A Review & Future of UCG, Underground Coal Gasification

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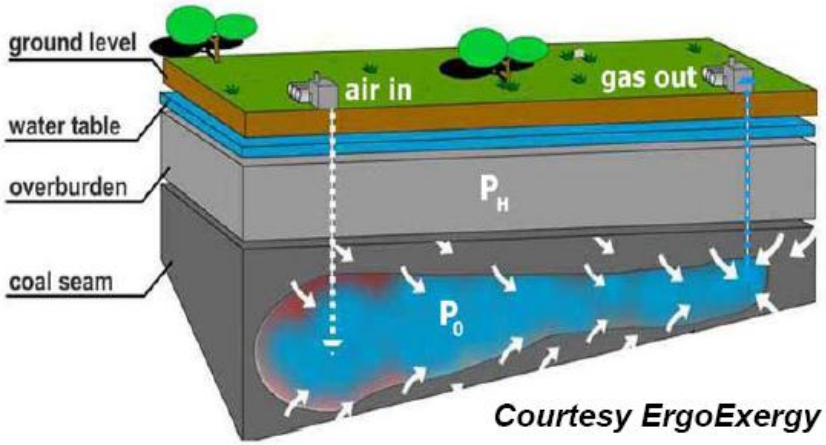


Courtesy ErgoExergy

COAL BRIEFING

Purdue Calumet, Hammond, IN
Dec 11-12, 2008

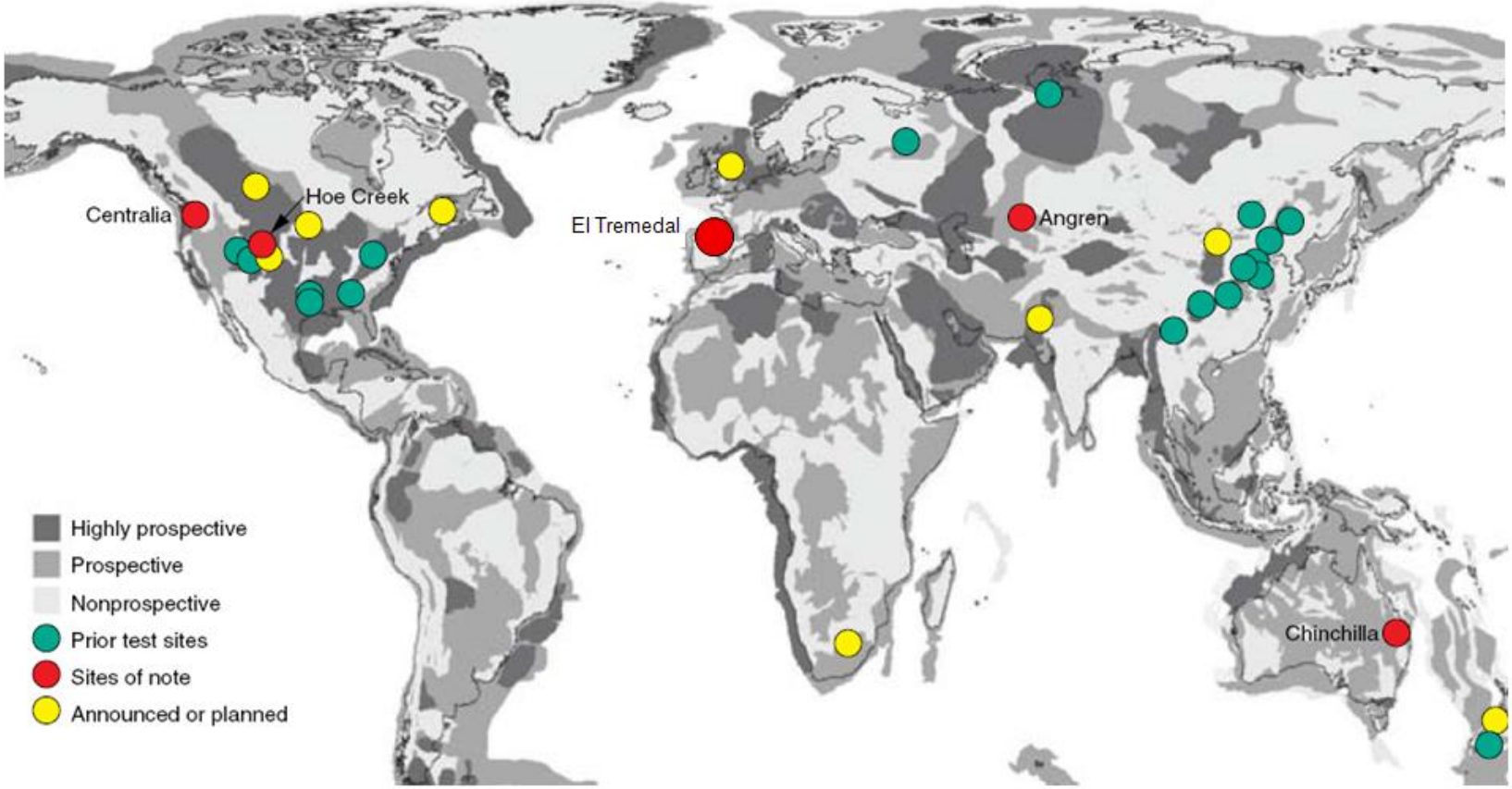
*All "London sources" refer to the materials supplied on the UCG Course at Imperial College & organized by **UCG Partnerships**, September 22-26, 2008*

Benefits of UCG

- There are estimates of **1.7 Trillion tonnes** of unminable coal that is recoverable by UCG
- **Less capital** equipment cost, *surface vs underground*
- **Reduced gas clean-up** equipment, *reduced tar & ash content*
- **Reduced operating expense**, *no mining or transportation costs, no ash disposal*
- **Reduced environmental management** costs, *no SOx, NOx, or ash; particulates are halved & less Hg; substantial environmental improvement*
- Fuel supply certainty, *no risk of supply disruption*

"Congressional hearing on climate change", November 14 in the Senate Foreign Relations Committee, Dr. S. Julio Friedmann Director, Carbon Management Program, Lawrence Livermore National Lab, Underground Coal Gasification in the USA and Abroad

Worldwide UCG Sites



USA: Centralia WA & Hoe Creek WY (LLNL test sites)
Australia, China, India, South Africa, Spain, Uzbekistan

Grey areas show potential areas for geological carbon storage

Source: "Fire in the Hole", Lawrence Livermore National Laboratory, April 2007 (with addition of El Tremedal)

UCG Principles & Essentials

(A) Underground Coal Gasification (UCG) converts coal into a gaseous form (syngas) through the **same chemical reactions that occur in surface gasifiers**

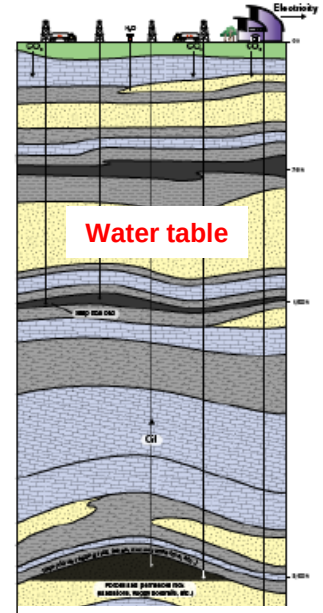
(B) The **economics of UCG look promising** as capital expenses should be considerably less than surface gasification

Essentials:

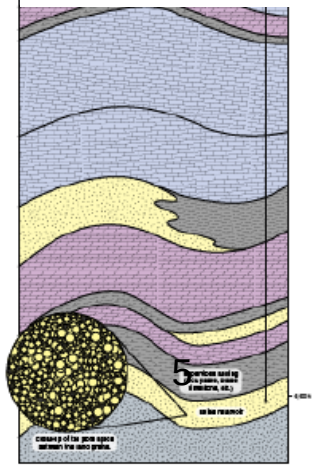
- **Site location - biggest issue**
- **Coal characteristics – operations**
- **Technologies - connecting wells**

Factors Affecting UCG Designs

1. Coal seam geology
   - Thickness, depth and dip
   - Permeability to gas, liquid
2. Coal properties
   - Rank (ash, volatile, carbon content)
   - Chemical composition (hydrogen, sulphur)
3. Strata/overburden properties
   - Geology
   - Hydrology
   - Geomechanics
   - Drilling properties
4. Operating conditions
   - Injection composition and flow rate
   - Operating pressure
   - Well layout
5. Product gas
   - Required volume
   - Composition, calorific value
   - Flow rate
6. Process efficiency
   - Thermal
   - Chemical
   - Resource recovery
7. Interaction with the environment
   - Thermal
   - Chemical
   - Resource recovery
   - Subsidence effects



UCG working zone



US Site Selection Criteria

Williams, 1982

- Seam thickness greater than one metre or 0.6 m for steeply dipping seams
- Avoid variable thickness seams
- Avoid seams with variable partings
- Avoid seams with overlying coal within 15m that is thicker than 0.6 m
- Minimum of 3.5 Mt in resource
- Minimum overburden of 100m
- Minimum of 1.6 km from populated areas (>100 people)
- Minimum distance of 0.8 km from major faults
- Minimum distance to oil and gas recovery development of 1.6 km
- Minimum distance of 0.4 km from major highways and rail
- Minimum distance of 1.6 km from rivers and lakes
- Minimum distance of 3.2 km from active mines
- Minimum distance of 1.6 km from abandoned mines

Other notes

- Steeply dipping (>30°) seams favoured due to lack of mining interest
- Floor and roof conditions need be examined

Ranking of Coal Prospects for UCG Trial Site Search in UK

Coal Attribute	Optimal
Seam Thickness	30 ft +
Rank	Lignite to Bituminous, non-swelling
Ash	< 40%
Faulting	Rare
Depth	600 to 1,500 ft
Dip	0 to 20 degrees
Intrusions	Minimal
Immediate Roof	Strong, stable
Hydraulic Head	> 600 ft
Water Quality	Poor

- Geological environment – faults, dip, intrusions, roof, floor, ground water.
- Seam Attributes – thickness, composition, caking, swelling, rank
- Other Attributes - no of seams, depth, data density and proximity to old workings.

Range of Values in Coal Properties

Seelyville Coal Bed, Indiana

	SEELYVILLE			
	Min.	Max.	Ave	n
Moisture [weight %]	0.8	29.2	9.9	81
Ash [weight %, dry]	6.7	35.6	14.9	88
Sulfur [weight %, dry]	2.50	9.84	5.02	28
Heat. Value [Btu/lb ,dry]	8494	13810	12149	83
Fixed Carbon [weight %, dry]	19.0	61.1	44.4	73
Volatile Material [weight %, dry]	31.2	65.4	41.4	73

There is a very wide range in property values. To what extent this will affect UCG operations has yet to be determined.

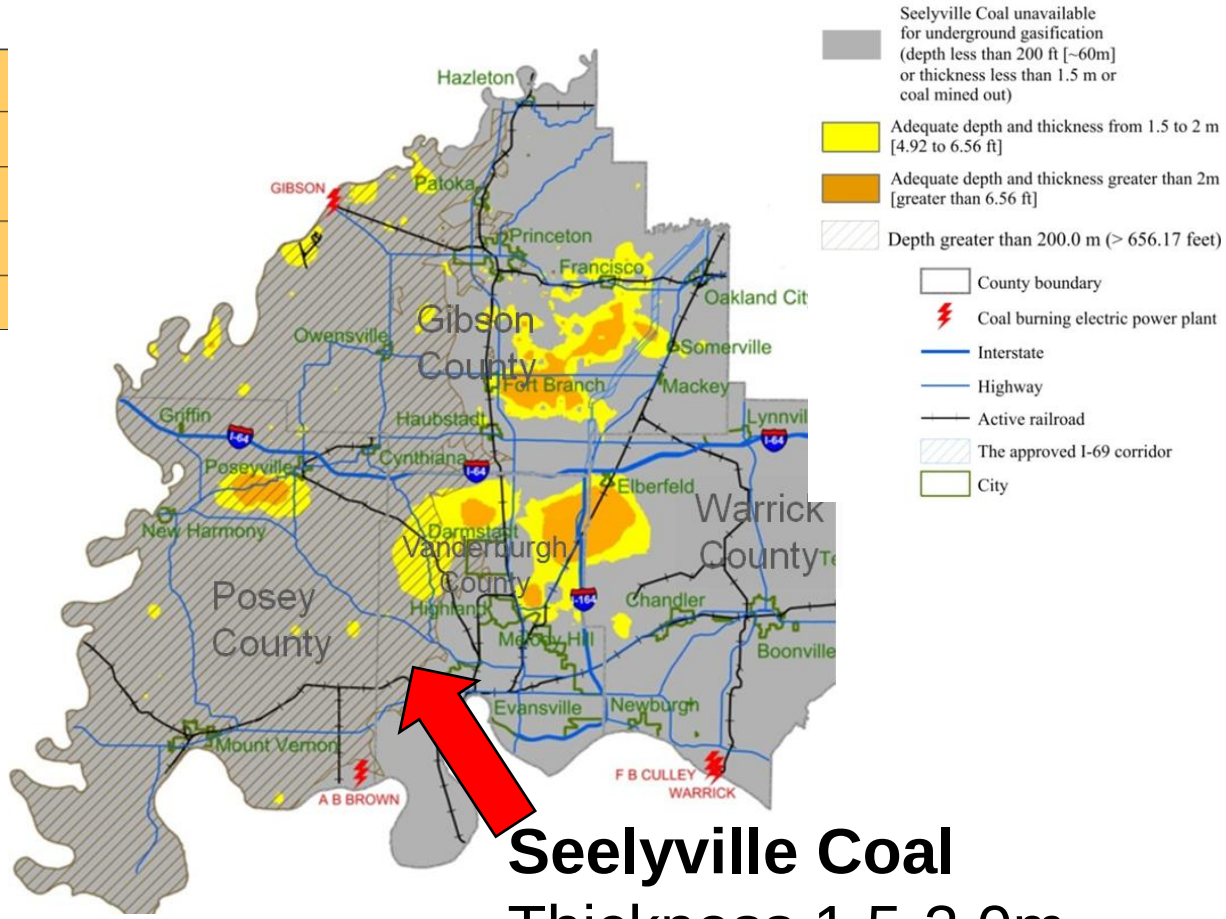
Source: "Assessment of the Quality of Indiana Coals for IGCC Performance", Final report to CCTR
Maria Mastalerz, Agnieszka Drobniak, John Rupp, Nelson Shaffer, November 2008

Purdue-IGS Site Preliminary Selection Criteria

December 2008

Thickness	Suitability
> 2.0 m	high
1.5 – 2.0 m	medium
1.0 – 1.5 m	low
< 1.0 m	unacceptable

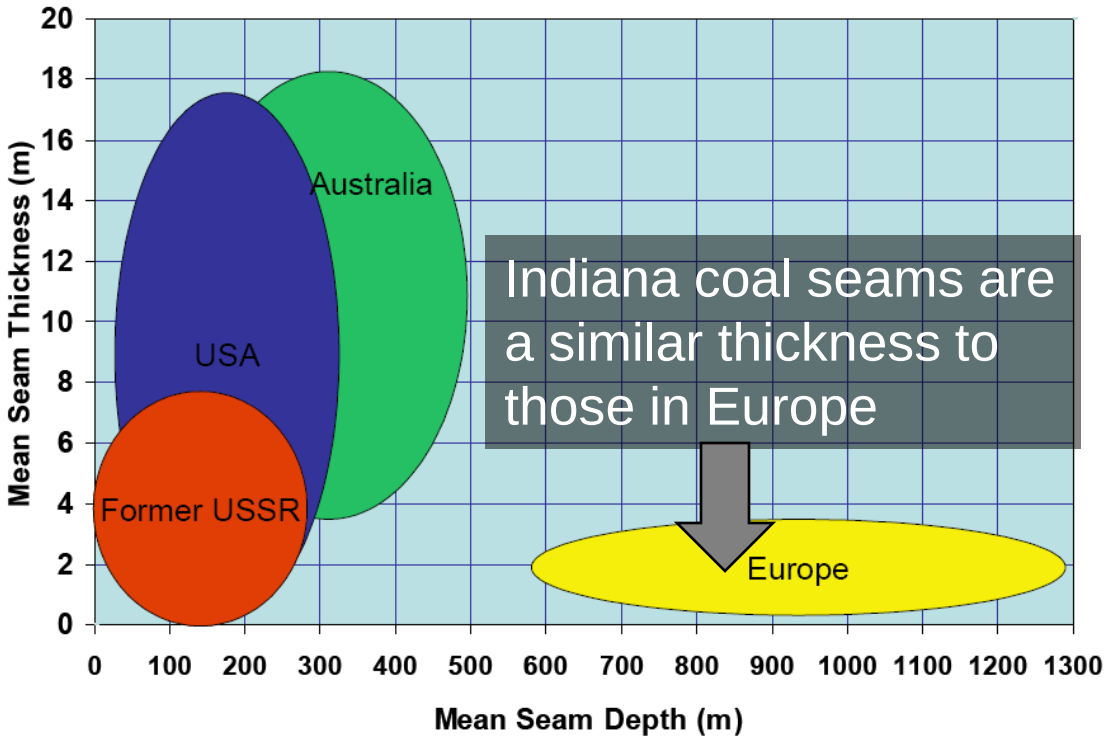
Depth	Suitability
> 200 m	high
60 - 200 m	adequate
< 60 m	unacceptable

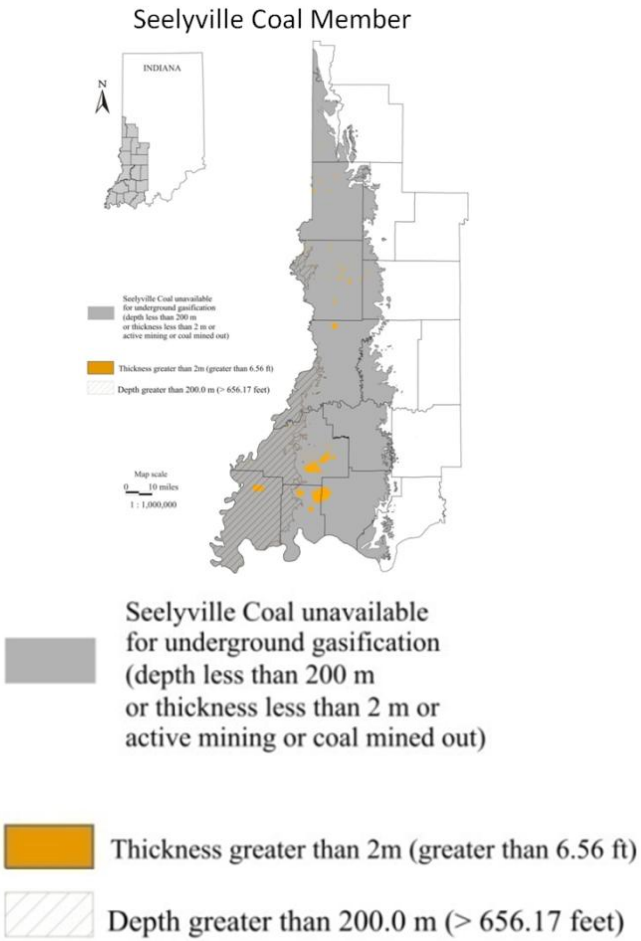


Seelyville Coal
Thickness 1.5-2.0m
Depth > 200m

Source: "The Potential for Underground Coal Gasification in Indiana", CCTR Phase II Report
Evgengy Shafirovich, Arvind Varma, Maria Mastalerz, Agnieszka, John Rupp, Dec 2008

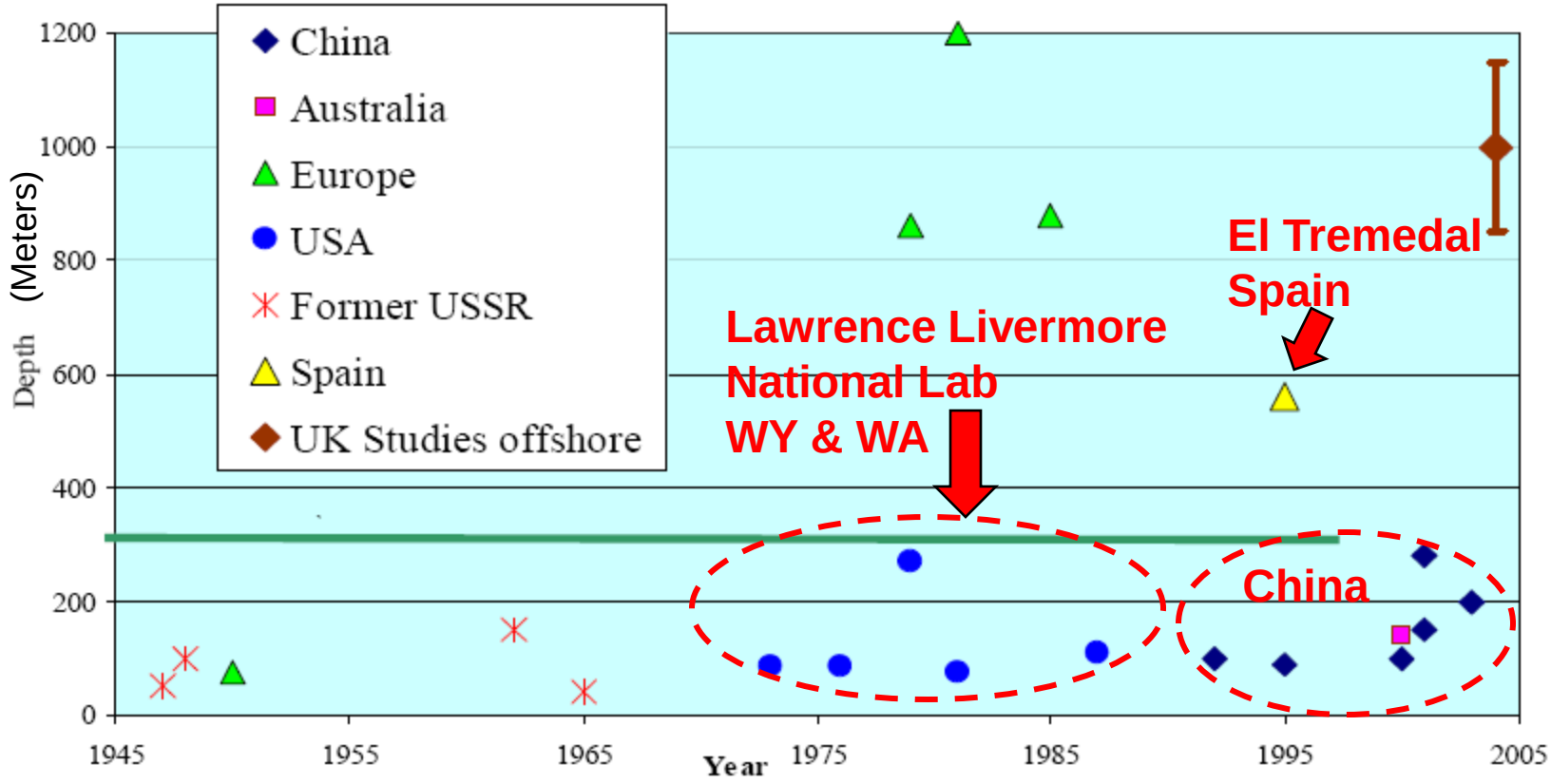
Worldwide UCG Experience, Depth & Thickness





"Best Practices in Underground Coal Gasification", E.Burton, J.Friedman, R. Upadhye, Lawrence Livermore Nat. Lab., DOE Contract No. W-7405-Eng-48

UCG Trials, Dates & Depths, 1948-2005



History of UCG in the USA

Research & development in UCG has been conducted since mid-nineteen-forties. It **became especially active during the energy crisis starting in 1973.** Before winding down in early 1990s, the program had produced 33 field trials conducted by DOE, the National Laboratories, & several industry entities. **The $350 Million program** has been a **technical & environmental success** but had not reached commercialization, in part due to the **dramatic drop in oil & natural gas prices** in the mid-1980's.

"Congressional hearing on climate change", November 14 in the Senate Foreign Relations Committee, Dr. S. Julio Friedmann Director, Carbon Management Program, Lawrence Livermore National Lab, Underground Coal Gasification in the USA and Abroad

LLNL Tests in Wyoming, 1973-1989

Conceived & executed to address specific sets of engineering concerns:

- Improved permeability of coals
- Testing linking methods
- Improving syngas energy yield

Hoe Creek, WY

Three different linking methods were used:

- Explosive fracture
- Reverse combustion
- Directional drilling

"Best Practices in Underground Coal Gasification", E.Burton, J.Friedman, R. Upadhye, Lawrence Livermore Nat. Lab., DOE Contract No. W-7405-Eng-48

El Tremedal, Spain, EU Project, 1991-1998

Objectives

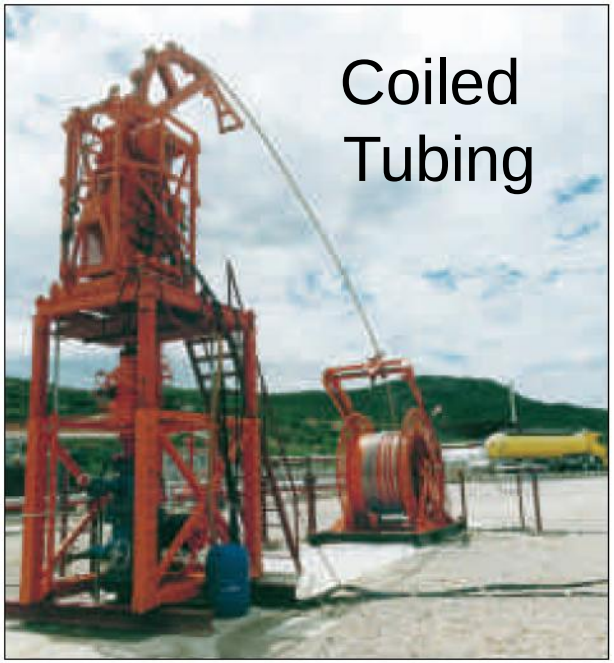
- To demonstrate the feasibility of UCG at intermediate depth in Europe, 500-700m
- To demonstrate drilling of long in-seam holes by deviated drilling & connect to vertical wells & establish competent gas flow circuits
- To develop gasifier initiation & cavity growth control techniques
- To monitor & measure gasifier development & product gas quality & quantity for economic assessment
- To prove materials capabilities & environmental safety

Source: “Underground Coal Gasification – A Joint European Field Trial in Spain”, Department of Trade & Industry, UK, December 1999

El Tremedal, Spain, 7 Years & $20M

Summary

Duration: 7years, 1991 to 1998
Total Cost: $20 Million
Contractor: Underground Gasification Europe, Teruel, Spain



Wells were completed with casing & concentric tubing to provide necessary paths for production, injection, purge-gas & cooling water flows.

A coiled tube located in the injection well was used to execute the controlled retraction injection point, CRIP

Source: "Underground Coal Gasification – A Joint European Field Trial in Spain", Department of Trade & Industry, UK, December 1999

Centralia & El Tremedal Syngas Quality

Process/Experiment	UGE	Centralia	Surface
	Raw gas basis	Raw gas basis	After gas cleaning
Operating pressure (Bar)	53	4	25
Gas composition (%)			
Carbon dioxide	41.0	34.9	3.87
Carbon monoxide	12.8	20.8	60.51
Hydrogen	24.8	38.1	22.08
Methane	13.2	4.7	0.01
Hydrogen sulphide	8.3	1.5	0.00
Nitrogen	free basis	free basis	13.53
LHV (dry basis) (kJ m^{-3})	10,907	8734	10,029

10,907 kJ/m^3 = 292 Btu/ft^3, 8734 kJ/m^3 = 234 Btu/ft^3

5MJ/m^3 = 134 Btu/ft^3

13MJ/m^3 = 349 Btu/ft^3

UGE = Underground Gasification Europe, Teruel, Spain

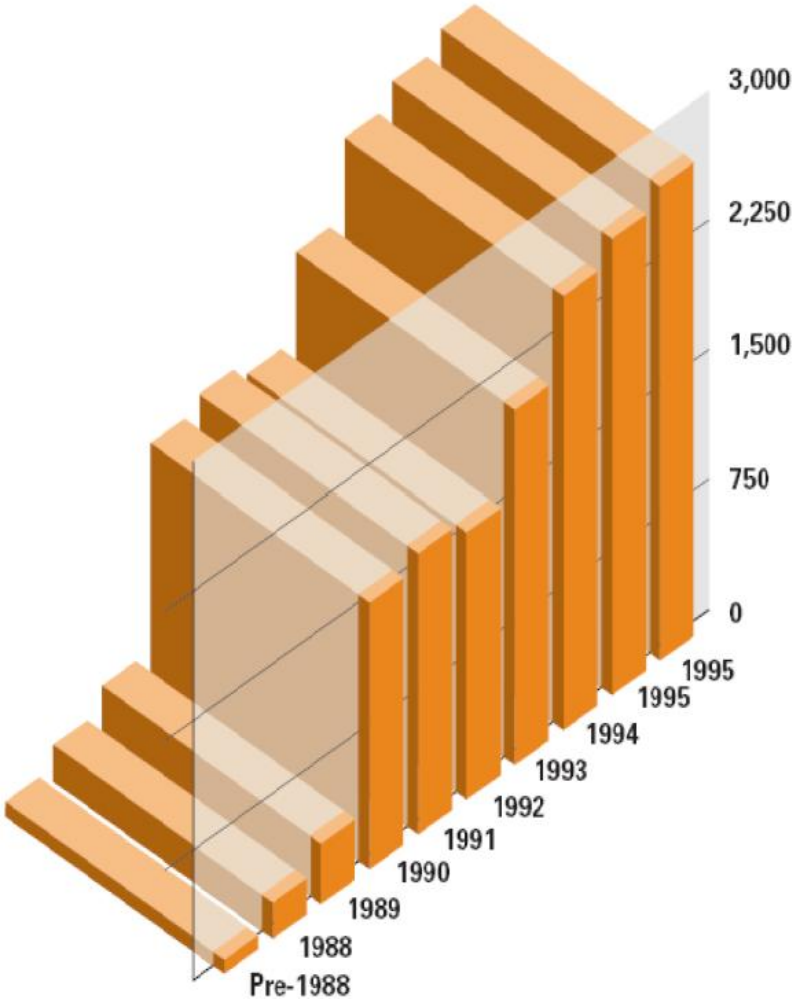
Source: "Underground Coal Gasification – A Joint European Field Trial in Spain", Department of Trade & Industry, UK, December 1999

Roller Cone Bit

Directional Drilling Application to Coal

- UCG drilling **follows CBM techniques**
- Rotor at drill bit - driven by steerable mud motor
- In 1980 directional drilling was still a ‘big deal’
- Drilling teams - to have previously drilled coal
- Availability of drilling rigs is a problem
- A rig can have 40 to 60 wells – congestion
- Drilling 2-4 ft seams is very good for CBM
- Focused gamma rays see limits of coal seams & keep 90% of time within the coal

Worldwide Horizontal Wells



Number of horizontal wells

Only 2625 horizontal wells worldwide in 1995

Since 1995 "Scientific Drilling" has drilled over 4000 horizontal wells in North America

Source: Oil & Gas Journal, November 23, 1998

Key Drilling Issues

Faulting & Fracturing

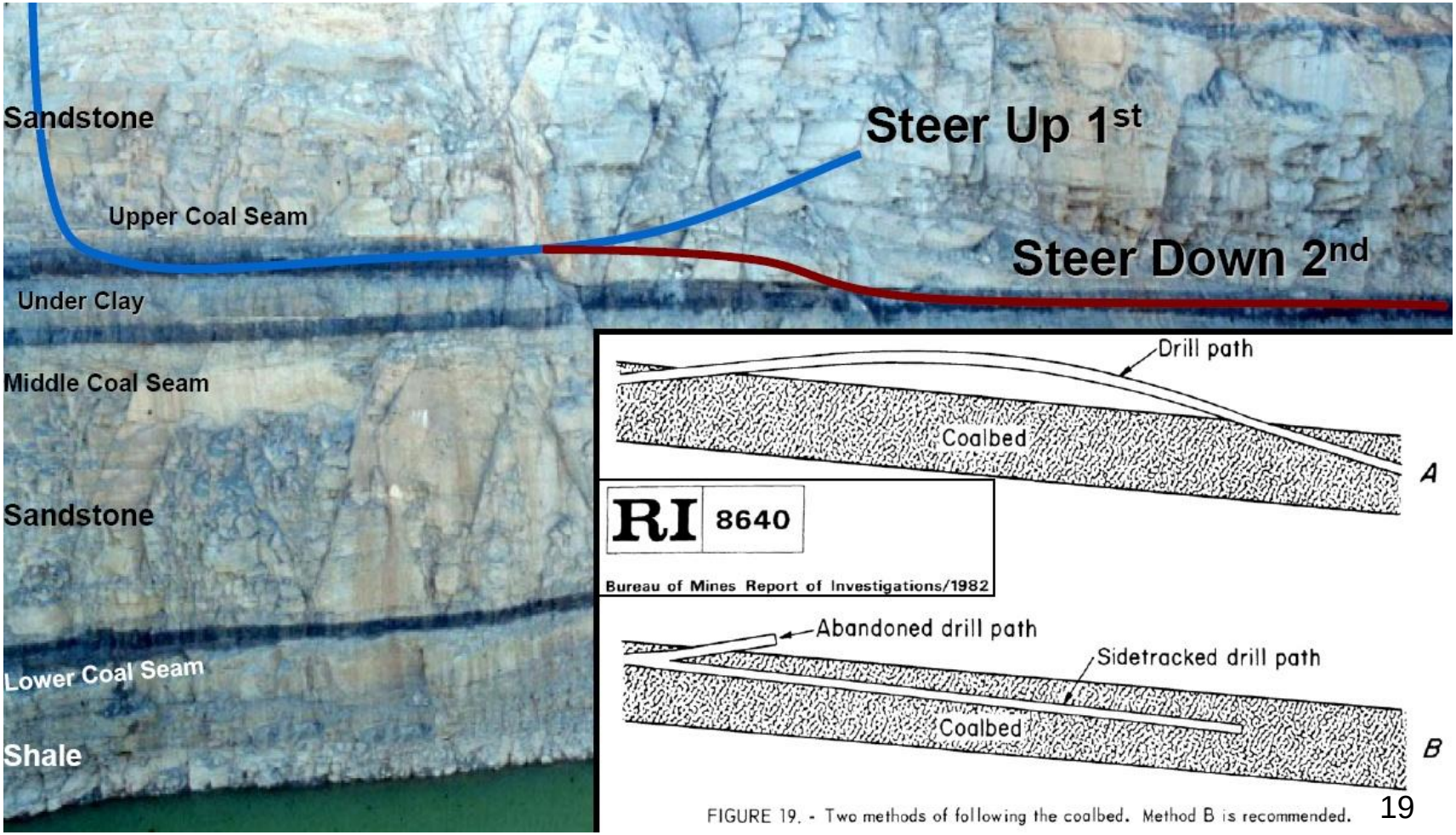
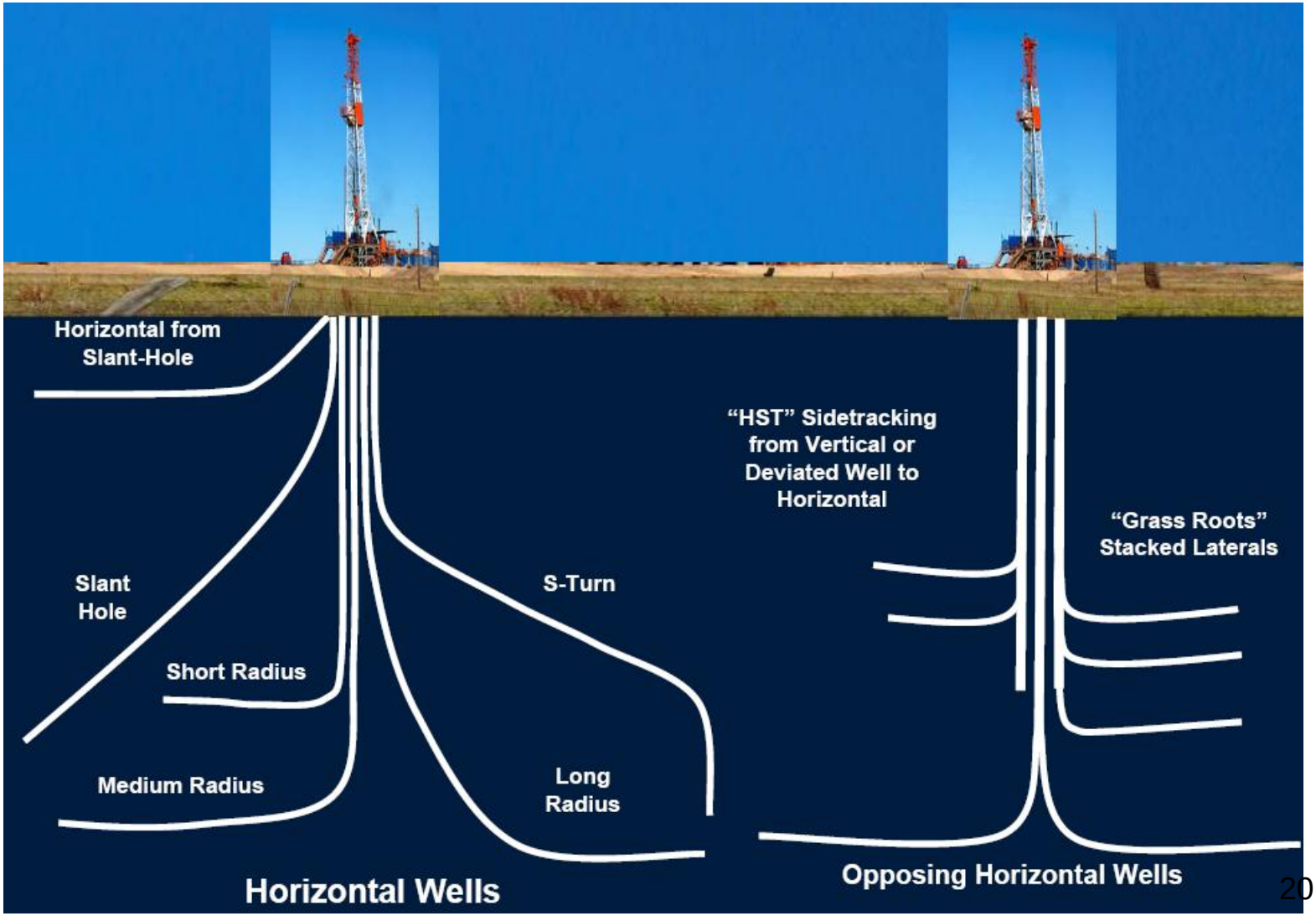


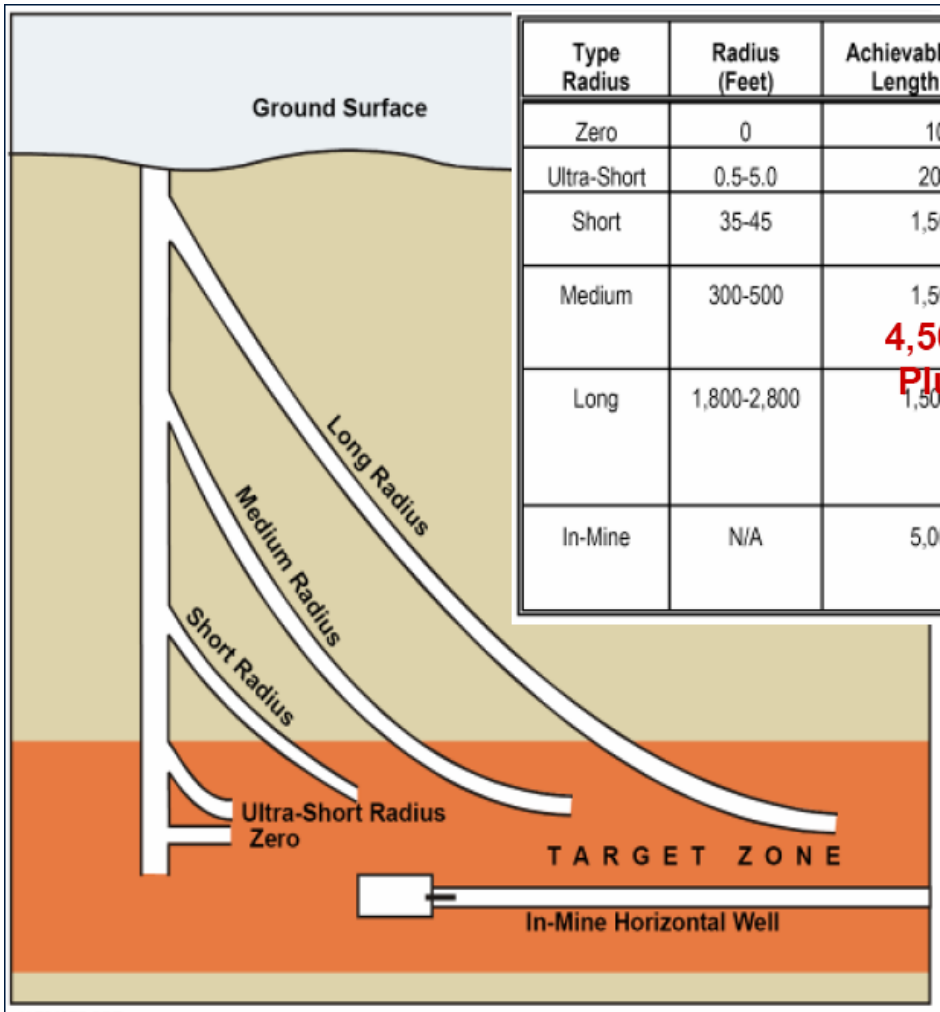
FIGURE 19. - Two methods of following the coalbed. Method B is recommended.

Directional Well Profiles



Bob Godbolt, Business Development, UK, Caspian & Africa, Scientific Drilling, London, September 2008

Horizontal Well Classification



Classification of Directional Wells

Type Radius	Radius (Feet)	Achievable Lateral Length (Feet)	Method
Zero	0	10	Telescopic probe with hydraulic jet
Ultra-Short	0.5-5.0	200	Coiled tubing with hydraulic jet
Short	35-45	1,500	Curved drilling guide with flexible drill pipe; entire string rotated from surface
Medium	300-500	1,500 4,500' Plus	Steerable mud motor used with compressive drill pipe; conventional drilling technology can also be used
Long	1,800-2,800	1,500 +	Conventional directional drilling equipment used; very long curve length of 2,800 to 4,400 feet needed to be drilled before achieving horizontal
In-Mine	N/A	5,000	Uses underground drilling rigs with steerable motors and position systems to achieve long, in-seam boreholes

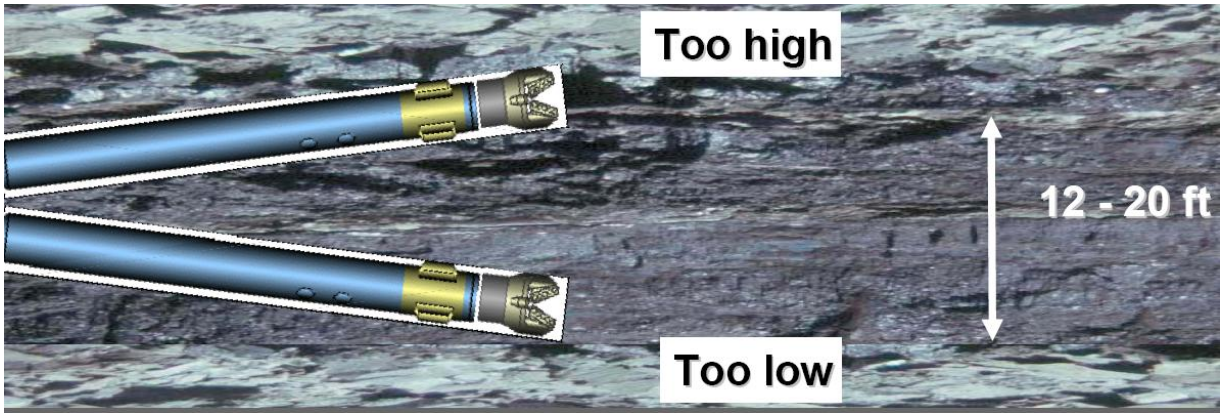
CURVE BUILD RATES

Long: 2 - 6° / 100'
Medium: 6 - 40° / 100'
Short: 40 - 70° / 100'
Ultra Short: 70 - 150° / 100'

Key Drilling Issues

Maintaining the bottom head assembly (BHA) heading within the target zone

Thick Seams are sometimes more difficult to drill in zone because the BHA is prone to get out of plane with the formation

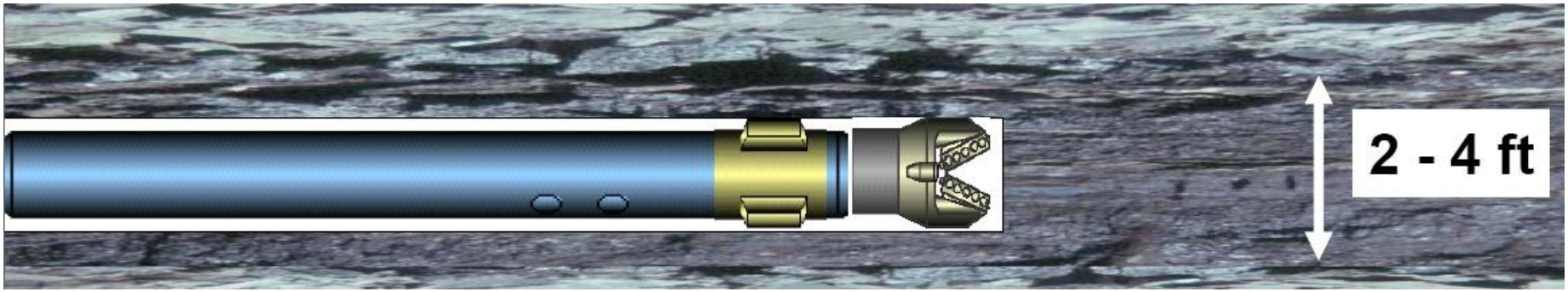


By pumping mud through the mud motor, the bit turns while the drillstring does not rotate, allowing the bit to drill in the direction it points

Key Drilling Issues

Maintaining the BHA heading within the target zone

– Thin Seams are sometimes easier to drill in zone because the BHA tends to deflect off the roof & floor of the coal seam & stay in plane with the formation



If bit gets stuck then 40% chance of getting it back

Directional Drilling, Typical Costs

- About $20k/day for drilling rig + material/other costs
- Cost per bit is $80k+
- Lost in hole costs amount to $0.5M to $1.0 Million
- Conventional 1000m vertical well rig costs $5-10M
- Low cost H_2 production ($2-3/MBtu)
- 750m long linear gasifier ~ $1.8M (2001 horizontal drilling)
- Guided drilling is about 2 to 3 times more expensive than vertical drilling
- Drilling costs are highly variable

Bob Godbolt, Business Development, UK, Caspian & Africa, Scientific Drilling, London, September 2008

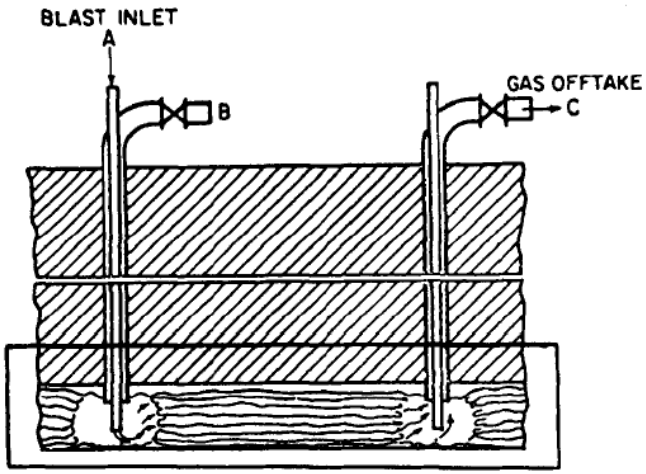
Report: COAL R211, DTI/Pub URN 01/1041

Main Operational Parameters of UCG Process

- **Pressure** of the underground reactor
- **Flow rates** of the injected gasification agents
- **Temperature** at the bottom of the production well

These must all be controlled at the surface

Controlling Operations – Cavity Area



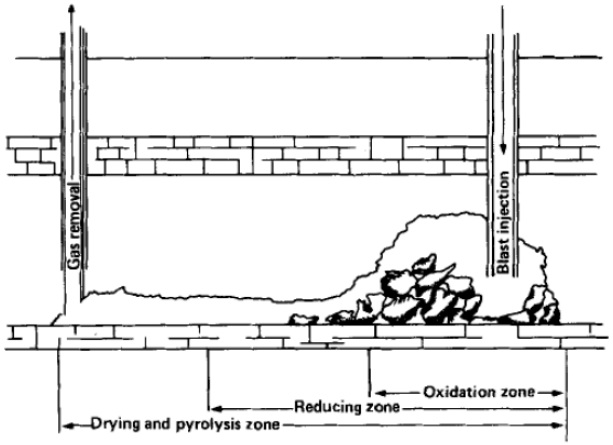
Enhanced permeability:

- Air pressurisation
- Man-built galleries
- Directional drilling

Injecting oxygen & steam instead of air produces the most useful product gas, since the dilution effect of nitrogen is avoided. The main constituents of product gas are H_2, CO_2, CO, CH_4 & steam. **The proportion of these gases varies with the type of coal & process efficiency**.

Constant gas composition requires a large surface area available for contact between coal and hot gases

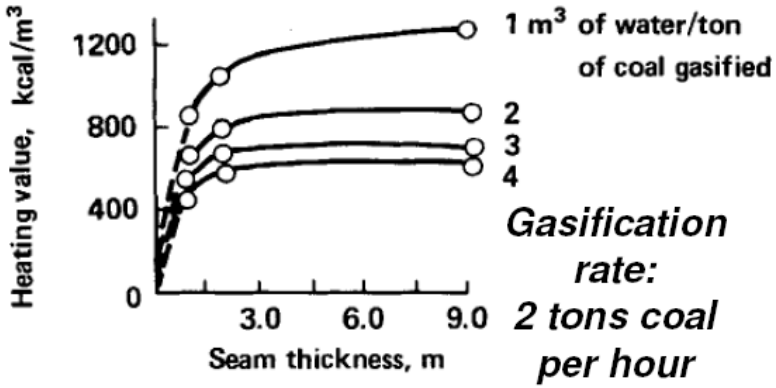
- Excess CO2 will be converted to CO: CO2 + C → 2 CO.
- This reaction increases the heating value of the gas.
- New sections of the seam need to be added in order to keep a high surface area.
- However, it is not desirable to cool down the gases too much.

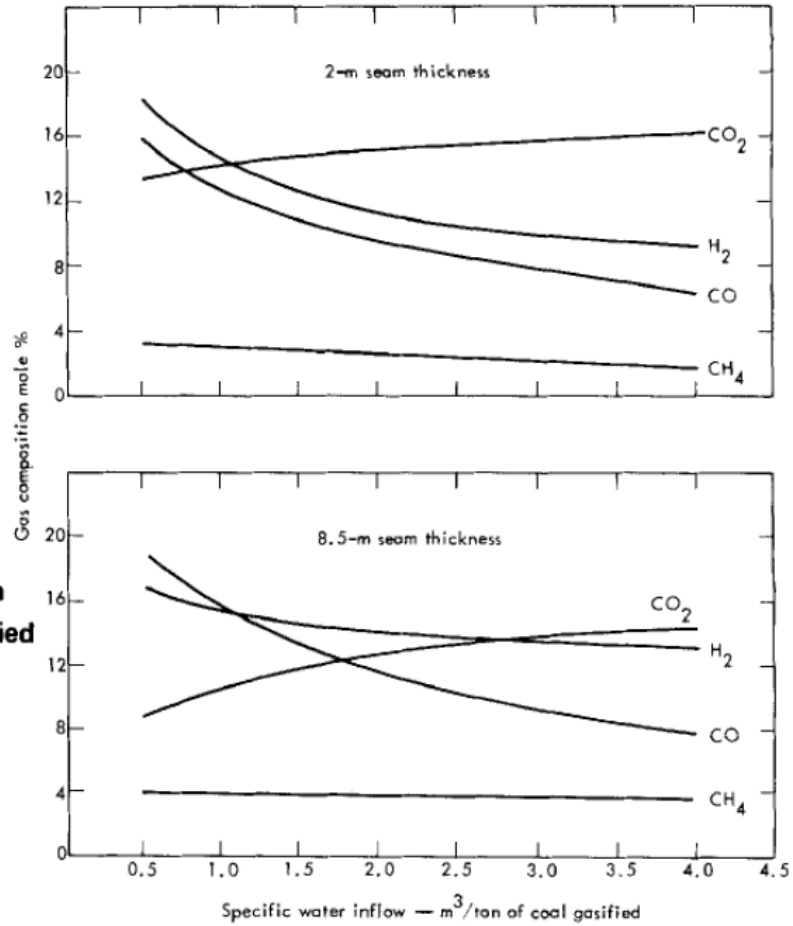


Control Parameters – Thickness & Moisture

- Coal seam thickness.

- Thin seams lose more heat to the surroundings.
- Decreasing seam thickness has roughly the same effect as increasing water intrusion.
- As expected, CH_4 concentration is largely unaffected.

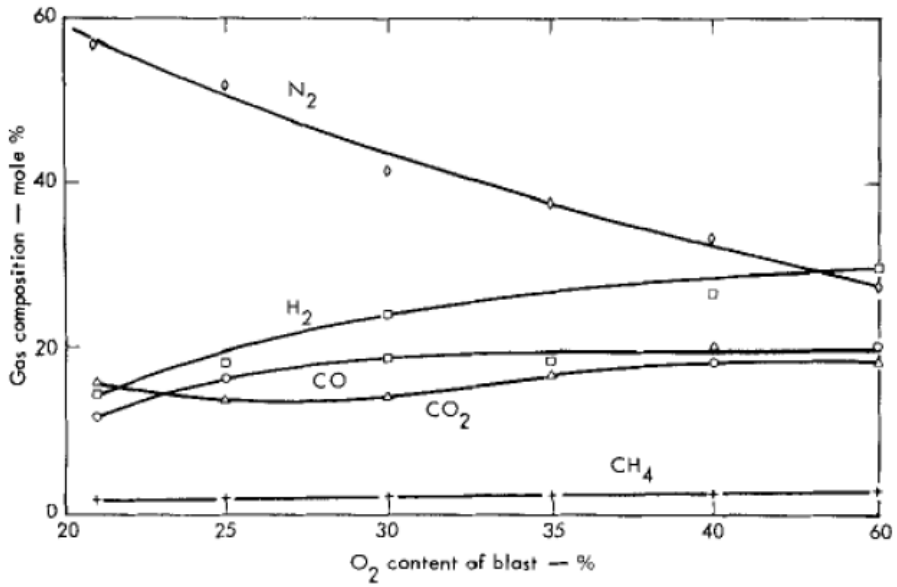




Control Parameters – Oxygen or Air Input

The use of oxygen instead of air:

- improves the calorific value of the product gas, 3-5 MJ/m^3 vs 13 MJ/m^3 in the trial at El Tremedal.
- Improves gasification stability
- Reduces the volume of gas injected



5MJ/m^3 = 134 Btu/ft^3

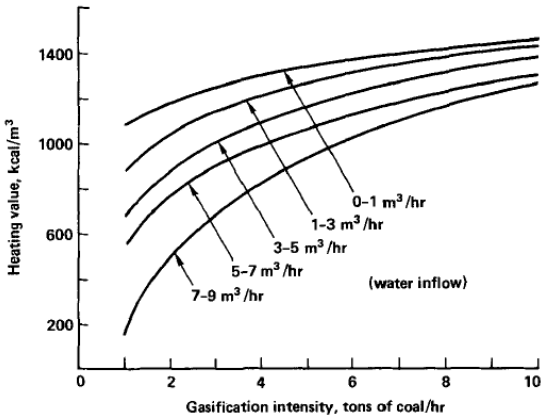
13MJ/m^3 = 349 Btu/ft^3

Control Parameters – Water, Blast Rate

- Water intrusion.
  - Its rate depends on hydrostatic pressure and permeability.
  - Higher blast rates decrease water content in the product gas.
  - It does matter where water intrusion takes place.

Blast rate.

- Higher blast rates may lead to high calorific values of the product gas.
- This is related to the effect of water inlet on the water-gas shift reaction.



Plastic properties of coal.

Swelling properties are important.
Some coals can swell up to 3-4 times their original volume.
This may result in channel blockages.

Modeling UCG

Model results for UCG gas composition compared with field measurements made during the 1980s Rocky Mountain 1 Controlled Retraction Ignition Point test.

Component	UCG model predictions (percent)	Field measurements (percent)
Hydrogen	27.2	27.3
Carbon monoxide	13.0	6.4
Carbon dioxide	19.4	27.2
Methane	7.4	6.4
Water	33.0	33.0

UC model quite accurately predicts the hydrogen, methane & water content of the gas. However, it predicts twice the actual level of CO & about 2/3 actual level of CO_2.

2007: BP executed an agreement with the Lawrence Livermore National Laboratory to develop simulations for optimizing the UCG process as well as tools for drilling, monitoring, & environmental management. University of California, at Berkeley, is modeling UCG.

Lawrence Livermore National Laboratory, “Fire in The Hole”, April 2007

UCG Economics

- Initial estimates suggest that UCG based power plants costs & consequent cost of electricity, COE, will be lower (25% to 50%) than conventional power plants. **Uncertainty in economic projections** will continue until UCG based power plants are operating in the Western world

- Syngas derived from UCG can be used in the production of chemicals – hydrogen, ammonia, methanol, liquid fuels. **Primary use consideration is electricity generation**

  UCG power plant will be very similar to an IGCC plant
  UCG power plant = IGCC plant – Surface Gasifier

- UCG plants will need less gas cleanup because the tar & ash content is less than with surface gasifiers. Reduced environmental costs – no SOx, NOx, or ash

"Best Practices in Underground Coal Gasification", Elizabeth Burton, Julio Friedmann, Ravi Upadhye, Lawrence Livermore National Laboratory, University of California, 2007

UCG Economics - Example

Considering a 50MW gas turbine with UCG supplies

Gas Turbine $ 37M
Process Equipment $ 24M

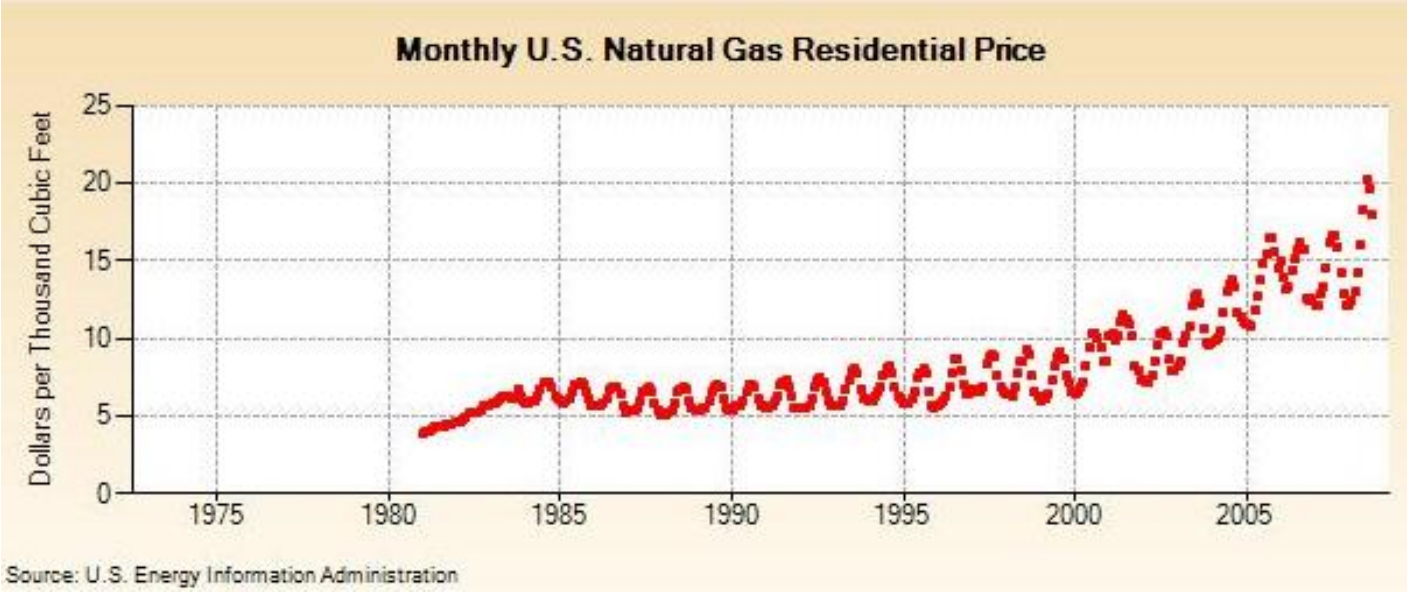
Drilling (10 years) $120M
(Europe, 800m depth, 400m horizontal)

Cost of UCG gas ~ $2 to $5/MBtu?

Report: COAL R211, DTI/Pub URN 01/1041

UCG Economics

In the 1970's & 1980's when LLNL conducted extensive UCG tests the cost of natural gas was much lower



EIA, http://tonto.eia.doe.gov/dnav/ng/hist/n3010us3M.htm

New Projects

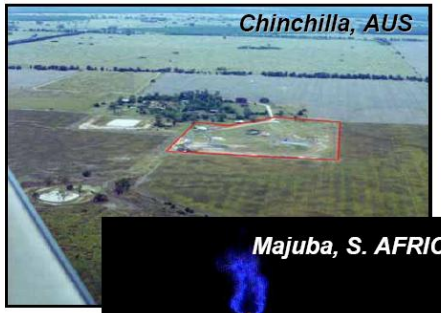
Linc Energy, Australia (Chinchilla)
- First gas, 1999; continuous for 2.5 years
- 35,000 tons brown coal evacuated
- Current plans for CTL plant

Eskom, S. Africa (Majuba)
- Ignition Jan. 2007; electric power
- Bituminous coal
- Planning 1000 MW IGCC step out this year

GAIL, India
- Scheduled production, 2009
- Lignite coal, planned electric power

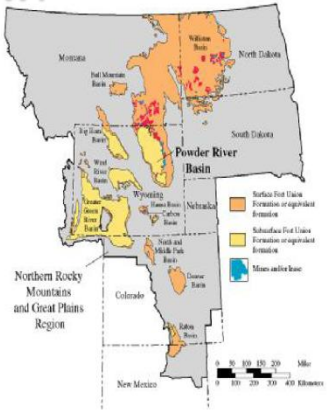
XinAo, China
- Pilot ignition, Aug. 2007
- Sub-bituminous; planned methanol plant

Other companies planning or operating hydrogen, synthetic natural gas, F-T, and power with CCS



GasTech & BP
Commercializing UCG in WY

- Outstanding lease position (16billion tons unmineable coal)
- BP agrees to underwrite & manage project with GasTech
- Site selection process near completion
- Engagement of state of WY, Univ. WY,
- Anticipated first gas < 3 years
- *The pilot project will be the first of many projects in the State*



CCTR, 2008, $79.6k
School of Chemical Engineering
Purdue University
& Indiana Geological Survey

CCTR, 2009, $TBA

*Julio Friedmann ,Elizabeth Burton, Ravi Upadhye, L*awrence Livermore National Laboratory,
Presented at the Potential for Underground Coal Gasification Meeting, Washington, DC June 5, 2007

Michael Green, UCG Partnership Ltd, London, September 2008