Underground Coal Gasification (UCG)

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Presentation to Heritage Research Laboratory
Indianapolis

October 21, 2008

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

UCG Essentials

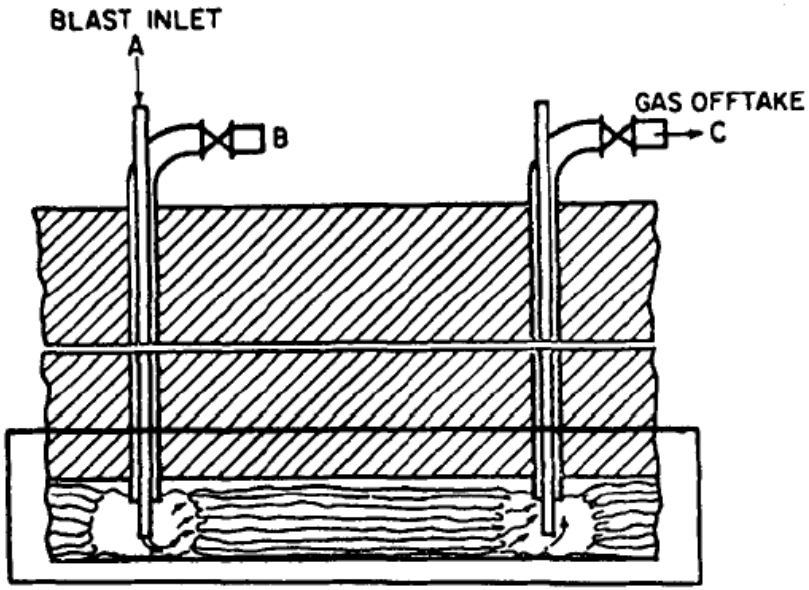
(A) Underground Coal Gasification (UCG) converts coal into a gaseous form (syngas) through the **same chemical reactions** that occur in surface gasifiers.

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

Four UCG essential areas to consider?

- **Site location - biggest issue to ensure success**
- **Principles- chemistry, coal characteristics**
- **Technologies - connecting wells, drilling, process control**
- **Demonstrations – Australia, USA, Spain, Angren**

Injection-Production Configuration



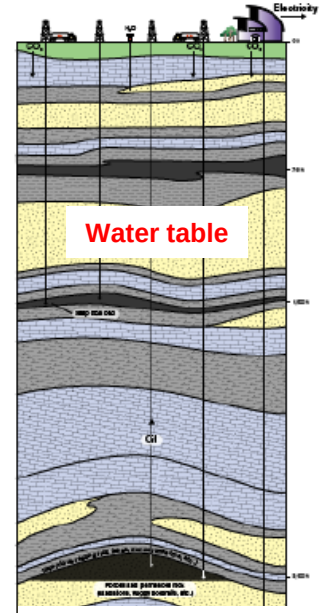
Enhanced permeability:

- Air pressurisation
- Man-built galleries
- Directional drilling

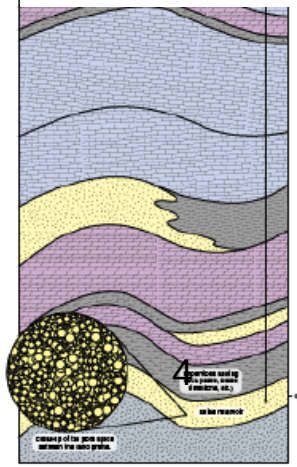
The oxidant & gasifying agent are fed through the injection borehole & the combustion & gasification products are recovered from the production bore hole. **Injecting oxygen & steam instead of air** produces the most useful product gas, since the dilution effect of nitrogen is avoided. The main constituents of the product gas are H2, CO2, CO, CH4 & steam. The **proportion of these gases varies** with the type of coal & the efficiency of the gasification process.

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



Anna Korre, Sevket Durucan, London, September 2008

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

Australia Site Selection Criteria

Commonwealth Scientific & Industrial Research Organization, CSIRO

- Seam thickness greater than five metres
- Coal ash less than 40% (air dried basis)
- Seem dip less than 20°
- Seam depth 200-400 metres
- Minimal faulting and no dips/sills
- Roof thermally stable with minimal permeability, preferably structured to encourage even caving
- Hydraulic head > 200m
- Adjacent aquifers can contain poor quality water and are of minimal permeability

Other notes

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

UK Site Selection Criteria

National Coal Board 1976

- 5 Mt of coal in resource to provide 20 years of operation
- Not marked for conventional mining
- Not adjacent to working mines
- Removal will not cause unacceptable subsidence
- Seam thickness at least one metre or banded seam totals over one metre
- Ash content less than 60% including any dirt bands as combustion may be impeded
- Area free of excessive faulting

Other notes

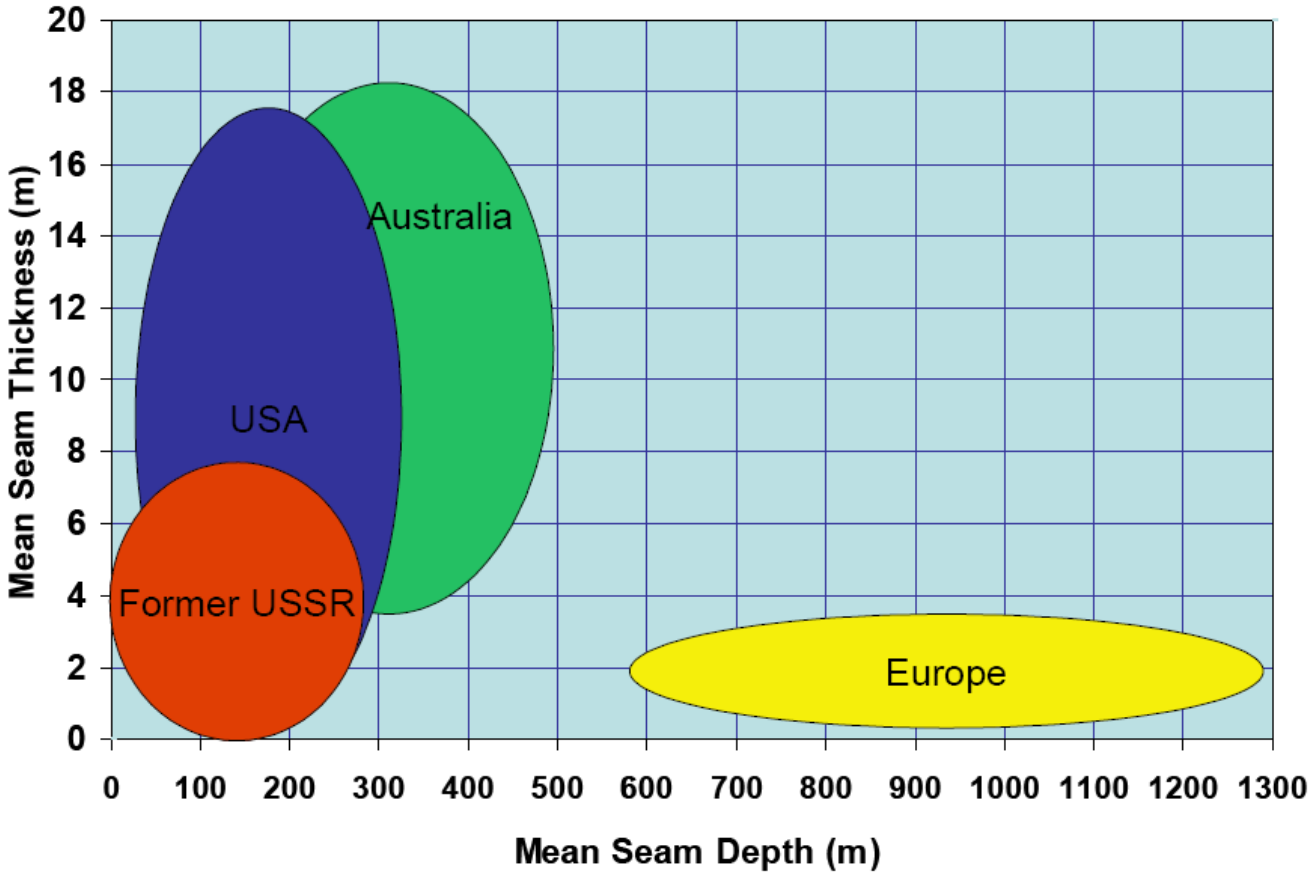
- Leakage may be excessive if adjacent to old mine workings or in a faulted area
- Impact of faulting and roof material on operation largely unknown
- Progress and control of multi-seam operations

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.

Worldwide UCG Experience
Coal Seam Depth & Thickness



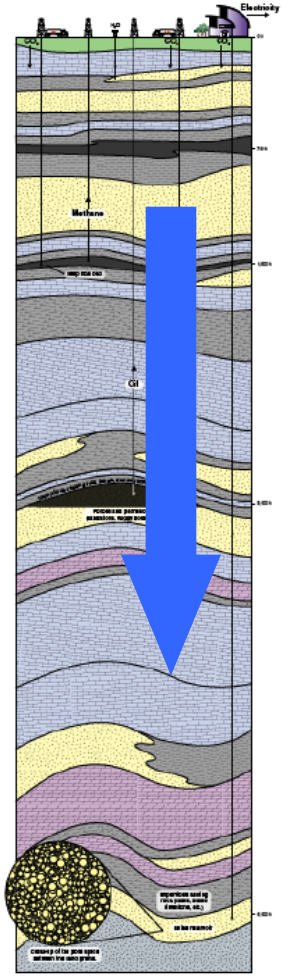
"Best Practices in Underground Coal Gasification", E.Burton, J.Friedman, R. Upadhye, Lawrence Livermore Nat. Lab., DOE Contract No. W-7405-Eng-48

UCG Site Selection Factor
Depth of Coal Seam

Deeper seams require **guided drilling technology** to initiate a well at the surface that is deviated to intercept & follow a coal seam & **establish a link between injection & production wells (**incurs higher drilling costs)

Deeper seams are less likely to be linked with potable aquifers, thus **avoiding drinkable water contamination & subsidence** problems

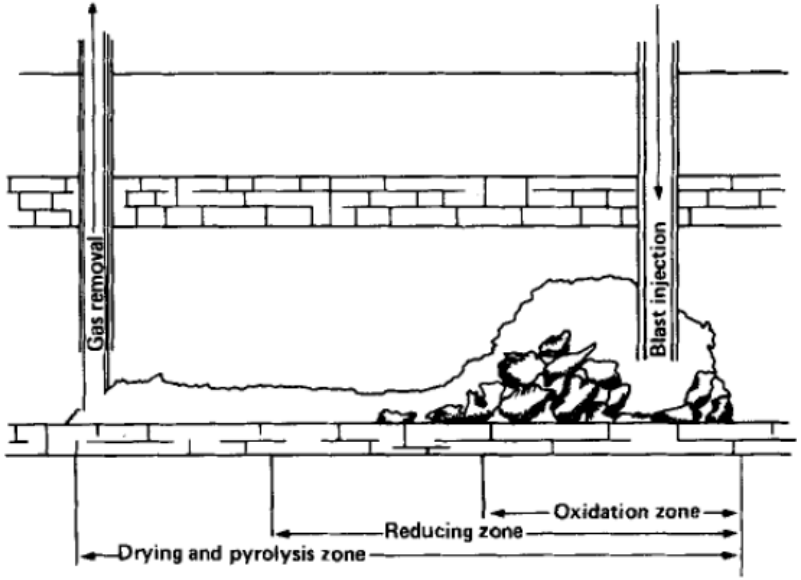
If the product gas is directly used in gas turbines, **additional compression may not be necessary**

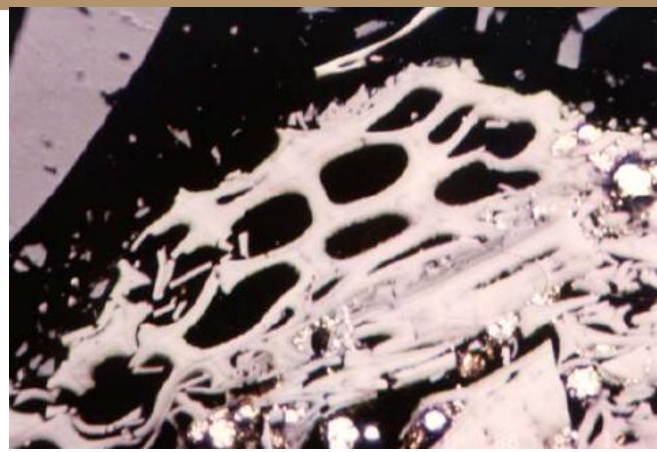


Contact Between Coal & Gases

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

- Excess CO_2 will be converted to CO: $CO_2 + C \rightarrow 2\ CO$.
- 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.





Site Selection Factors
Porosity & Permeability

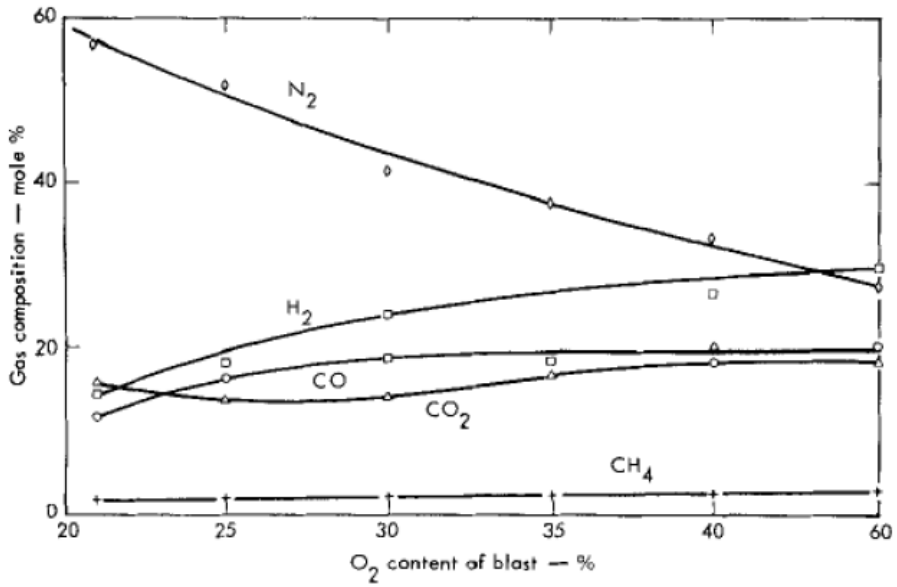
More **permeable coal seams make it easier** to link the injection & production wells, & increases the rate of gasification by making reactant transport easier

But higher porosity & permeability **increase the influx of water, & increase product gas losses**

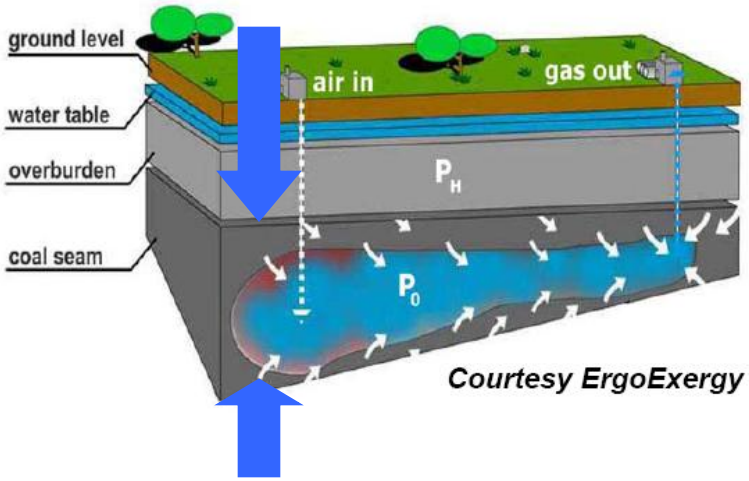
Control Parameters

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



UCG Site Selection Factor Coal Seam Thickness



Thicker seams need fewer wells, so reducing drilling costs

Often **problems** when attempting **to gasify seams < 2m thick**

Heat losses are considerable with thin seams, leads to low thermal efficiency & lower product gas quality

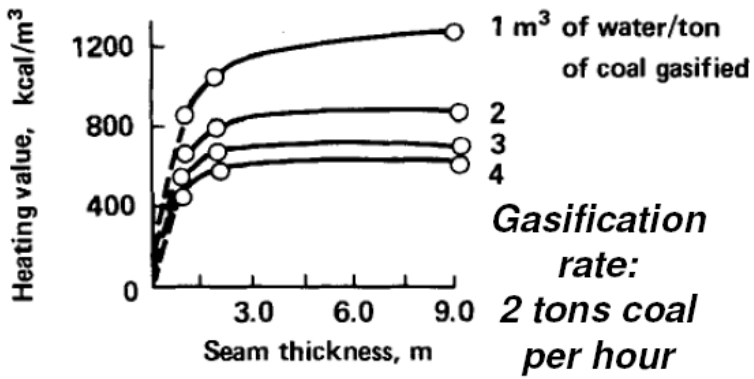
UCG is **generally easier to sustain in dipping seams** as tars & fluids flow away from the gasification zone

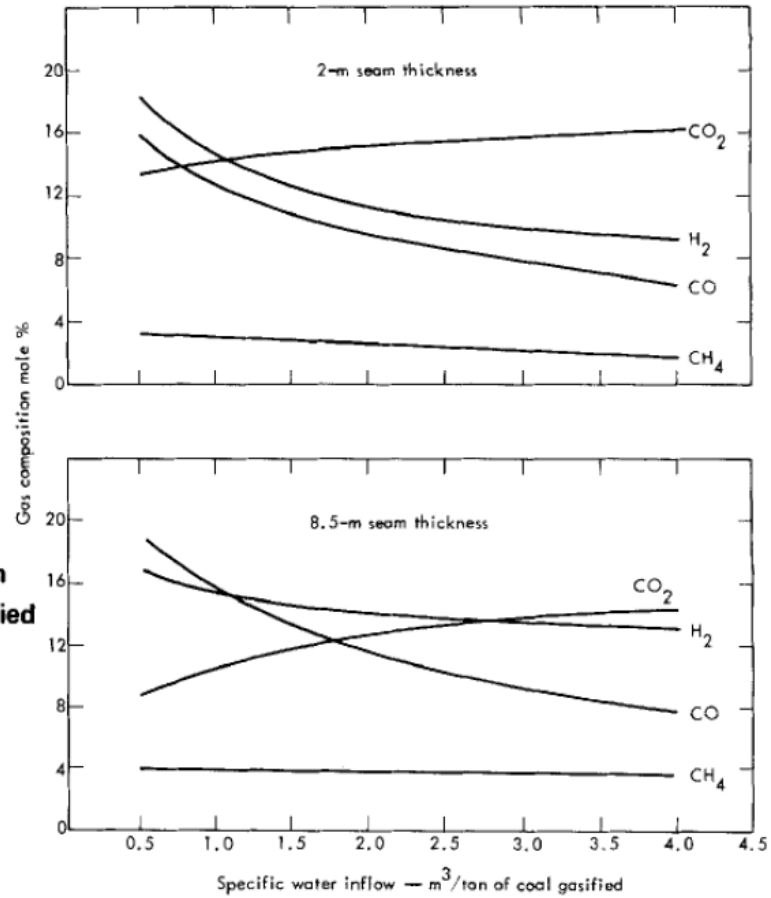
"Best Practices in Underground Coal Gasification", E.Burton, J.Friedman, R. Upadhye, Lawrence Livermore Nat. Lab., DOE Contract No. W-7405-Eng-48

Control Parameters

- 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.

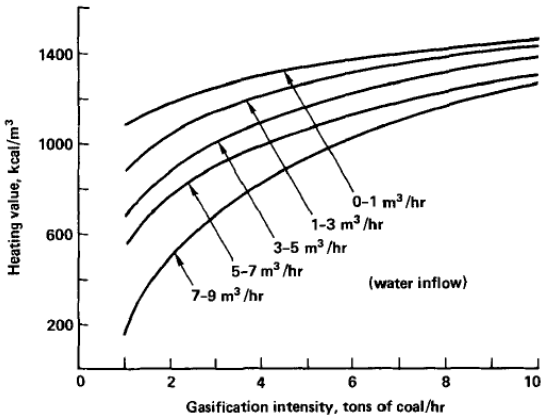




Control Parameters

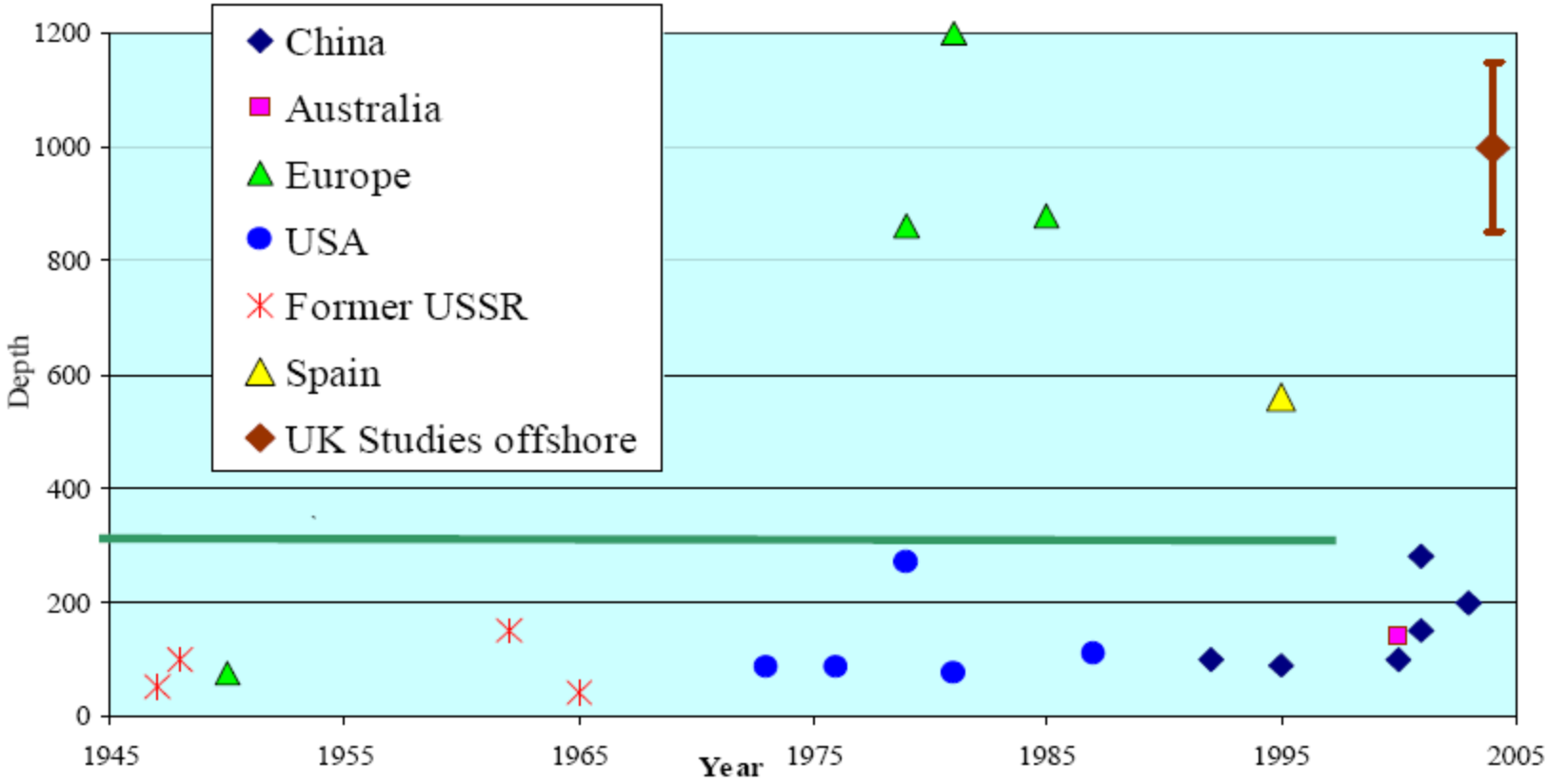
- Water intrusion.
  - Its rate depends on hydrostatic pressure and permeability.
  - Higher blast rates decrease water content in the product gas.
  - It does matter where water intrusion takes place.

- 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.

UCG Trials, Dates & Depths, 1948-2005 (Meters)



Michael Green, UCG Partnership Ltd, London, September 2008

UCG Trials: Date, Depth, Thickness

Location	Coal type	Thickness (m)	Depth (m)	Year
Lisichanskaya	Bituminous	0.44–2	60–250	1948–1965
Yuzhno-Abinskaya	Bituminous	2.2–9	50–300	1999–current
Angrensikaya	Lignite	2–22	120–250	1957–current
Podmoskovnaya	Lignite	2.5	30–80	1946–1953
Shatskaya	Lignite	2.6–4	30–60	1963–1956
Sinelnikovsky	Lignite	3.6–6	80	–
Chinchilla (Australia)	–	8–10	130	1999–2004
Tremedal (Spain)	Sub-bituminous, lignite	2–5	530–580	1989-1998
France	Anthracite	–	1200	1981–1986
Belgium	Anthracite	–	860	1979–1987
Newman Spinney (UK)	Sub-bituminious	0.75	75	1959
USA (Hanna 2)	Sub-bituminious	6.8	90–120	1973–1974
USA (Hoe Creek)	Sub-bituminious	7.6	38	1976–1979

http://www.sciencedirect.com/science?_ob=ArticleURL&_udi=B6V2S-4P2J32B-1&_user=29441&_rdoc=1&_fmt=&_orig=search&_sort=d&view=c&_version=1&_urlVersion=0&_userid=29441&md5=5a1f31dcfa458a1c2f5b075633ddd75b

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

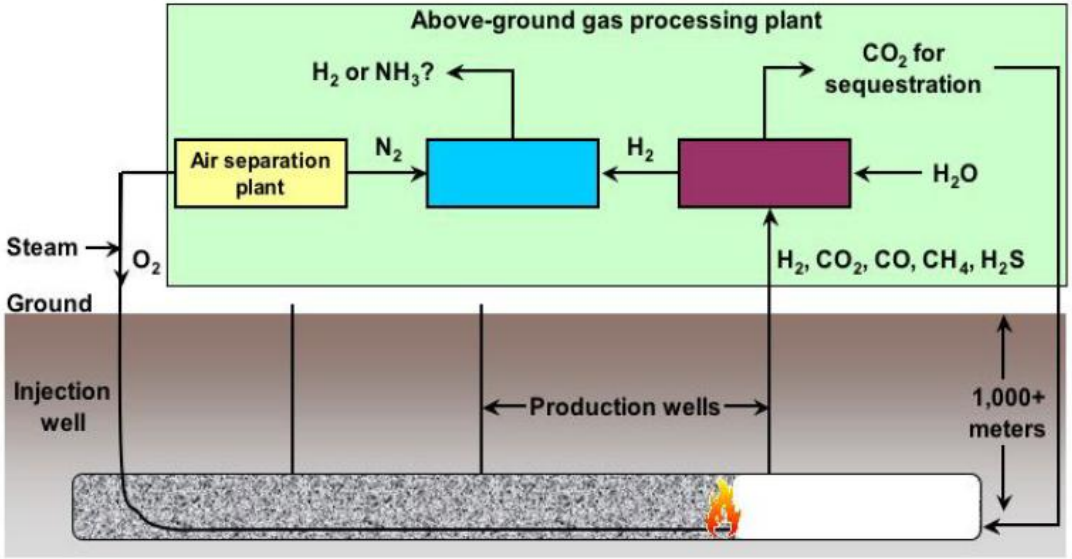
UC model quite accurately predicts the hydrogen, methane & water content of the gas. However, it predicts twice the actual level of CO & about 2/3 actual level of CO2.

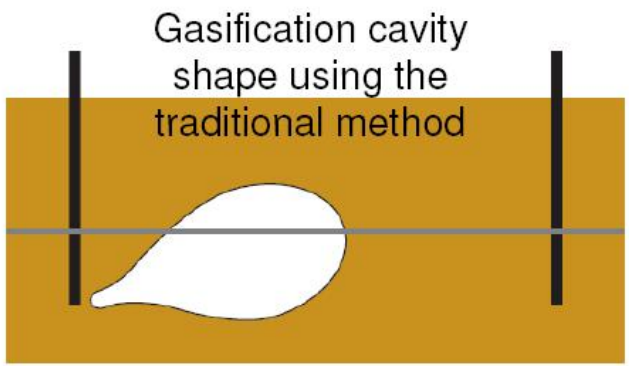
2007: BP executed an agreement with the Lawrence Livermore National Laboratory to develop simulations for optimizing the UCG process as well as tools for drilling, monitoring, & environmental management. University of California, at Berkeley, is modeling UCG.

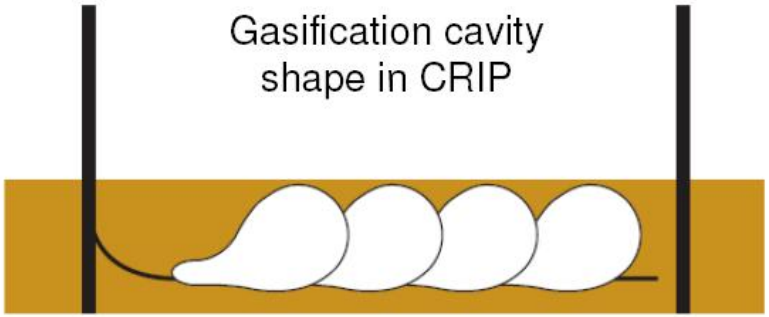
Lawrence Livermore National Laboratory, “Fire in The Hole”, April 2007

Injection-Production Configuration

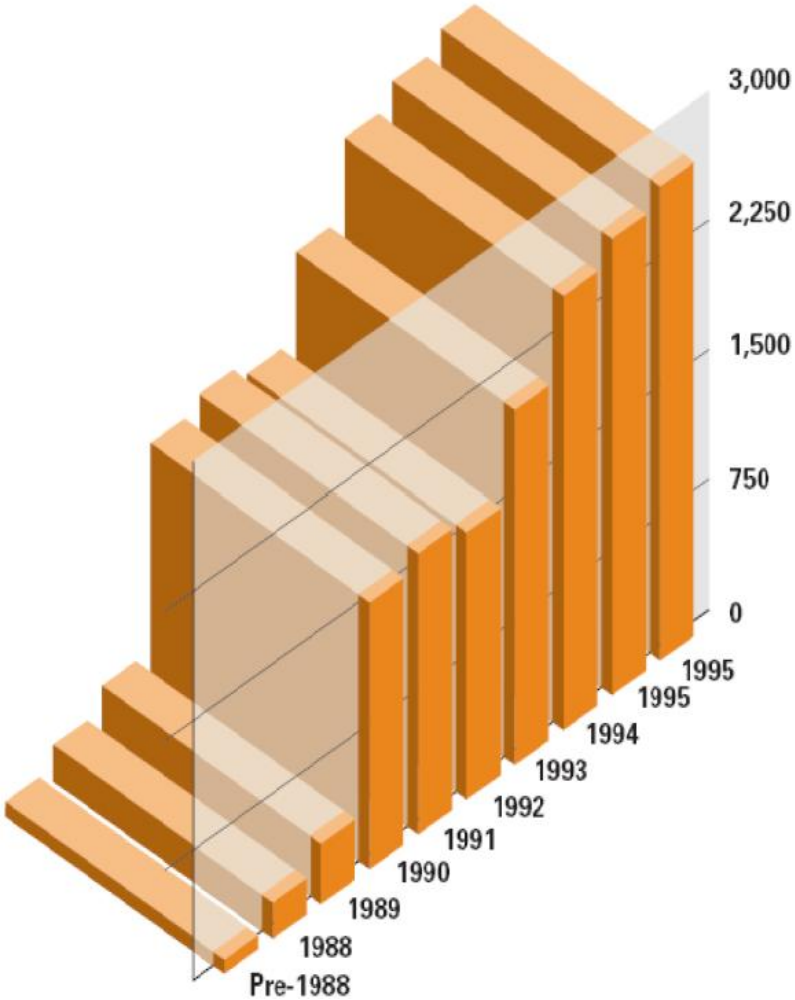
– A more controlled injection is obtained with the Controlled Retractable Injection Procedure (CRIP):







Worldwide Horizontal Wells



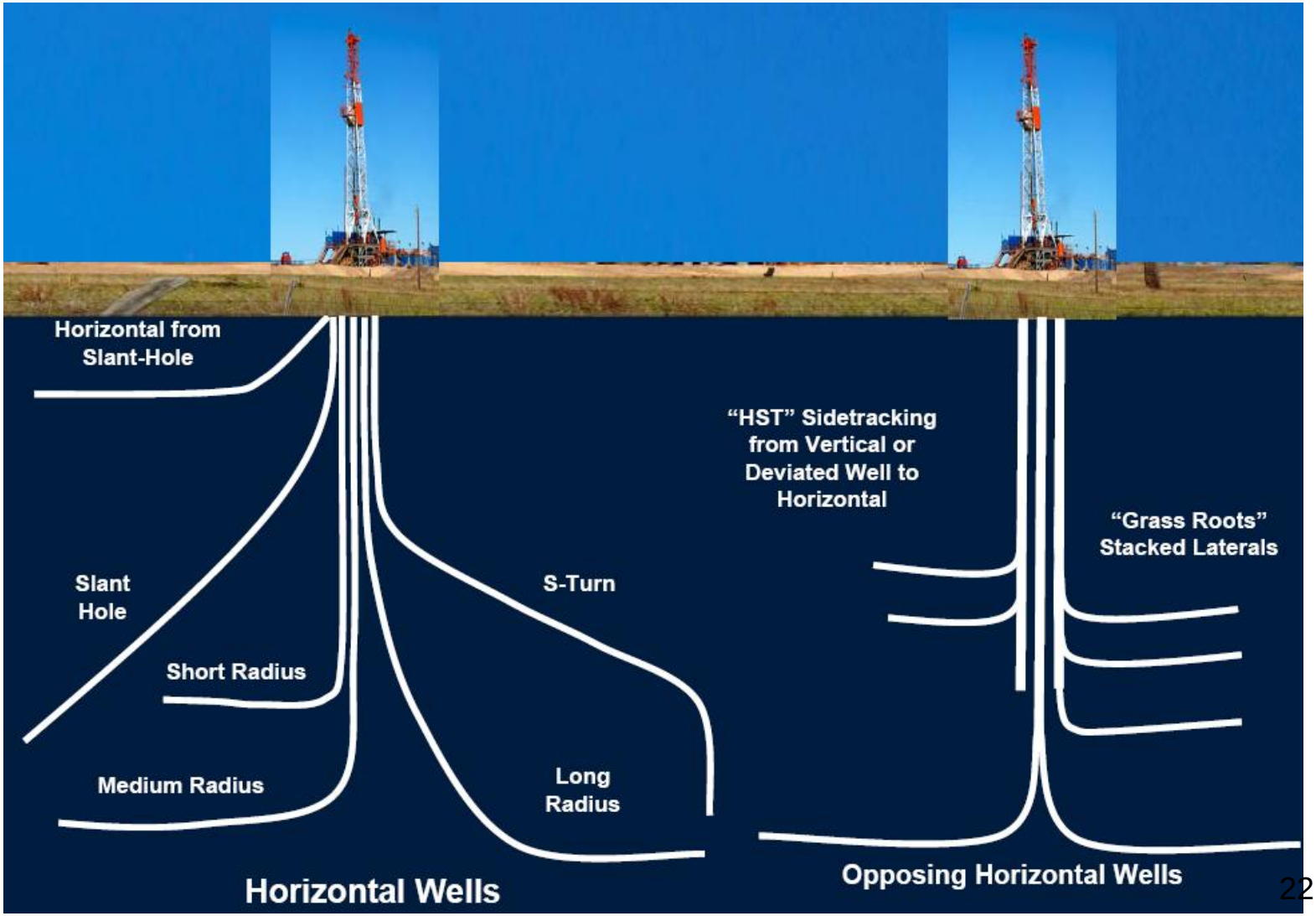
Source: Oil & Gas Journal, November 23, 1998

Number of horizontal wells

Only 2625 horizontal wells worldwide in 1995.

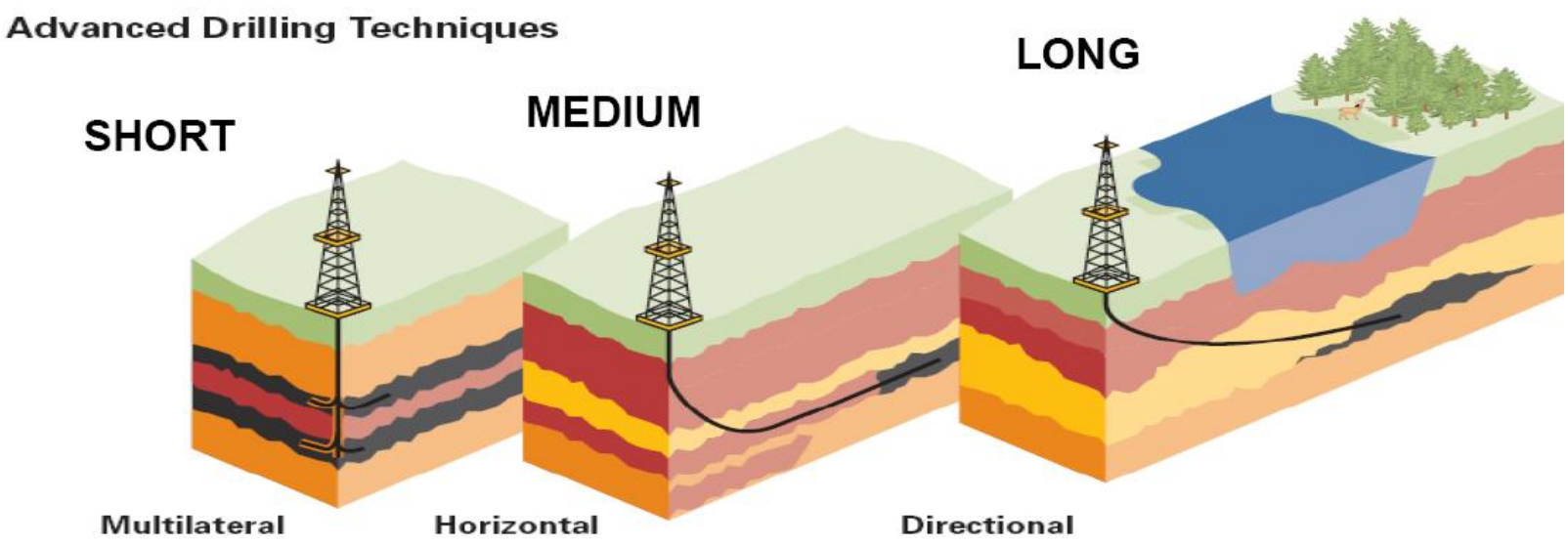
Since 1995 “Scientific Drilling” has drilled over 4000 horizontal wells in North America

Directional Well Profiles



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

Horizontal Well Types

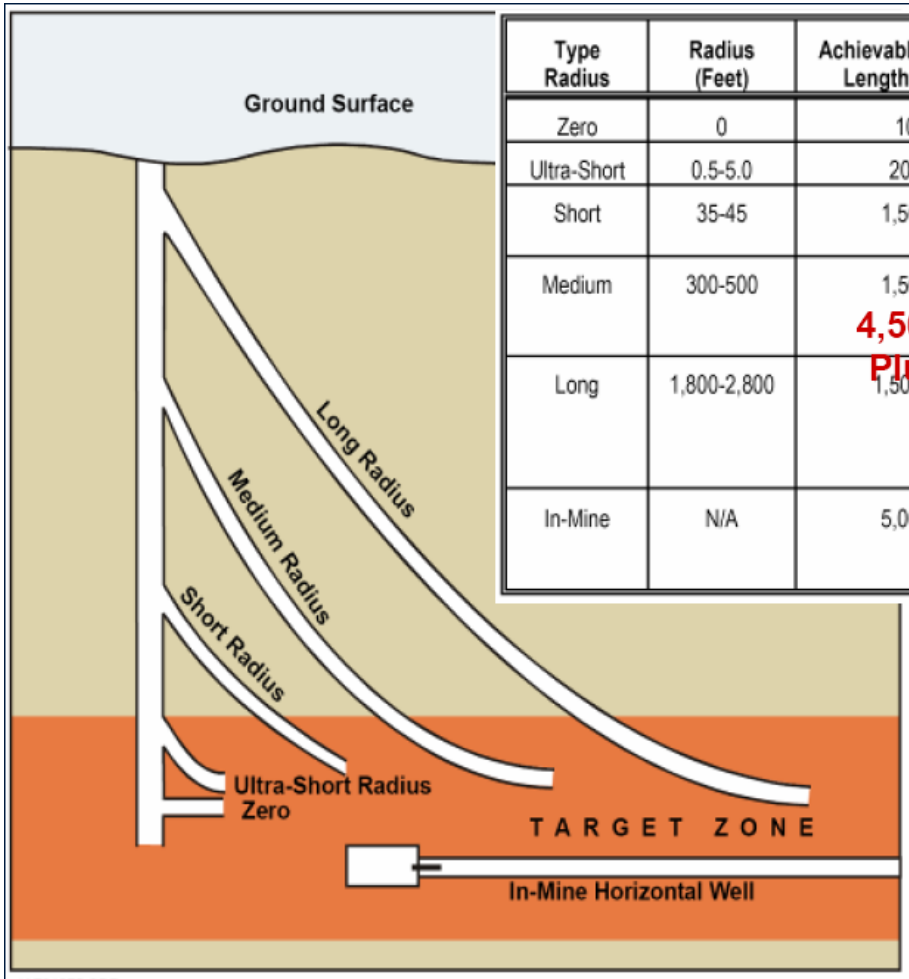


Categories of Horizontal Wells

- ☐ **LRH (LONG RADIUS)**
- ☐ **MRH (MEDIUM RADIUS)**
- ☐ **SHR (SHORT RADIUS)**

Example
North Sea typically
1000m down &
2000m horizontally

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	Steerable mud motor used with compressive drill pipe; conventional drilling technology can also be used
Long	1,800-2,800	1,500 + 4,500' Plus	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

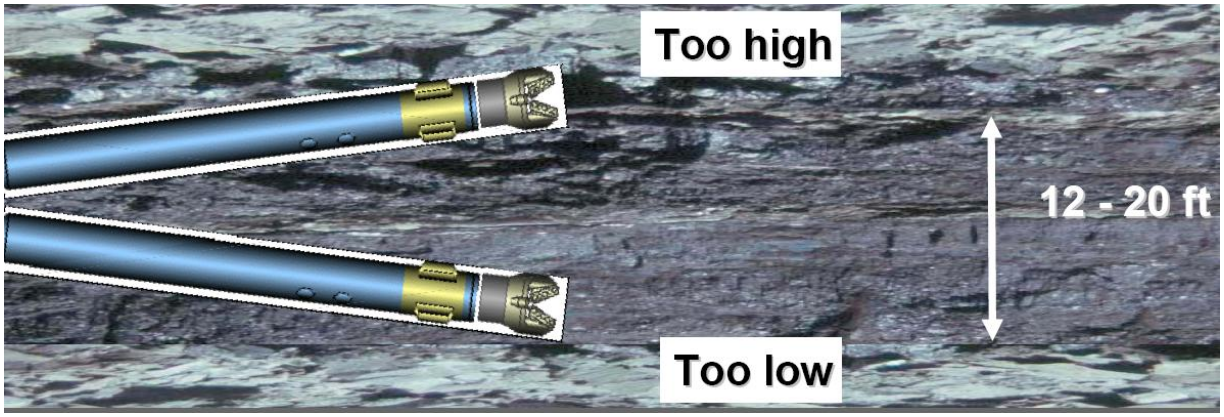
CURVE BUILD RATES

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

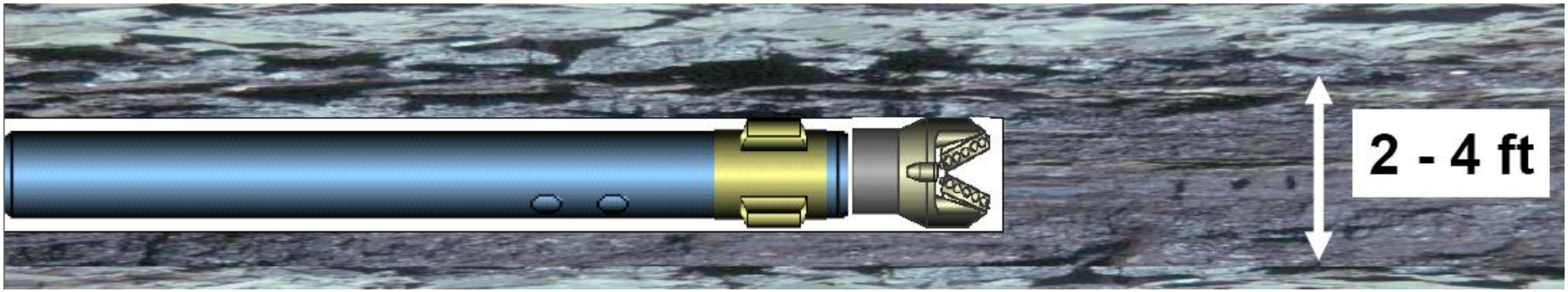


By pumping mud through the mud motor, the bit turns while the drillstring does not rotate, allowing the bit to drill in the direction it points

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

Key Drilling Issues

Faulting & Fracturing

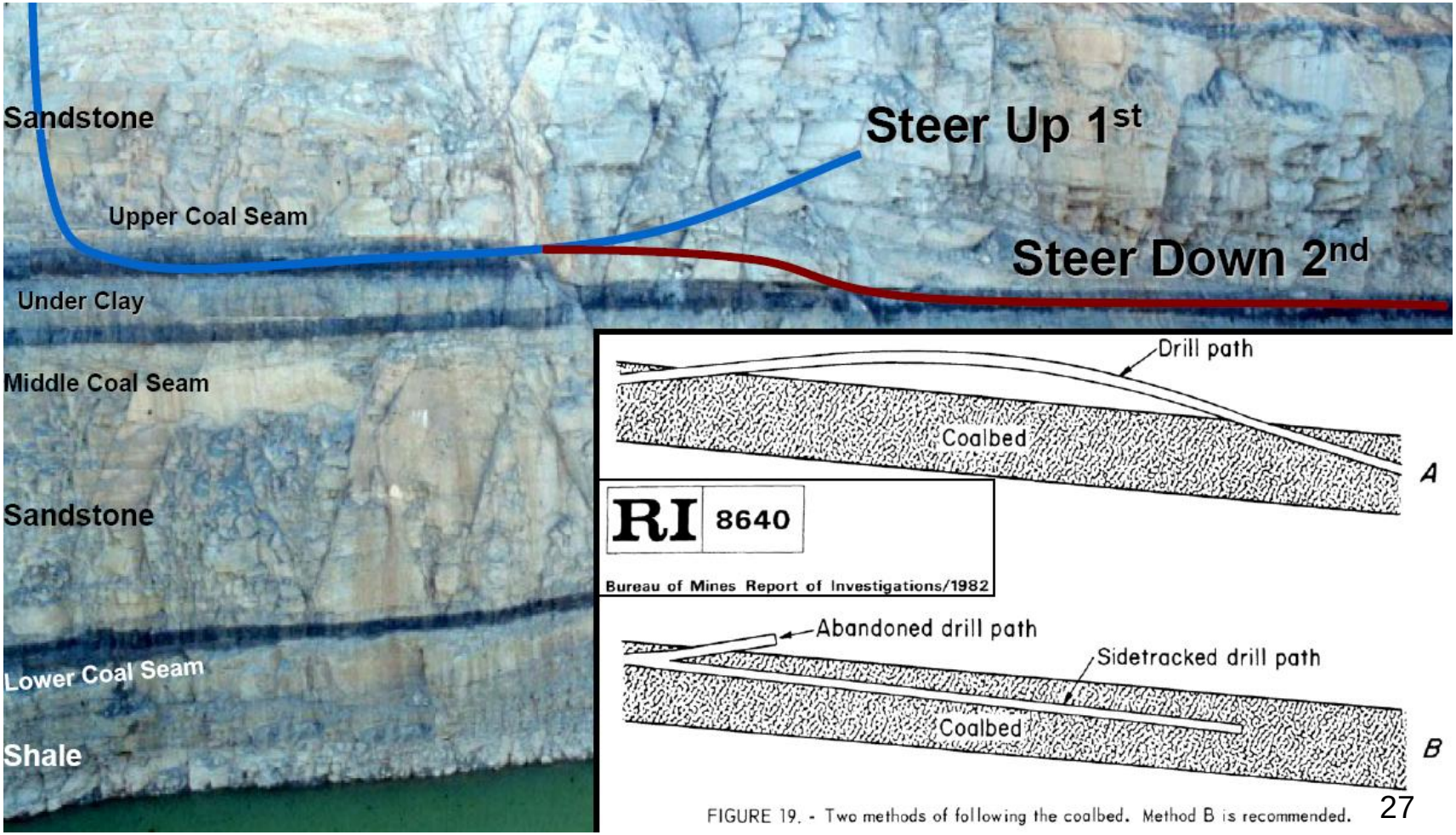


FIGURE 19. - Two methods of following the coalbed. Method B is recommended.

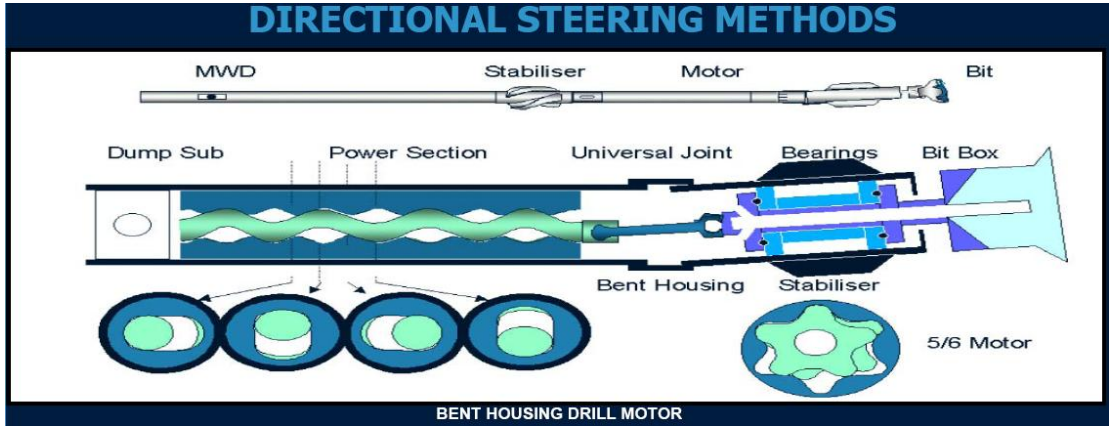
Roller Cone Bit

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

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 H2 production ($2-3/MBtu)



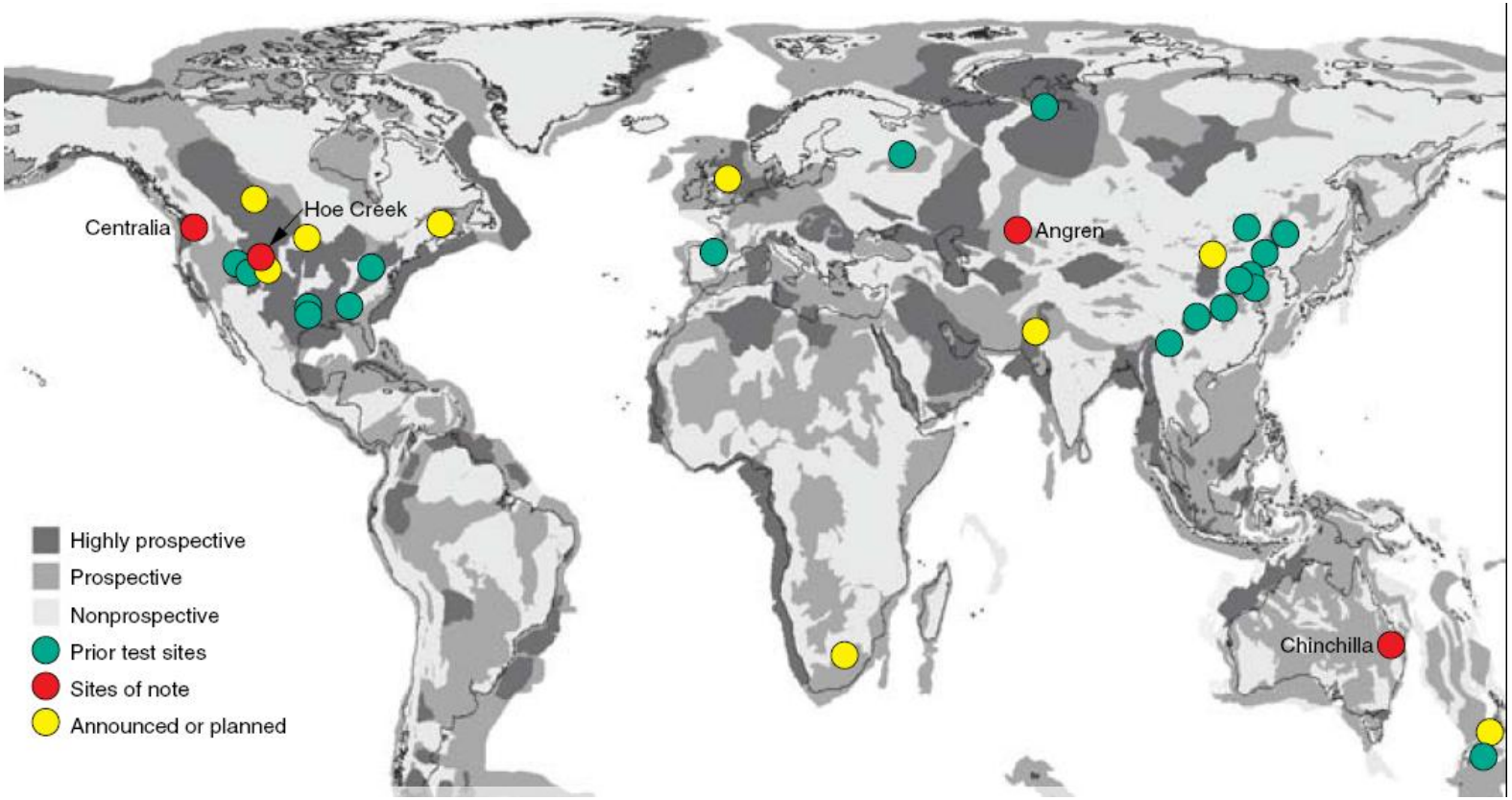
UCG Trials in US & World-Wide

Testing UCG in the **US from 1973 to 1989**. The Lawrence Livermore National Laboratory conducted tests at the Hoe Creek site in Wyoming

The **United Kingdom started UCG testing** in 1912 & the **Former Soviet Union** in 1928. **China** has been conducting tests since the 1980s **& Australia** since the 1990s

European UCG testing has taken place in Belgium (1982-1984), France (1983-1984), Spain (1992-1999), & United Kingdom (1999-2000)

Worldwide UCG Sites



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

Grey areas show potential areas for geological carbon storage

Source: “Fire in the Hole”, Lawrence Livermore National Laboratory, April 2007

UCG Activities in 2007-8

Europe
- EU Project underway
- Firth of Forth 2nd phase
- Hungary, and E Europe interest growing

USA & Canada
- US Nat Labs undertaking reviews
- GasTech Inc 5MW demonstration involving BP
- Wyoming Business study
- New entrepreneurial initiatives in US & Canada

China
- 11-16 State sponsored trials
- Start of entrepreneurial activity
- Demonstration by Xinao in Mongolia underway

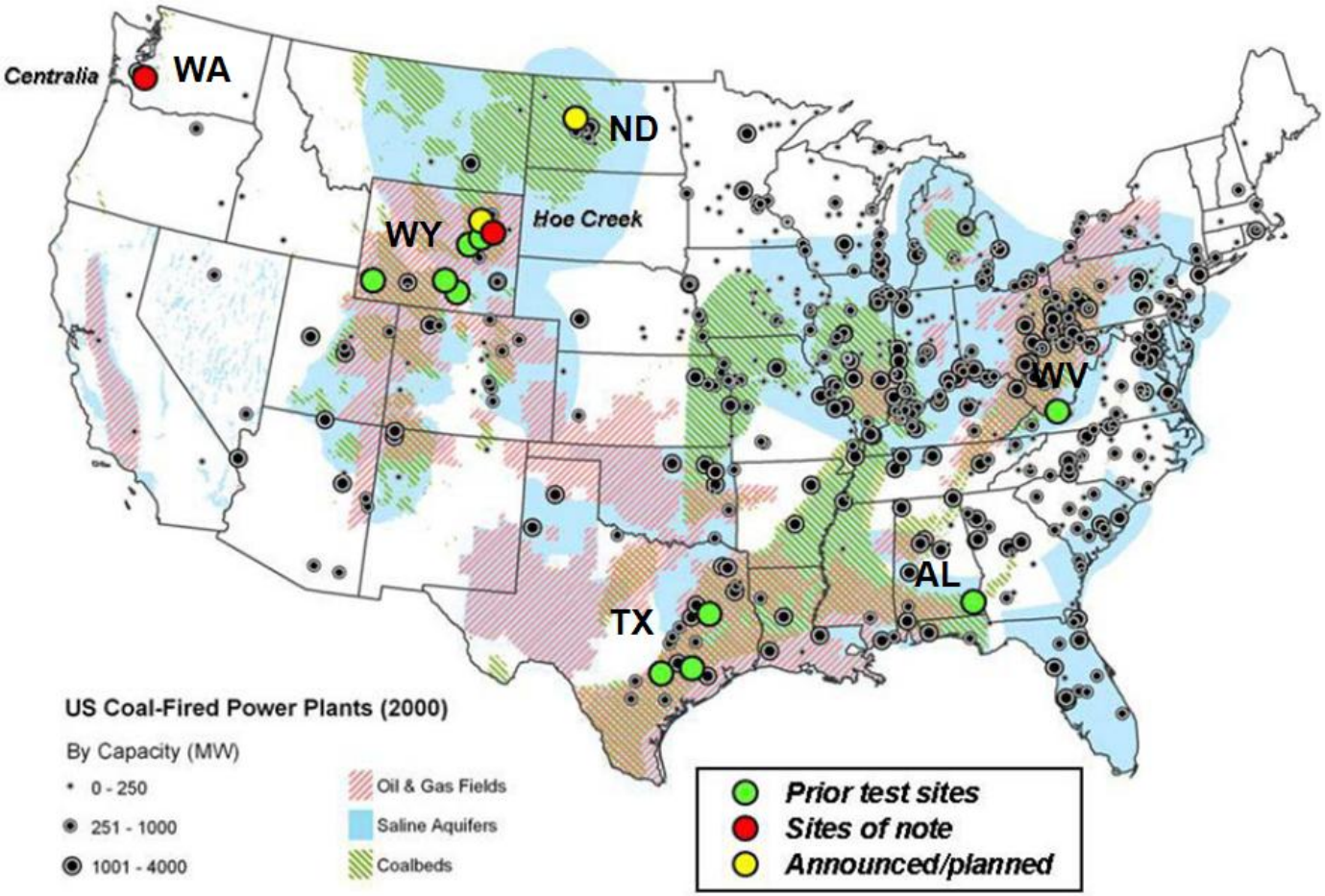
India
- ONGC Site selected, and technical designs underway
- Reliance, BHEL, NLC and others planning trials
- Coal of India review

Worldwide Activity
- UCG Partnership with training & annual Conference
- Technology suppliers worldwide, UCGEL, Ergo, Linc, In Situ Energy

South Africa
- Eskom trial produces first gas
- Sasol and others doing feasibility work

Australia
- Linc IPO financial offering raised to A$65M for UCG-GTL
- New Joint venture with CSIRO demonstration 08
- At least one other new initiative in S Australia

UCG Projects in the United States



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

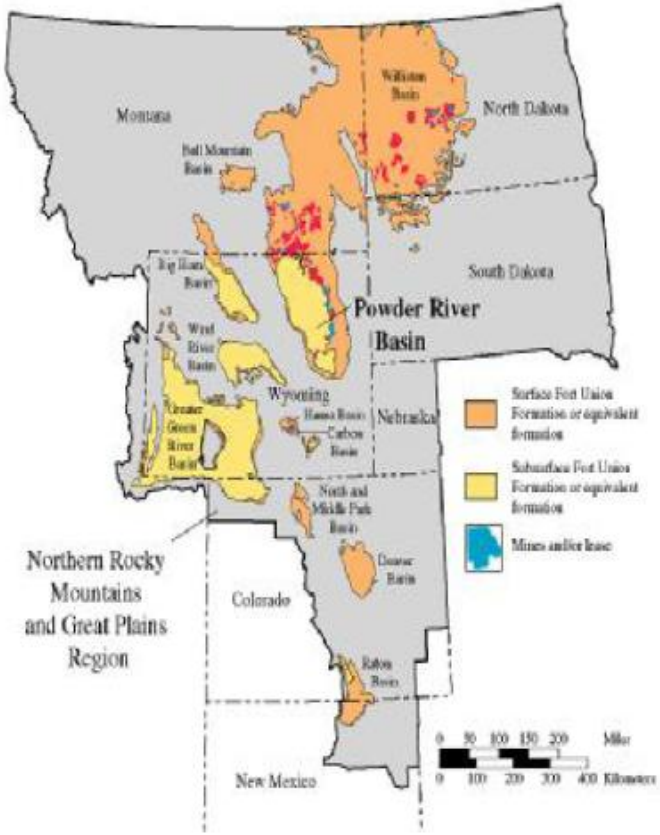
Gas Composition

Typical dry Gas Characteristics

Data from the EU trial at "El Tremedal", Spain, 1992-1998, run at depths of about 550m.	Data from the Hanna trial at Wyoming, US, Mid-70's, run at depths of 90-120m.
• CO: 14-18% • H_2: 27% • CH_4: 14-24% • CO_2: 31-44% • CV: 13 MJ/Nm^3 • Temperature: 200 ℃. • Pressure: 60-100 bar	• CO: 14.7% • H_2: 17.3% • CH_4: 3.3% • CO_2: 12.4% • N_2: 51% • CV: 5 MJ/Nm^3 • Temperature: 300 ℃

New Projects, 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*



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

Indiana UCG Research

THE POTENTIAL FOR UNDERGROUND COAL GASIFICATION IN INDIANA

Phase I Report
to the
Indiana Center for Coal Technology Research (CCTR)

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Recommendations with Site Selection Criteria