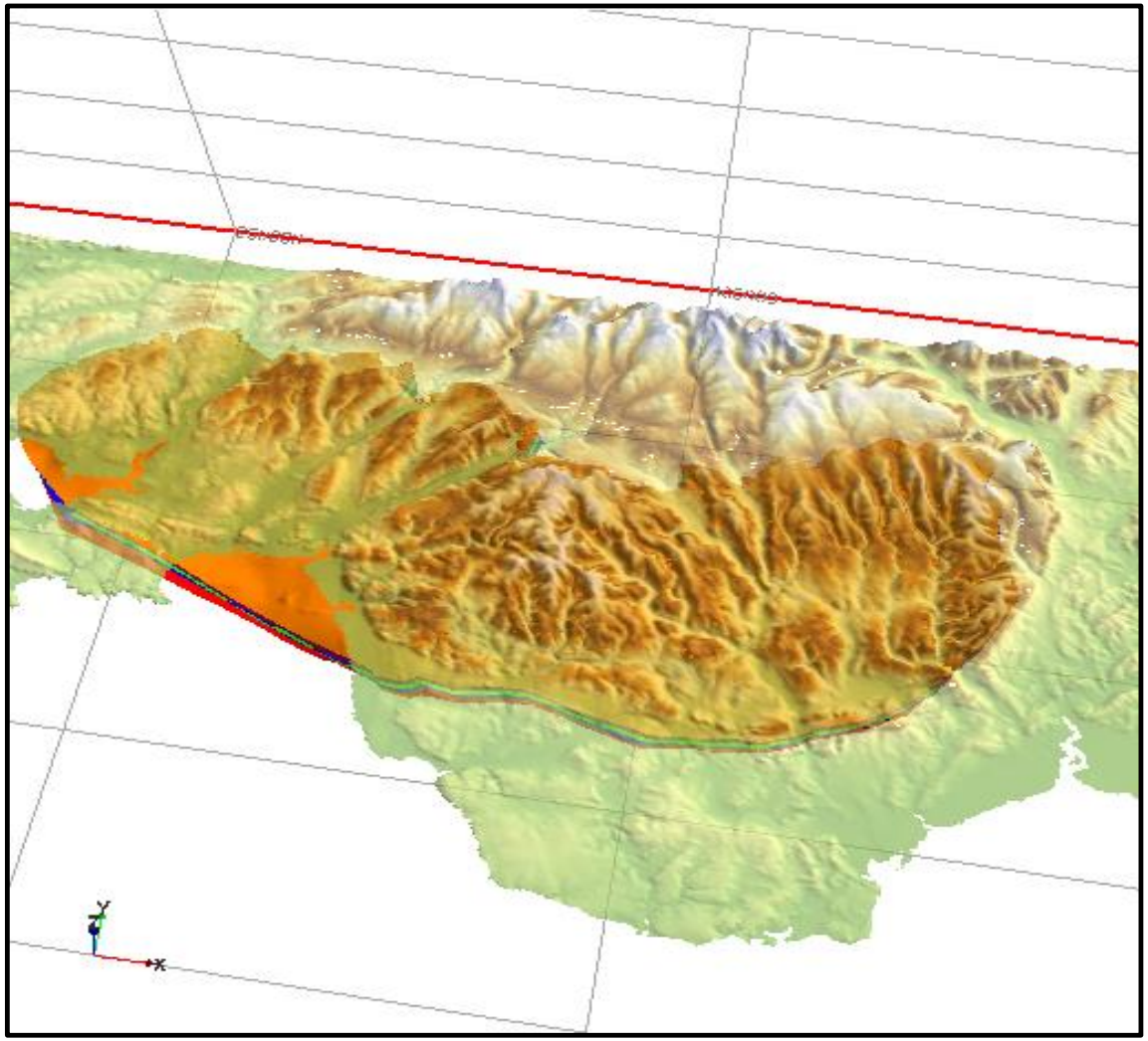

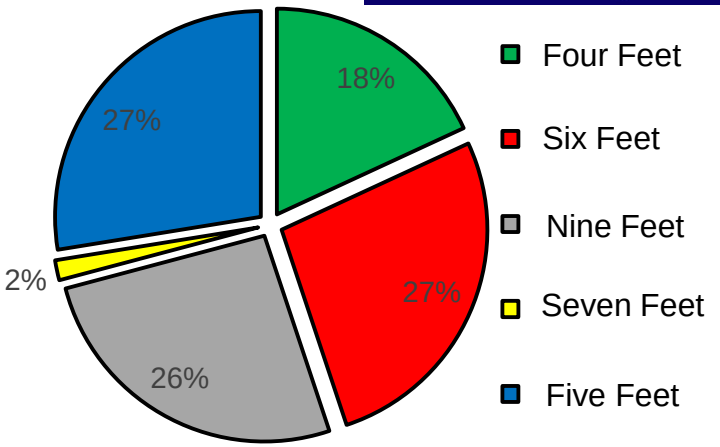

Experimental Test: High pressure high temperature rig

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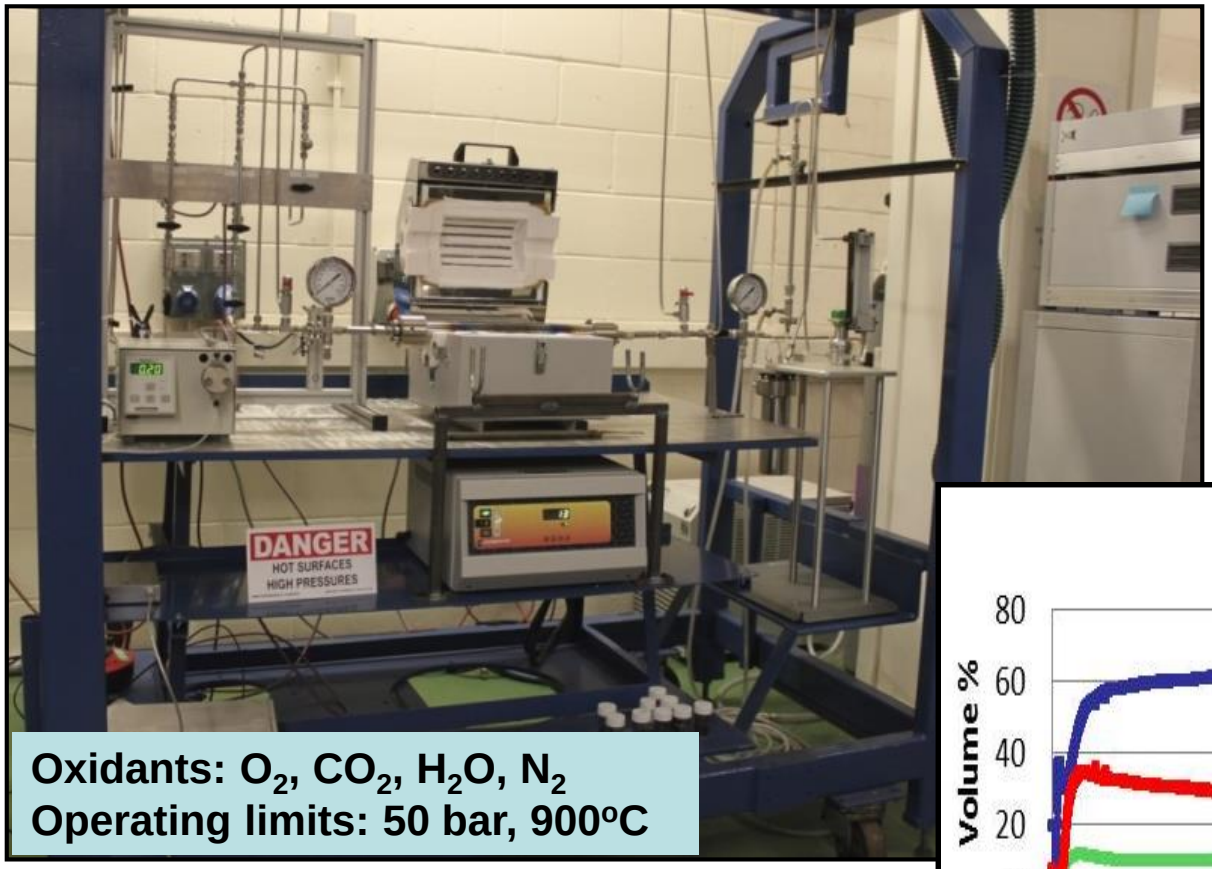
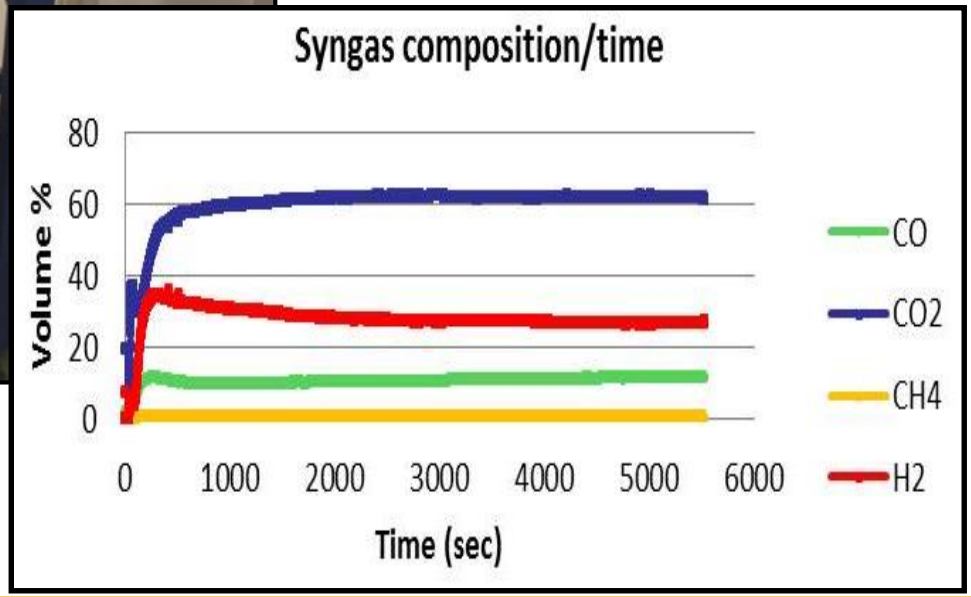


Oxidants: O_2, CO_2, H_2O, N_2
Operating limits: 50 bar, 900°C

Determine the temperature, pressure and gasifying agent on product gas composition.



Research and experimental work is currently being carried out on different types of Welsh coal.

CO2 sequestration in association with UCG

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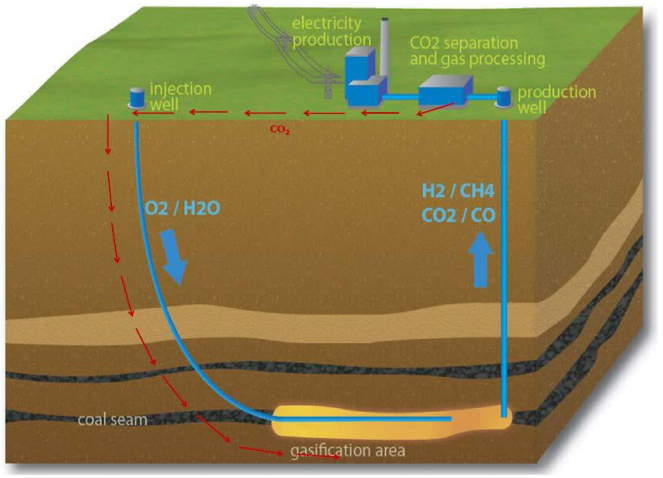
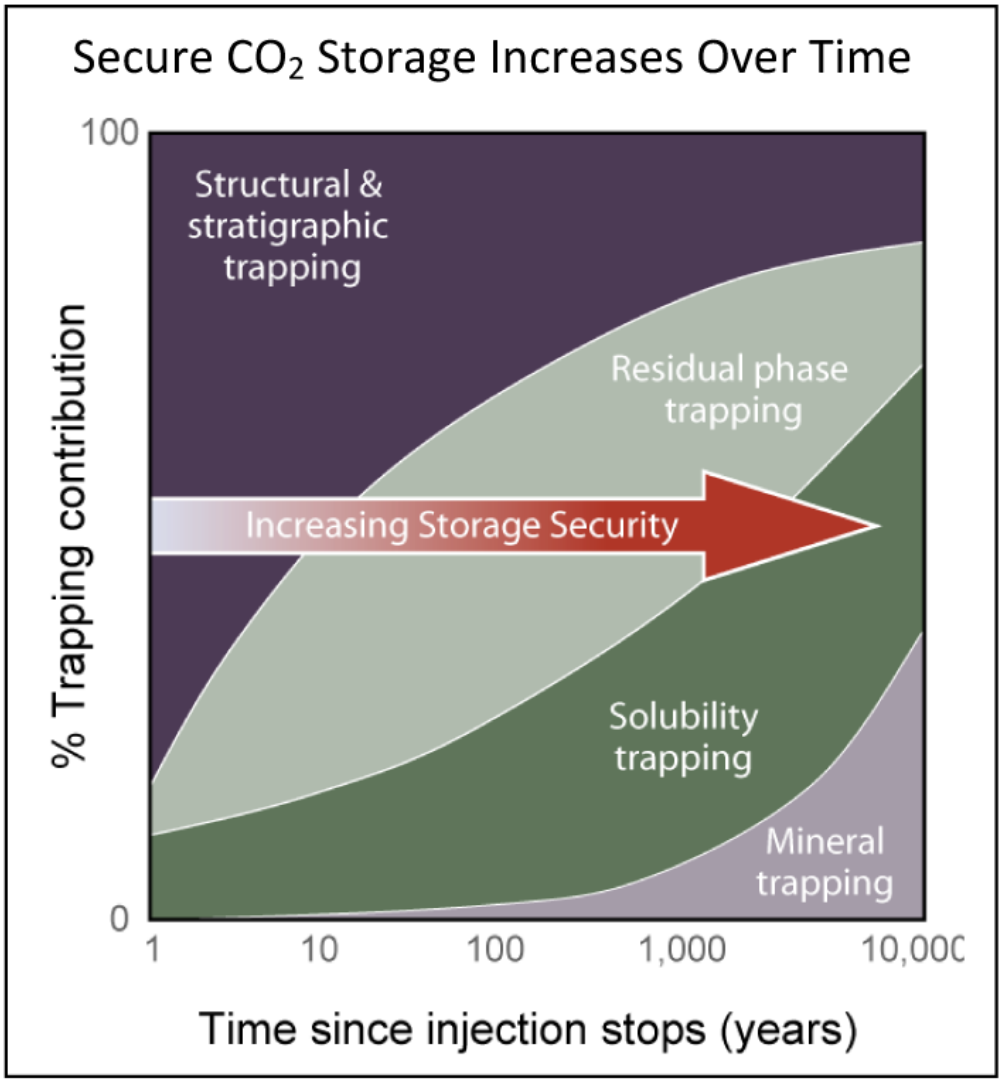
- UCG produces large quantities of CO_2.
- Depending on the site, there may be the option a part of CO2 produced from the UCG to be stored in-situ.
  - ➢ Injection of CO2 into the cavity created by the UCG burn.
  - ➢ Injection of the CO2 into the overlying coal seams distressed by the collapse of the roof of a UCG burn cavity.

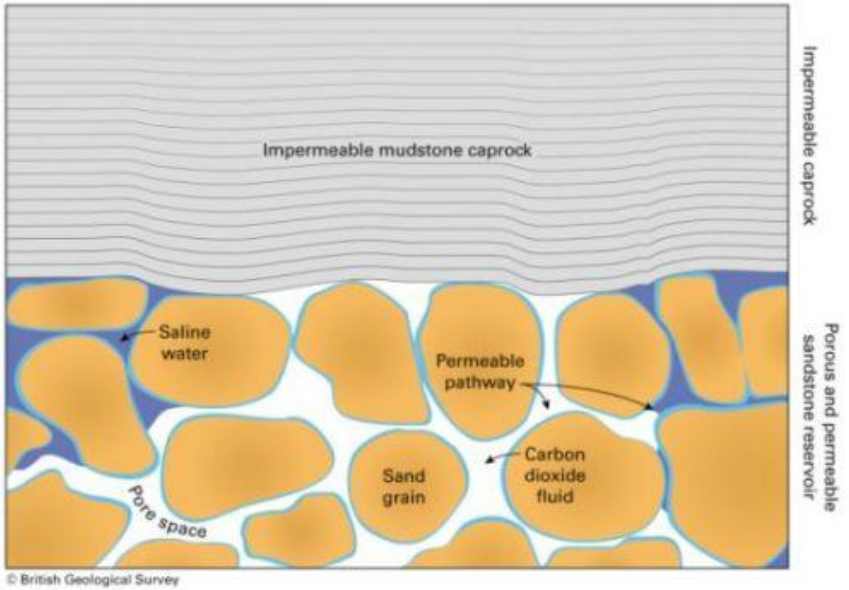


Concept of the combined UCG-CCS process

SEREN UCG rig

SEREN adsorption/desorption unit





Sally Benson, "Carbon Dioxide Capture and Sequestration: Hype or Hope?" Google Energy Seminar, October 23, 2008.

Non-stoichiometric multiphase equilibrium based method

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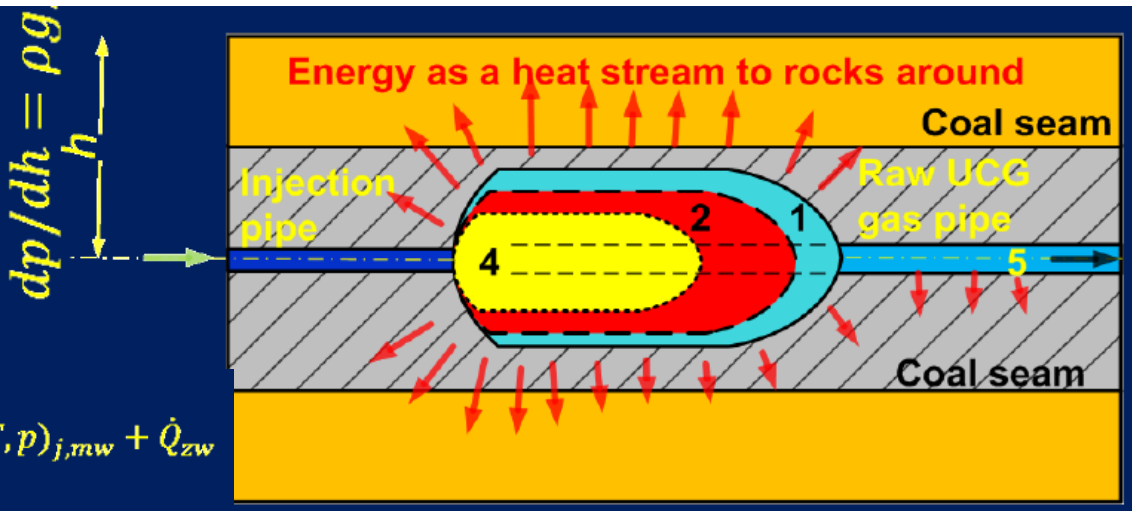
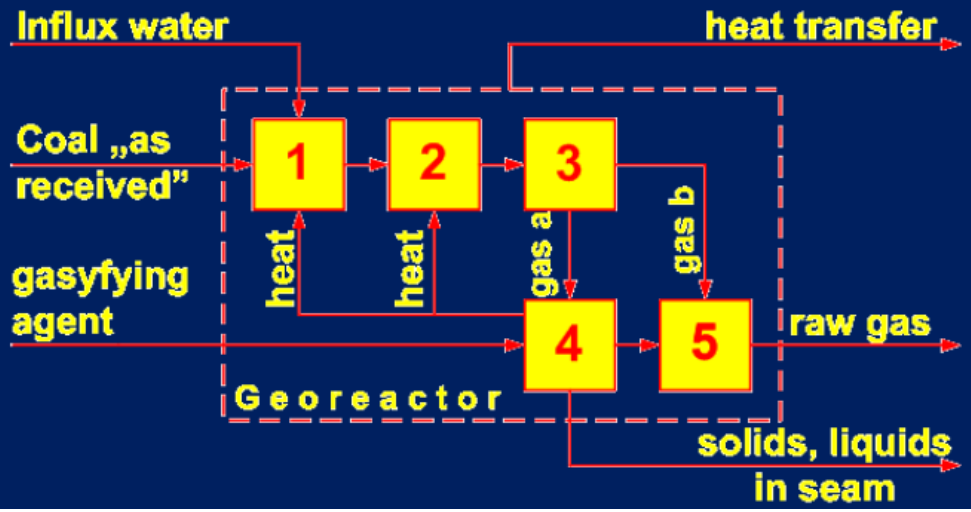
Scheme:



$$\sum_{j=1}^{n} \dot{H}(T,p)_{j,ki} + \dot{Q}_{zd} = \sum_{l=1}^{m} \dot{H}(T,p)_{j,mw} + \dot{Q}_{zw}$$

Described as a reactors system:



Numerical modelling of UCG-CCS

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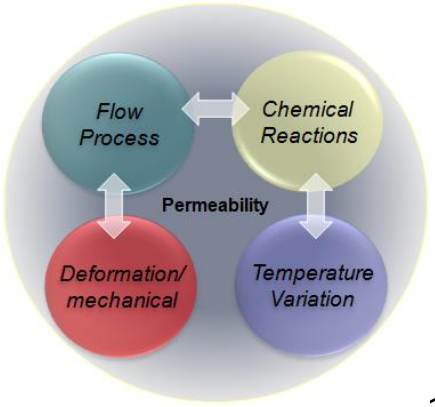

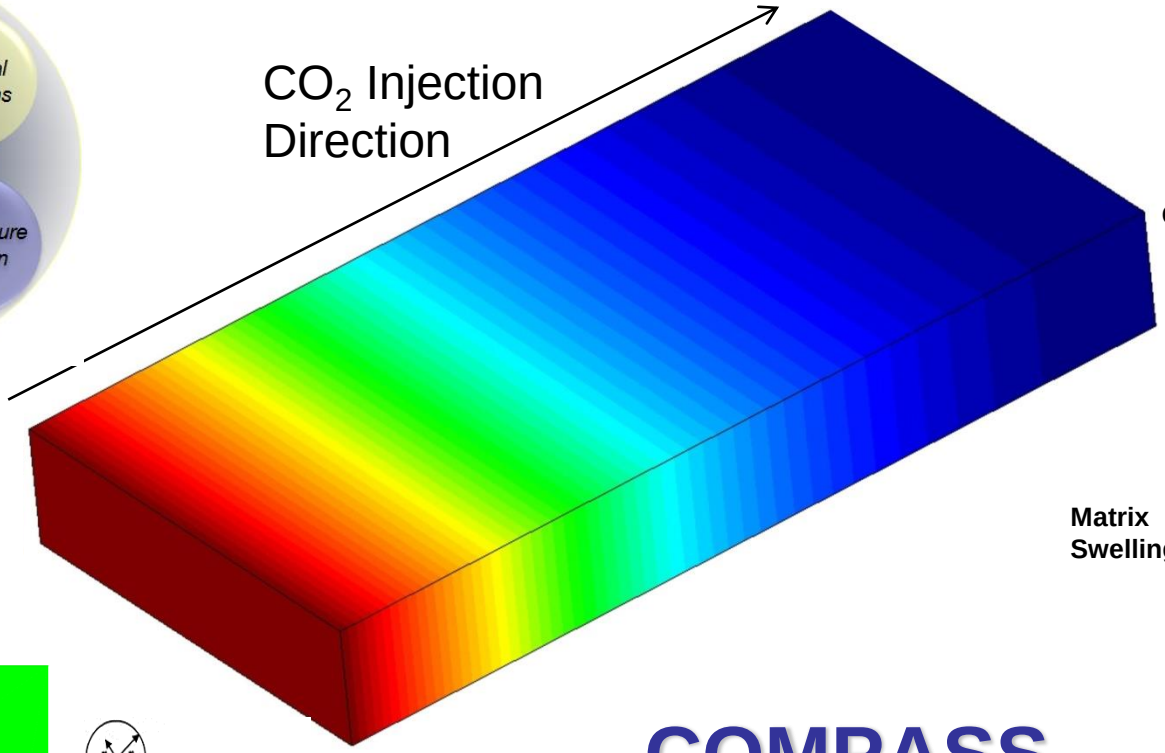

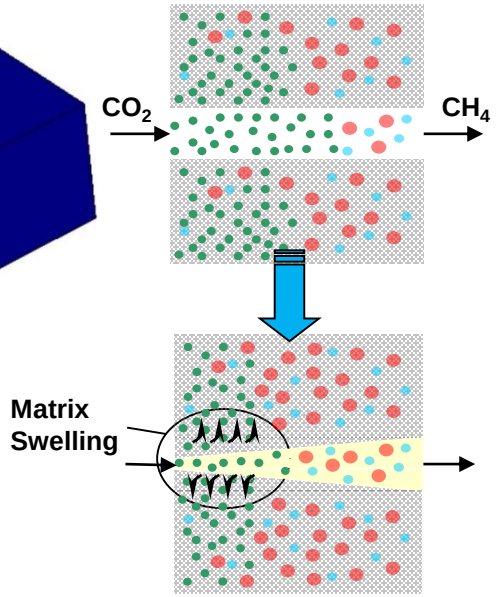

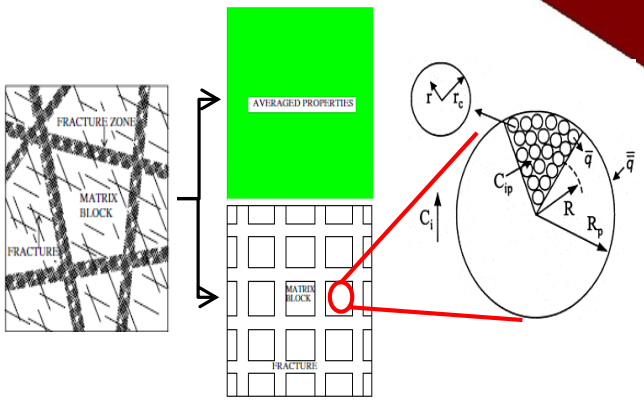

COMPASS

$$\left(nc^{i}_{g}\frac{\partial S_l}{\partial s}\right)\frac{\partial u_l}{\partial t}+\sum_{j=1}^{ng}\left(\delta_{ij}nS_g-nc^{i}_{g}ZRT\frac{\partial S_l}{\partial s}+\frac{V^{i}_{L}P^{i}_{L}ZRT\left(1-P^{j}_{L}ZRTc^{i}_{g}+ZRT\sum_{k=1}^{ng}P^{k}_{L}c^{k}_{g}\right)}{\left(1+ZRT\sum_{k=1}^{ng}P^{k}_{L}c^{k}_{g}\right)^{2}}\right)\frac{\partial c^{j}_{g}}{\partial t}$$

$$=-\nabla\cdot\left[\left(c^{i}_{g}k_gZRT+\delta_{ij}nS_g\tau D^{i}_{m}\right)\sum_{j=1}^{ng}\nabla\cdot c^{j}_{g}\right]-\nabla\cdot\left(c^{i}_{g}k_g\gamma_g\nabla\cdot z\right)$$

Coal Resources Assessment Toolkit

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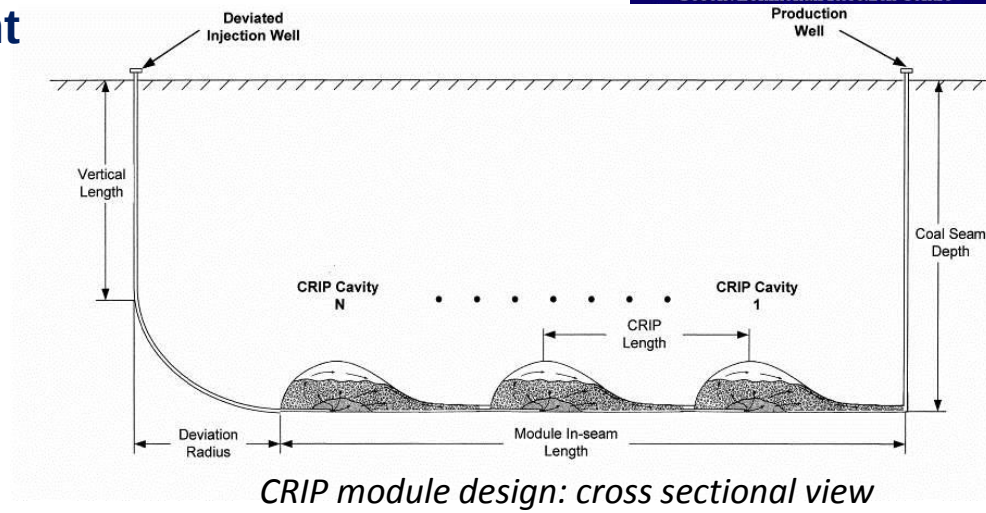
Geoenvironmental Research Centre

Determination of the size of power plant (MW) and the UCG model underground

Site selection criteria

Criteria	Minimum Acceptable Value	Maximum Acceptable Value
Coal seam thickness	>5m	<30m
Coal seam depth	>300m	<1000m
Coal rank	Lignite	Bituminous
Proximity to fault structures	>200m depending on site conditions	
Proximity to built up areas	>500m	
Proximity to mines (active and historic).	>500m	
Moisture content	<40%	
Ash content	<50%	
Ash & moisture content combined	<50%	
Gross calorific value	>12MJ kg^{-1}	
Sulphur (coal as received or dry)	<6%	
Chlorine (coal as received or dry)	<3%	
Free swelling index (FSI)	<3	
Ash fusion temperature	>1000ºC	
Resource size	>100Mt	
Proximity to potable aquifers	>25 times coal seam thickness	

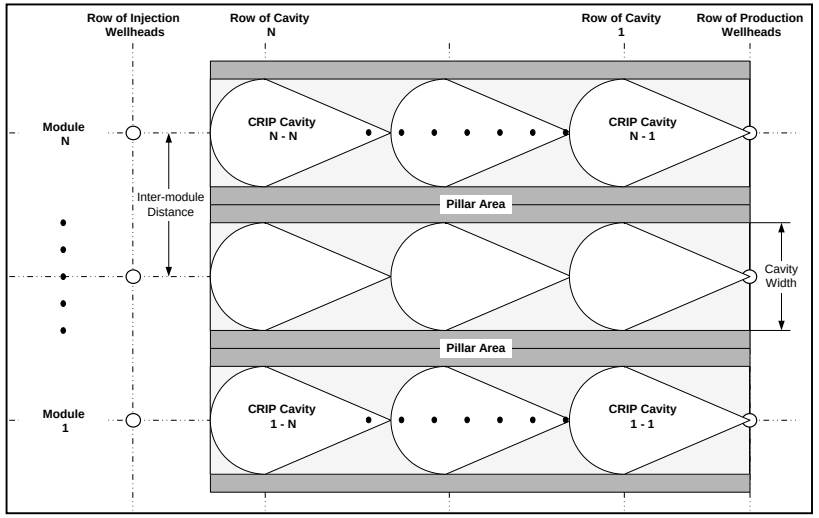


CRIP module design: cross sectional view

Underground Coal Gasification

Thermal Power	MWth	600
Electrical power	Mwe	240
Years of operation	Years	25
Thermal Power/year	MWth/year	24
Number of modules in parallel		24
Thermal Power/module	MWth/module	25
Duration of each module ≈ 0.5 -1 year	Years	1.04
Operation	%	100
Operation	Hours	219000
MWh of thermal power	Million MWh	131.40
Total energy needed GJ	Million GJ	473
Operation/module	Hours/module	9125
MWh/module	MWh	228125
Energy needed GJ/module	GJ/module	821250

About us



CRIP module design: view from above

Ground Investigation Works - Practical provability borehole

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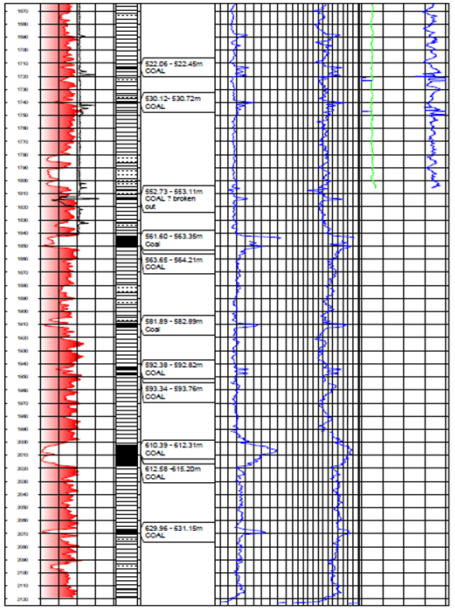
In collaboration with a local industrial partner, we designed and constructed 3 boreholes to a depth of 650m. **Drilling started in July 2014 and completed in Nov. 2014.**

- **Understand the geology and hydrogeology of the area.**
- **Undertake geophysics** (incl. natural gamma, verticality, fluid temperature, acoustic imager etc).
- **Environmental monitoring:** Surface methane monitoring, water quality testing and rock mineral testing.

SEREN Borehole Drilling

Environmental Monitoring



Geophysical Survey

SEREN exploration boreholes

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Ground methane emissions monitoring

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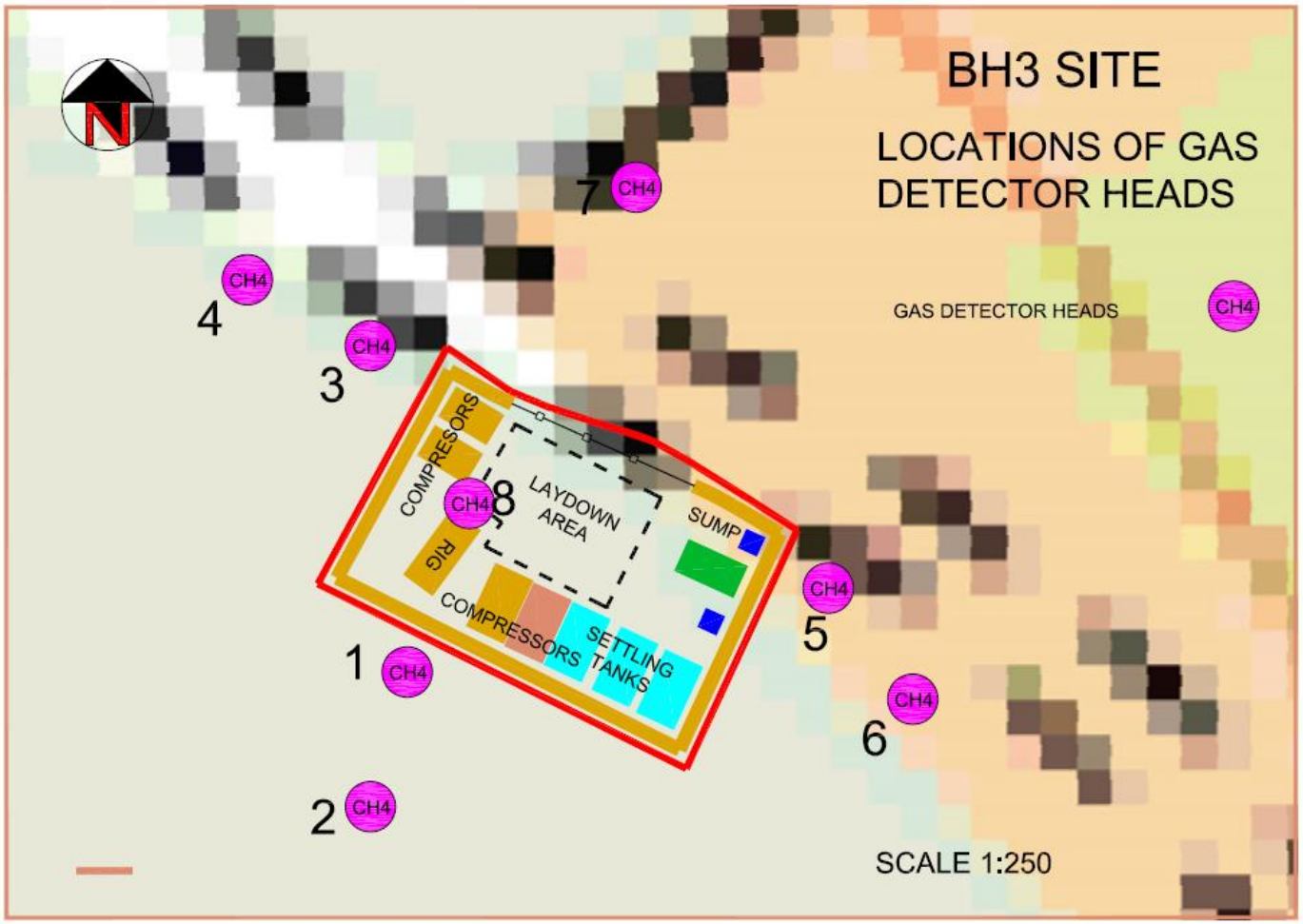

Collection of gases from borehole

Environmental Aspects of UCG

Contaminant Transport coal/rock interaction in the context of UCG

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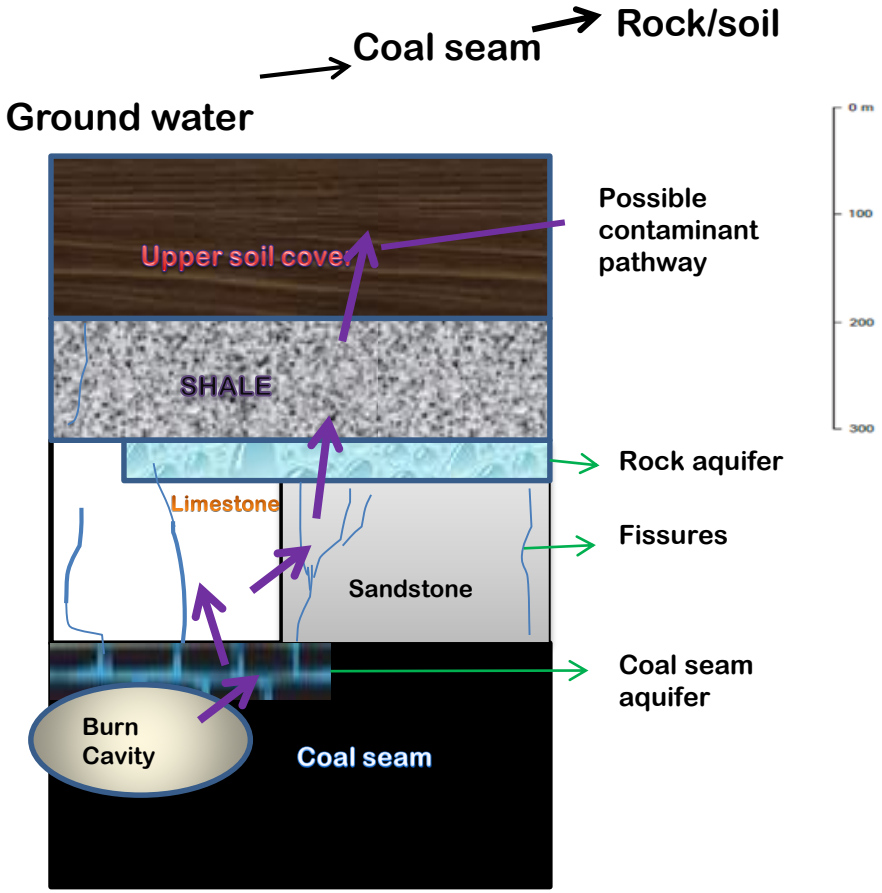
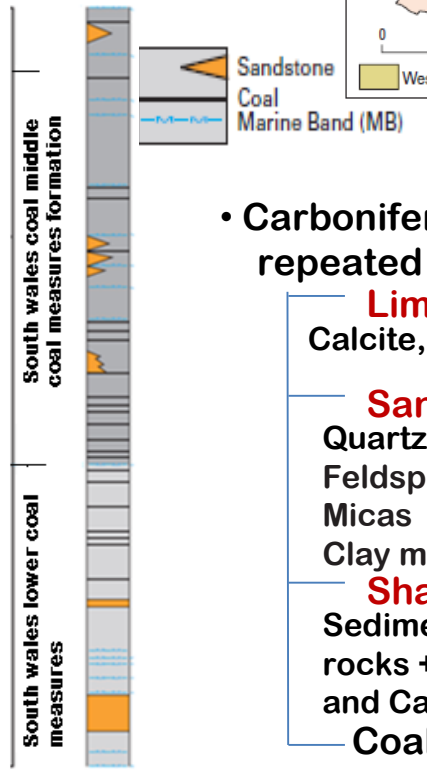
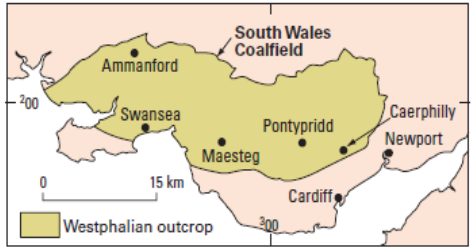
Considering the coalfield geology it is appropriate to study the OM-coal/rock minerals interactions to understand the OM exposure to the subsurface.







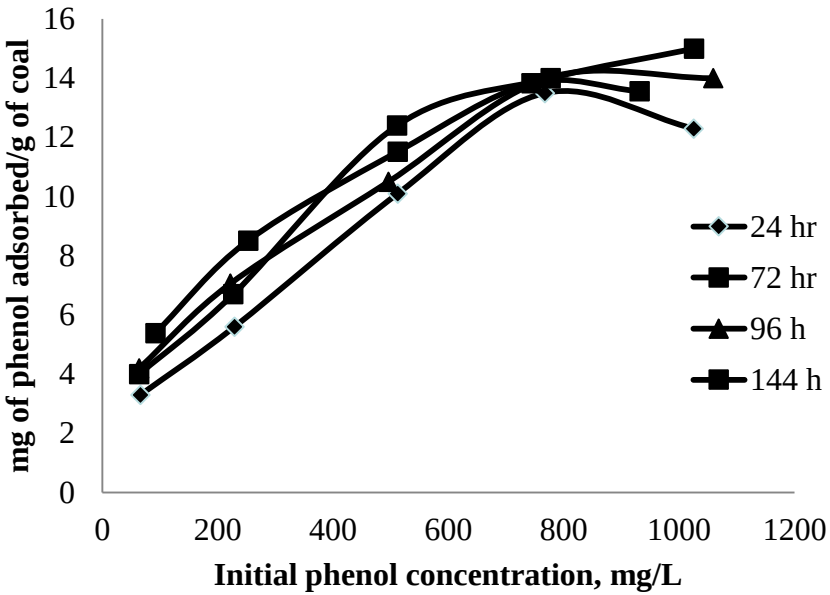
British geological survey Research Report RR/09/01

- Carboniferous rocks repeated units of....
  - **Lime stone**
    Calcite, Aragonite
  - **Sand stone**
    Quartz
    Feldspars
    Micas
    Clay minerals
  - **Shale**
    Sedimentary rocks + Quartz and Calcite
  - Coal

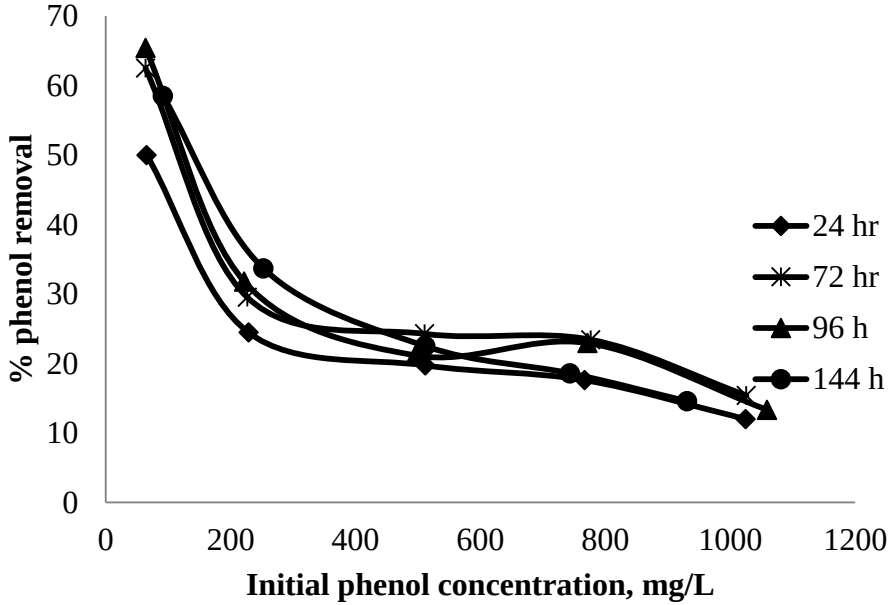
Organic contamination pathway in coal field

Geology of coal fields (e.g. South Wales coal field)

Influence of initial concentration on phenol retention by coal



Influence of phenol concentration on phenol retention by coal



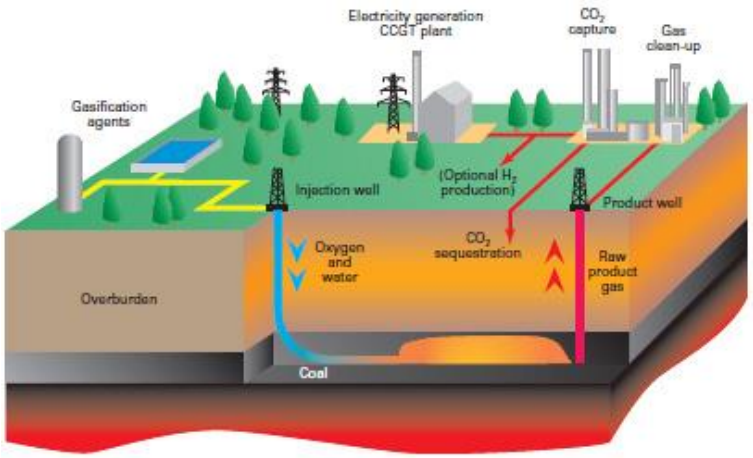
Phenol removal efficiency of coal

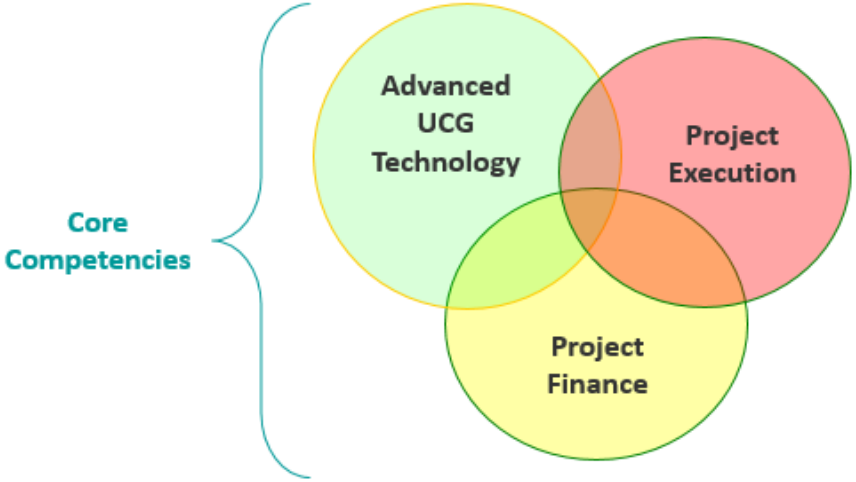
Contact time	A (mg/g), Langmuir adsorption capacity factor	b (L/mg), Longmuir constant	b (converted to dimensionless,)	ΔG^0 kJ/mol	Freundlich Constants	
					Kf	1/n
144 h	13.45895	0.017002	17002.29	-23.7415	0.33	1.6

Gibbs free energy ΔG^0 of -23.74 kJ/mol which indicates that the phenol retention by coal is favoured physical adsorption process

Looking to the future

- **Strengthen the technical capability** of the supply chain in Wales (i.e. directional drilling)
- Examine the **suitability of burning the gas** produced from UCG
- Carry out a **semi-commercial trial of UCG**. This would require a block of coal 600x600 and seam thickness of at least 2m.
- Identify the parameters that **UCG** would have to meet if it were to be competitive with current North sea gas production **costs/CBM/Shale gas developments**.





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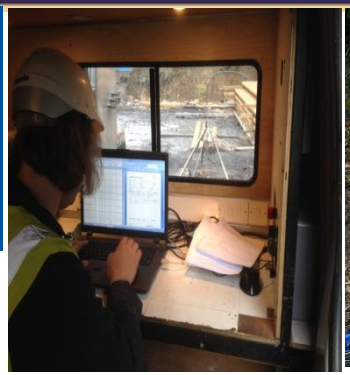
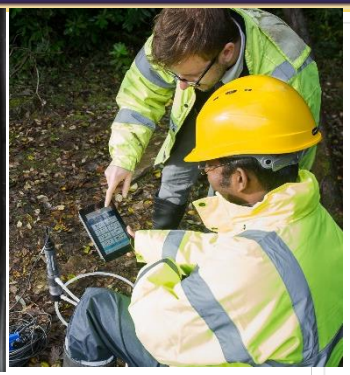
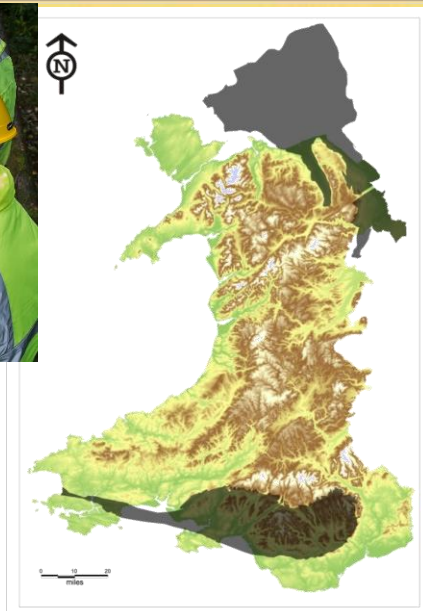
- APEX Drilling
- European Geophysics

ERDF
Llywodraeth Cymru
Welsh Government
Ewrop & Chymru: Buddsoddi yn eich dyfodol
Cronfa Datblygu Rhanbarthol Ewrop
Europe & Wales: Investing in your future
European Regional Development Fund







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Thank You

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