UNDERGROUND COAL GASIFICATION AND POWER GENERATION; HEALTH SAFETY AND ENVIRONMENTAL ASPECTS

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ABSTRACT

Underground Coal Gasification is the conversion of solid Coal to gas in-situ by heating the coal and injecting oxidants air/oxygen to cause the gasification by partial combustion instead of complete combustion of coal. UCG is the promising technology having a lot of health, safety and environmental advantages over the conventional mining techniques; the major motivational aspects of UCG involves increased worker health & safety by using no man underground, no surface disposal of ash and coal tailings, low dust and noise pollution, low water consumption, larger coal reserves exploitation, and low Volatile organic components, methane and greenhouse gases emission to atmosphere.

UCG is an inherently clean coal technology as it reduces deadly sulfur and nitrogen oxide emissions to very low levels. It is the only coal power generation technology that can virtually eliminate mercury air emissions and capture most of the coal mercury content in a concentrated form that can potentially be sequestered from environmental release. Total solid waste from UCG is typically half the volume generated by conventional coal plants and water use is substantially lower as well.

1. INTRODUCTION

Underground coal gasification (UCG), wherein coal is converted to gas in-situ, moves the process of coal gasification underground. Gas is produced and extracted through a pair or Grid wells drilled down into the coal seam, one well is used to inject air or oxygen to combust the coal in-situ known as injection well and second is used to extract the syngas to the surface for further processing known as production well. The process relies on the natural permeability of the coal seam to transmit gases to and from the combustion zone, or on enhanced permeability created through Reversed Combustion Linking (RCL) process, that provide an in-seam channel by high pressure air injection. Soon after the RCL completion the process of gasification starts. Gasification is done by the injection of low pressure high volume air. The syngas collected through production well then brought to purification plant. The syn gas can then be used in similar applications to natural gas, like producing electricity or as a chemical feedstock.

1.1. History of UCG

UCG was first conceived as early as 1868 by Sir William Siemens in Germany and independently by The Russian chemist Mendeleev in 1888. The UCG process technology was patented by the American Betts in 1909 and the first UCG field test program was carried out by Ramsey in England in1912. Lenin's interest in employing UCG to relieve the Russian workers from the drudgery and hazards of coal mining led to a major field test program in the Soviet Union in 1931. This effort led to the construction of three UCG commercial size UCG plants in Russia. Subsequent huge oil and natural gas discoveries in Russia and availability of cheap oil from Middle East curtailed UCG process development through the world until very recently. However, a few facilities continued to operate including one in Angren, Uzbekistan. The United States also experimented with the technology during the 1970s and 80s. Although interest in UCG waned at the end of the 1970s, there were still 30 pilot projects worldwide between 1975 and 1996 (Elizabeth et al, 2004). Increasing energy costs and energy demand have renewed global interest in the technology.

1.2. Advantages of UCG

The advantages of UCG relate to its recovery, chemical feedstock value, environmental impact, health and safety benefits, process efficiency and economic potential. It can be used to recover the energy content of low rank fossil fuels such as sub bituminous coals and lignite that are not economically or technically feasible to recover by conventional technologies because of their seam thickness, depth, high ash and excessive moisture content, large dip angle, or undesirable overburden properties. It also may offer the only feasible technology for recovering the extensive offshore coal deposits.

Large area of the land are not removed from use for any long periods of time in UCG recovery as they would be in deep shaft or strip mining. Reclamation of the land is not a serious problem since the surface disturbance is minimal. In particular, there is no solid waste disposal problem since all the ash remains underground. The UCG process also generates minimal atmospheric pollution, less surface disruption and sulfur appears in the coal as hydrogen sulfide rather than sulfur dioxide. It also uses less water than surface gasification processes which must maintain a high steam- air ratio to avoid slagging. These environmental benefits as well as the fact that mining is avoided imply that UCG offers corresponding health and safety advantages.

The UCG process has high thermal efficiency than surface gasification processes since it does not require high steam to air ratios and has substantially low heat losses due to insulating properties of overburden. Finally the capital investment costs for UCG are estimated to be 75 percent of those for surface gasification since it is not necessary to construct high pressure reaction vessels.

1.2.1. Low Carbon Emission Electricity

By applying UCG-CCS technology to suitable coal deposits, electricity can be produced at a similar cost to conventional coal power stations with half the greenhouse emissions.

Figure 1.1 shows the Australian cost and greenhouse gas emissions for a range of new clean coal technologies compared to conventional pulverized fuel (PF) coal fired power stations and natural gas fueled generators. The upper square plots show the performance for surface coal gasification plants with three options, one using the gas directly from the Gasifier, second removing CO2 from the gas before combusting it, and the third, most expensive 'zero' emission option, converting the gas to hydrogen and CO2 and removing the CO2 before combustion. The lower circle plots show the same three options for UCG gas. There is a 'sweet spot' with the second option which provides 50% reduction in CO2 emissions with no increase in cost over current coal fired power stations (Carbon Energy Limited, 2009).

1.3. UCG: The Environment Friendly Technology

The UCG process is the most environmentally friendly use of coal. Beyond the primary benefit of CO_2 capture and sequestration, UCG has several other environmental benefits over traditional coal extraction. By gasifying in-situ, there is no surface scarring or reclamation necessary; the UCG surface footprint is minimal and requires no surface dislocation. Meanwhile, the ash created in the process remains below ground alleviating disposal concern. Since the coal is not mined, the traditional mining equipment (trucks, scoops, etc.) and their associated emission are removed from the process. By not scarring our planet, creating waste ashes or involving heavy equipment, UCG is the cleanest of coal usage (Clean Coal Technologies, weblink).

Underground coal gasification has some environmental benefits relative to conventional mining including no discharge of tailings, reduced sulfur emissions and reduced discharge of ash, mercury and tar and the additional benefits of CCS (Shuqin et al, 2007). Atmospheric CO_2 is a major greenhouse gas concern in fossil fuel processes. Due to global climate change, CCS is an important technology that can be combined with UCG Carbon capture and sequestration is the process to remove the store greenhouse gases from resulting process streams to reduce buildup of these gases in the atmosphere (GasTech, Inc., 2007).

1.4. The uses of the UCG product gas

The main uses of the UCG product gas are:

1.4.1. Fuel gas used for electricity generation

The UCG operation is optimized to produce a high calorific value product gas for this purpose. The gas turbine (simple or combined cycle) and boiler plant (alone or as supplementary fuel) can be used for power generation (Beath, 2003).

1.4.2. Syngas for synthesis of chemicals or liquid fuels

The conditions in UCG operation may be manipulated to produce high hydrogen content in the product gas typically a H_2: CO ratio of 2:1 is optimal. The Syngas is used for the manufacture of crude oil equivalents (diesel, naphtha and wax) other liquid fuels (DME, methanol) ammonia and methane (Beath, 2003).

The gas obtained by UCG of low grade coal has mostly been used for power generation in the past. The gas product at angrensikaya (Walker et al, 2001) and chinchilla (Dufaux et al, 1990) are used for power generation. The chinchilla UCG-ISCC project is designed for maximum power generation. The byproduct along with power generation favors the economics of the project. The out of the fully developed chinchilla project will be as shown under (Dufaux et al, 1990).

UCG operation in Chinchilla is the longest in duration and the largest outside Russia the UCG technology was provided to Linc Energy by Ergo Inc. (Canada) and originated from the former USSR (Dufaux et al, 1990).

1.5. Economics of UCG for power generation

A 100 MW power plant with coal having a GCV of 3300 Kcal/kg was chosen for a case study. The coal seam thickness was assumed to be 2 m (NTPC, 2006). The following conclusions were reached based on cost estimations using available data the capital cost for IGCC is estimated as 850 corers and for UCG as 640 corers. This is attributed mainly to the additional cost of the specially design Gasifier and coal and ash handling in case of IGCC However the cost of generation (Rs. /kWh) is higher in case of UCG (Rs.3.6/kWh) this is mainly due to the higher fuel cost and lower gross efficiency associated with UCG. Finally it has been mentioned that COG in case of UCG will be comparable to that for IGCC if the seam thickness is greater than 2m and the calorific value of the coal is above 3300 kcal/kg (NTPC, 2006).

1.6. HSE Aspects of UCG Technology

1.6.1. CO2 Emission and Carbon Capture and Storage (CCS)

UCG with electricity generation will likely result in Green House Gases (GHG) emissions 25% lower than conventional coal electricity generation. UCG can also integrates CCS, where carbon dioxide(CO2) is captured and then transported via pipeline and either sequestered or used to enhance oil recovery, into its operation to achieve more significant GHG emissions reductions. Current CCS cost indicate that integrating CCS into UCG operations will be less costly in comparison with other electricity- generating technologies because capturing the CO2 stream is easier and does not require the same capital investments as other technologies.

1.6.2. Ground Subsidence

UCG creates cavities underground similar to other long wall underground mining activities. Eventually the rock and other material that are no longer supported by the coal that the UCG process has removed will fill the cavities. Subsidence is manageable and when managed properly, has resulted in minimal local impact. Subsidence is also not unique to this technology and is common for conventional underground mining.

1.6.3. Air Emissions

The combustion of Syngas, like the combustion of natural gas, will generate air emission with associated environmental and health concerns like acid rain. However, the emission of air contaminants such as sulfur dioxide, nitrogen oxides and particulate matter per unit electricity are expected to be significantly lower than a conventional coal power plant.

Nonetheless, air emission concerns will depend on the combined sources of emissions in the region and pollution control standard to which the facility is designed.

1.6.4. Ground Water

Ground water contamination is considered "the most significant (environmental) risk related to UCG (Price Water house Coopers, 2008)." The gasification process creates a number of compounds in the coal seam including phenols and polycyclic aromatic hydrocarbons, benzene, carbon dioxide, ammonia and sulphide (Price Water house Coopers, 2008). These compounds can migrate from the gasification zone and contaminate surrounding ground water. For example, studies in the Soviet Union in the 1960 revealed that UCG could result in widespread ground water contamination (Burton et al). Looking at the broader context, most UCG operations have not produced any significant environmental consequences (Liu et al, 2007). For example, European trials were completed with no environmental contamination detected during operation or within five years after operation (Burton et al). Similarly a UCG test site in Chinchilla, Australia did not result in ground water contamination (Liu Shu-qin et al).

1.7. Comparison of UCG with Conventional Coal Mining Techniques

The environmental concerns associated with UCG processing are no worse than those associated with winning coal by underground or surface mining followed by gasification in a surface Gasifier. In both cases, the wining of coal from underground will result in some subsidence and its accompanying problems. Indeed, in situ processing of coal can be a significant improvement over some aspects of surface processing. For example, the steps usually followed for surface extraction and recovery include:

(i) Mining of the coal,

(ii) Cleaning the coal in a coal preparation plant,

(iii) Transporting the coal to the point of use,

(iv) Storing the coal,

(v) Preparing the coal for use, and finally

(vi) Combusting, gasifying or liquefying the coal.

Each of these steps provide a variety of solid, liquid, and gas residues that must be treated prior to disposal. In addition, a significant amount of portable water is consumed, and this water has to be treated before it can be returned to the environment. UCG, on the other hand, offers the potential to combine several steps such as mining, cleaning, preparation and processing into a single operation which may well be acceptable environmentally and in addition, offers the potential of reduced costs relative to the total costs associated with surface processing.

1.7.1. Clean Cavern Concept

A possible additional environmental problem with UCG is the risk of contaminating the groundwater system. Early UCG tests, which resulted in contaminated groundwater in the un-reacted coal as well as in adjacent water bearing zones, were performed with high cavity pressures to inhibit excessive water influx into gasification reactor. Subsequent laboratory tests led to the conclusion that high cavity pressures have little effect on the quantity of water influx into the reactor during gasification operations. As a result of the laboratory studies and modeling of the generation of ground water contaminants, a procedure (clean cavern concept) was formulated to minimize groundwater contamination during and immediately following UCG operations. In this concept, the subsurface reactor pressure is maintained below hydrostatic to minimize the loss of organic laden gases and to ensure a small but continuous influx of ground water into gasification cavity. When the gasification operations are complete, steam is then injected into the cavity to promote the rapid cooling of the cavity walls and residues, and to   “strip “the soluble and volatile organics from cavity. The steam and contaminated gases are routed through an incinerator before being exhausted to the atmosphere. Operating in this fashion has confined the contaminants from UCG to the gasification cavity, and the contaminated cavity water can then be pumped to the surface for treatment before it spreads to surrounding ground water system.

2. PRACTICAL CONSIDERATION OF HSE ASPECTS IN UCG

2.1. Site Selection

Appropriate site selection is the most important mitigation measure and is essential to minimize potential groundwater contamination. Operators should ensure the site is well characterized and that the coal seam has limited connectivity with other water sources (S. Julio et al, 2009).

2.2. Operational practices

There are inherent aspects of UCG that help to reduce the contamination potential of UCG projects. During operation, a steam barrier or “steam jacket” is created that surrounds and contains the process and leakage (Liu Shu-qin et al). Operators should maintain the gasification chamber below hydrostatic pressure in the surrounding aquifer to ensure that all groundwater flow in the area is directed inward, towards the gasification chamber (Pana). UCG operators must also invest in groundwater monitoring around the facility to ensure contaminants are not migrating from the gasification chamber.

2.3. Abandonment practices

The appropriate shutdown process is a controlled shut down in which the gasification zone is allowed to cool slowly. During this time, the operator should continue extracting gas until the gasification process stops completely. In this way contaminants can be evacuated out of the gasification zone before the site is abandoned. Operators should also monitor groundwater for contaminants for a period of time after the site is abandoned. The actual duration of monitoring will depend of the specific site.

2.4. Subsidence

Subsidence is the sinking or lowering of a surface region relative to the surrounding region. It occurs as a result of the removal of material from the underground coal formation. In general, UCG subsidence results in height decrease equivalent to one- third of the vertical thickness of coal seam and would affect only land directly above the gasified coal seam. The magnitude and characteristics of subsidence depends on many factors including seam depth, rock stiffness and yield strength, disposition of seam, the stress resulting from gasification, and other geological properties (Liu Shu-qin et al). Subsidence typically results in a uniform lowering of a region as opposed to abrupt patholes (Burton et al).

In general, subsidence appears to be a site specific issue. With proper site selection and operational; management, it should be possible to avoid significant impacts to surface water, road and industry infrastructure and buildings by avoiding regions most sensitive to surface level changes.

2.4.1. Pollution-free UCG: The Triple Lock Mechanism

The Triple Lock Mechanism results in the formation of a Pressure arch that block the movement of particulates outside the pressure arch.

This Mechanism based upon three main steps as shown in fig 2.2:

a) **Hydrodynamic Trapping**

Hydrodynamic Trapping involves extremely slow groundwater movement at depths of hundreds of meters

b) **Pressure-Arch Trapping**

This steps involves same theory as above mention by younger and Adams that the UCG process induces development of a low-permeability zone beyond the immediate zone of stratal caving.

c) Geochemical Trapping

This step involves the irreversible sorption, mineralization and biotransformation limits transport of pollutants to <30 m (even if flow regime would permit this).

This step can be justified by using the general UCG site Selection Criteria (Mastalerz et al, 2011) as mention in this encircled in the fig-2.3. Which providing the guideline for site selection and mentioning minimum distance of up laid aquifer must be more than 31 meters above the UCG cavity Zone. That will eliminate the chances of Ground water contamination through geochemical trapping mechanism. So as a result of all above steps pollutants would be triply locked-in within the cavity of former UCG burn zone. So there will be no chance of Ground water contamination.

2.5. CO_2 Emissions and Carbon Capture& Sequestration

UCG combined with power generation is expected to be 25% less green house gas intensive on a per MWh basis then a super critical coal plant when both are operated without post- combustion carbon capture and storage (CCS) (UCG expert, 2010; BHP Billiton, 2002). However, real potential of UCG is that it produces syngas that is amenable to pre-combustion carbon capture (Literature Review). UCG offers a CO_2 stream that will have a capture cost estimated in range of$ 50 to$ 110 per ton of CO_2. More generally, most suitable for UCG are usually near potential sequestration sites. A study of North American previous, current or planned UCG pilots found that more than 75% of the projects were within 50 kilometres of potential saline aquifers, depleted oil and gas fields and EOR schemes (Calgary, 2009).

2.6. Operational control

The pressure in the underground gasification zone is primarily controlled by the rate of air/oxygen injection and the corresponding rate of extraction. A difference between these two rates allows the operator the ability to vary the pressure. The directional travel of UCG operation along a coal seam also be controlled. This is accomplished by strategically locating the injection and extraction wells. Once two wells are interconnected, the negative pressure created as gas leave the extraction well will draw the gasification reaction toward the exit well.

2.7. Air Quality

UCG will clean the Syngas at surface facilities near the UCG site to reduce air emissions. The cleaned gas then will be transported via pipeline to the power generation facility. With UCG, there are essentially two categories of non-GHG air emission: criteria air contaminants (e.g., mercury, arsenic, selenium) (Friedmann, et al; Shuqin et al, 2006).

UCG plans to use traditional gas cleaning technologies like acid gas removal for H2S and bag houses for PM removal to reduce air emissions to within regulated limits.

UCG offers some inherent air emission benefits to conventional coal. During UCG, a significant portion of volatile trace elements like mercury, arsenic and selenium as well as sulfur remain in the underground cavity. In coal combustion, these compounds must be recovered from the flu gas at relatively higher cost. Combustion of Syngas should also result in fewer NO_X emissions because the combustion occurs at lower temperature than coal combustion (Burton et al).

2.8. Land Use Impacts

While the pilot project will have a minimal number of wells drilled during operation, the commercial scale will occupy approximately two to three sections (one section= 2.6 km^2) of land over his life time and will include a few hundred wells spaced 30 to 100 m apart. The 300 MW commercial facility is anticipated to operate for 30 years. UCG operations progress along the coal seam exhausting one panel (300m across) before starting a new one.

At any given time the operation will actively disturb approximately one half-section, while the previous regions that no longer have active operations will be progressively reclaimed as needed.

3. RESULTS & DISCUSSION

3.1. HSE Aspects & Monitoring in UCG Thar Coal Project

3.1.1. Hydrology of Block-5 and groundwater Contamination Aspect

The water resources of the Thar Coal field can be divided in two categories

a) Shallow water aquifer; used for domestic use in Local communities

b) Deep water aquifer: Highly Brackish range

a) Shallow Water aquifer: used for domestic use in Local Communities

The communities residing in the Thar area rely on rainfall and groundwater aquifers to meet their water needs. So the evaporation rate is high, very little moisture is retained in the soil. There are no perennial surface flows and hence no system of natural drainage lines and streams is found in the Thar region. Rainwater either seeps through the soil or flows to the nearest *dhand* or playa where it accumulates and is used by the community while it lasts.

Water for domestic use acquired from wells tapping the rain-fed top or quaternary aquifer. The thickness of the top aquifer varies between 4m to 18 m and the aquifers are 30 m to 80 m below the ground level. The monsoon rain feeding the aquifer occurs from July to September. By February or March, the shallower parts of the aquifer get depleted and the well became saline.

b) Deep water aquifer: Highly Brackish range

According to Litho-log (fig-3.1) of well bore it is obvious that there are two aquifers present above the coal seams of Thar coal block–5 and one underneath the coal seams. The 1st aquifer lies at 180-192 ft (55-59 m) depth. 2nd aquifer ranges from (105-109 m) 344-358 ft. The third aquifer is laid below the extractable coal seams at an average depth of 195-250m (640-820 ft). The local communities use the dug wells for drinking water purposes that rely on 1st aquifer with depth range 180-192 ft (55-59 m), while the coal seam of UCG interest lies at depth of 520-590 ft (158.5-180 m). So the 1st aquifer used for portable water of local communities is situated at 328 ft

(100 m) above the area of expect UCG reactor. Therefore there is no chance of water contamination of potable water aquifer in the project area. Similarly 2nd aquifer is laid at 162 ft (49 m) elevation to the targeted coal seams. So it is also in the safe range of height.

In considering the water quality of 2nd and 3rd water aquifers of the project area with TDS range of 6000-10,000 ppm that is brackish water with respect to quality due to which both of the aquifers are exempted from drinking regulation of EPA.

Water samples from the dug wells of local communities as well as from observation of UCG Grid area were collected regularly and tested for the organic pollutants like Phenol, Benzene, Ethyl Benzene, Toluene, and Xylene. But due to controlled operational practices adopted during the test burn the risk of contamination was eliminate. As it is cleared according to the table–3.3 showing the results of these parameters within the water samples all the parameters stands within the safe limit of WHO for drinking water guidance.

3.2. Subsidence

The sinking or lowering of a surface region relative to surrounding region occurs in UCG as a result of the removal of material from underground coal formation. In case of test burn at UCG Thar coal project the subsidence was not observed the problem of subsidence was solved through the design of the UCG grid by managing well spacing of 25 meters of two adjacent wells. This well space was designed by keeping in view the geology of overburden. By using the well spacing as per design the risk of subsidence was eliminated in the UCG Thar Coal Project.

3.3. Purification of product gas

The UCG Syn Gas comes out of the production well at a flow rate of 20,000 Nm^3/hr at 2 bar (absolute) pressure and 300^oC temperature (max). The raw product gas may contain some quantity of dust (100-200 ppm by weight). Total hydrocarbon (≤20gm/Nm^3) Tar (≤1gm/ Nm/3), CH4 (1-2%), and contain 0.4 kg water content/ kg of gas at 2 bar (a) and 300°C). The particle size is expected to be in the range of 5-10 microns the composition of raw Syn gas is shown in table 3.4, these contaminants, sulfur and moisture if not removed may badly affect the generator operation resulting in frequent maintenance and loss of capacity especially at ambient temperature approaching the dew points of moisture and hydrocarbons the gas therefore needs to be cleaned desulfurized and dehydrated to a product gas at temperature less than 40°C, containing H_2S (≤50 mg/Nm^3), NH_3 (≤20 mg/Nm^3), tar contents (≤50mg/Nm^3), impurity grain size (≤5μm), impurity content (≤30 mg/Nm^3) and moisture content (≤100 mg/Nm^3) the purified Syn gas composition is shown in table-3.5

3.4. CO_2 Capturing & Sequestration

Carbon dioxide will be separated from Syn Gas using Gas purification plant and will be compressed and re injected into empty coal cavity of the test burn reactor. Main stream of the product gas contains CO2 that will be separated pre-combustion through the main stream using Gas purification plant. After the power generation the post-combustion CO2 will evolve that would be compressed and both types of CO_2 will be sequestered using the empty cavity of test burn that is the most useful feature of the empty cavity of the UCG reactor.

4. CONCLUSION

UCG technology has a great potential to grow and replace the conventional methods for coal mining and surface gasification due to its environment friendly nature. New commercial UCG projects for power generation as well as for chemical feed stocks have started recently in several countries, and more projects will probably start soon. UCG is gaining interest day by day due to its lowest capital cost lowest carbon footprints, lowest rate of human accidents, lowest land use & surface impacts, lowest disturbance of ecology of the project area. So this is the technology through which we can utilize the coal to change the face of energy scenario of Pakistan.

5. FUTURE RESEARCH PLAN

1. Carbon dioxide Capture and Sequestration
2. Gas to Liquid petroleum products synthesis
3. Syngas to Chemical feed stock synthesis

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6. REFERENCES

Beath A. Process studies for clean electricity and liquid fuels from UCG. In: International workshop on underground coal gasification, DTI conference centre, London, 1–2 October 2003.

BHP Billiton, Case Study B20: Electricity Production Using Underground Coal Gasification (UCG), (Newcastle, Australia, 2002).

Burton et al, Best Practices in Underground Coal Gasification.

Calgary, 2009. Alberta Carbon Capture And Storage Development Council, Accelerating Carbon Capture and Storage Implementation in Alberta.

Carbon Energy Limited "Underground Coal Gasification Syn Gas Production and Power Generation Bloodwood Creek Project" Initial Advice Statement - December 2009

Clean Coal Technologies link: www.lifepowerandfuels.com/clean-energy-technologies/underground-coal-gasifictaion.html

Dufaux A, Gaveau B, Lbtolle R, Mostade M, Noel M, Pirard JP. Modelling of UCG processes at Thulin on the basis of thermodynamic equilibria and isotopic measurements. Fuel 1990;69:624–33.

Elizabeth Burton, Julio Friedman and Ravi Upadhye, Best Practices in Underground Coal Gasification, 2004.

Friedmann, et al., "Prospects for Underground Coal Gasification in a Carbon-Constrained World."

GasTech, Inc. 2007. Viability of Underground Coal Gasification in the "Deep Coals" of the Powder River Basin, Wyoming. Prepared for the Wyoming Business Council. http://www.wyomingbusiness.org/program/ucg-viability-analysis-powder-river-/1169 accessed September 19, 2011.

Literature review: Coal without CCS based on a literature survey of 15 academic papers on life cycle greenhouse gas emissions from electricity generation sources. i.e primary emissions for UCG will be the combustion of the syngas therefore comparing against life cycle emissions of other power technologies is representative.

Liu Shu-qin et al., "Groundwater Pollution from Underground Coal Gasification."

Liu Shu-qin, Li Jing-gang, Mei Mei and Dong Dong-lin, "Groundwater Pollution from Underground Coal Gasification," Journal of China University of Mining & Technology 17, 4(2007).

Mastalerz et al. "Underground Coal Gasification Characteristics" 2011.

NTPC. Economics of power generation with UCG. UGC Workshop at Kolkatta, India, November 2006.

Pana, Review of Underground Coal Gasification with Reference to Alberta's Potential.

Price Water house Coopers, Linc Energy Limited Underground Coal Gasification: Industry Review and an Assessment of the Potential of UCG and UCG Value Added Products, (2008).

Price Waterhouse Coopers, Linc Energy Limited Underground Coal Gasification.

S. Julio Friedmann, Ravi Upadhye and Fung- Ming Konga, “Prospects for Underground Coal Gasification in a Carbon-Constrained World,” Energy Procedia 1 (2009):4551-4557.

Shuqin Liu, Li Jing-gang, Mei Mei and Dong Dong-lin, 2007. Groundwater Pollution from Underground Coal Gasification. Journal of China University of Mining & Technology Vol 17 Issue 4 pgs 467-472.

Shuqin Liu, Yongtao Wang, Li Yu and John Oakey, “Volatilization of Mercury, Arsenic and Selenium During Underground Coal Gasification,” Fuel 85 (2006):1550-1558.

UCG expert, personal correspondence, 2010.tes

Walker LK, Blinderman MS, Brun K. An IGCC Project at Chinchilla, Australia based on underground coal gasificationIn: 2001 gasification technologies conference, San Francisco, 2001. p. 8–10.

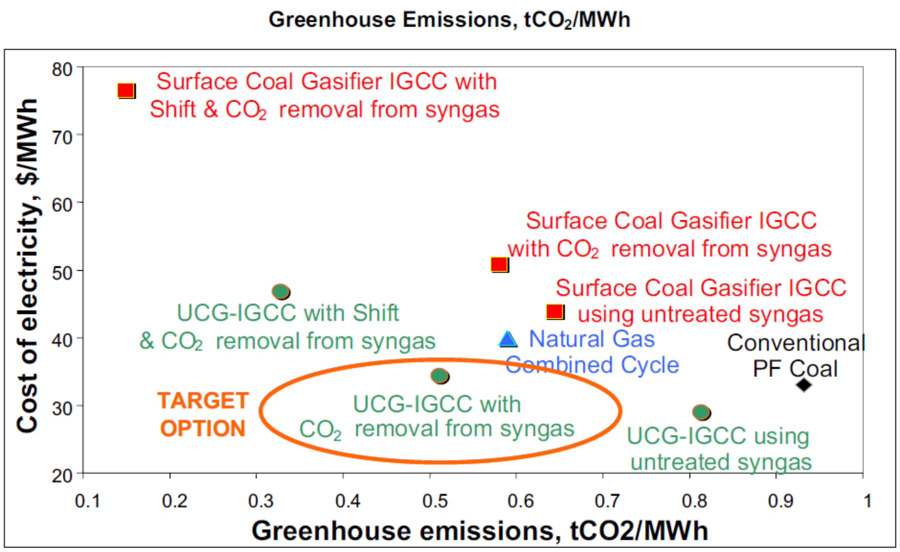
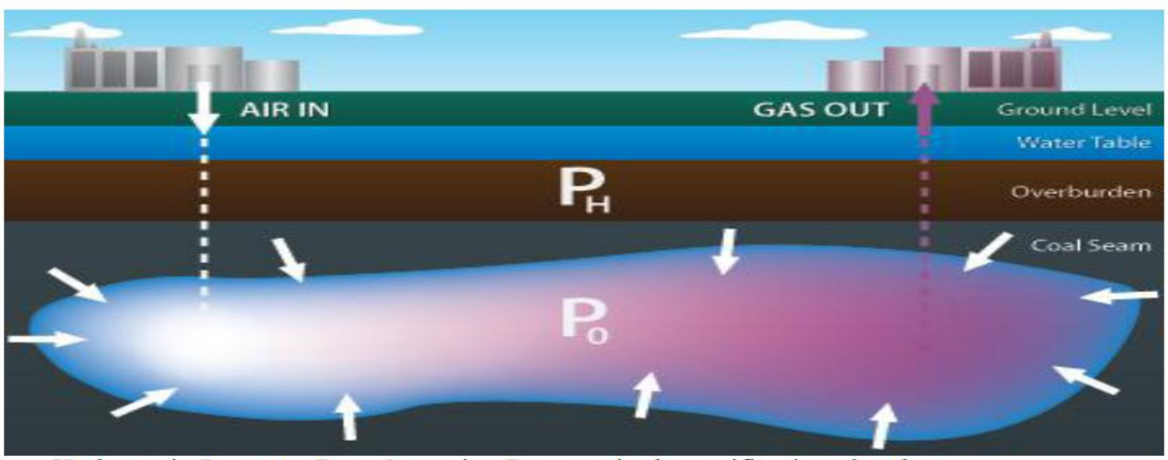


Fig 1.1. Greenhouse Emission



P_H = Hydrostatic Pressure; P_O = Operating Pressure in the gasification chamber.

Fig 2.1. Showing hydrostatic pressure v/s operating gas chamber pressure

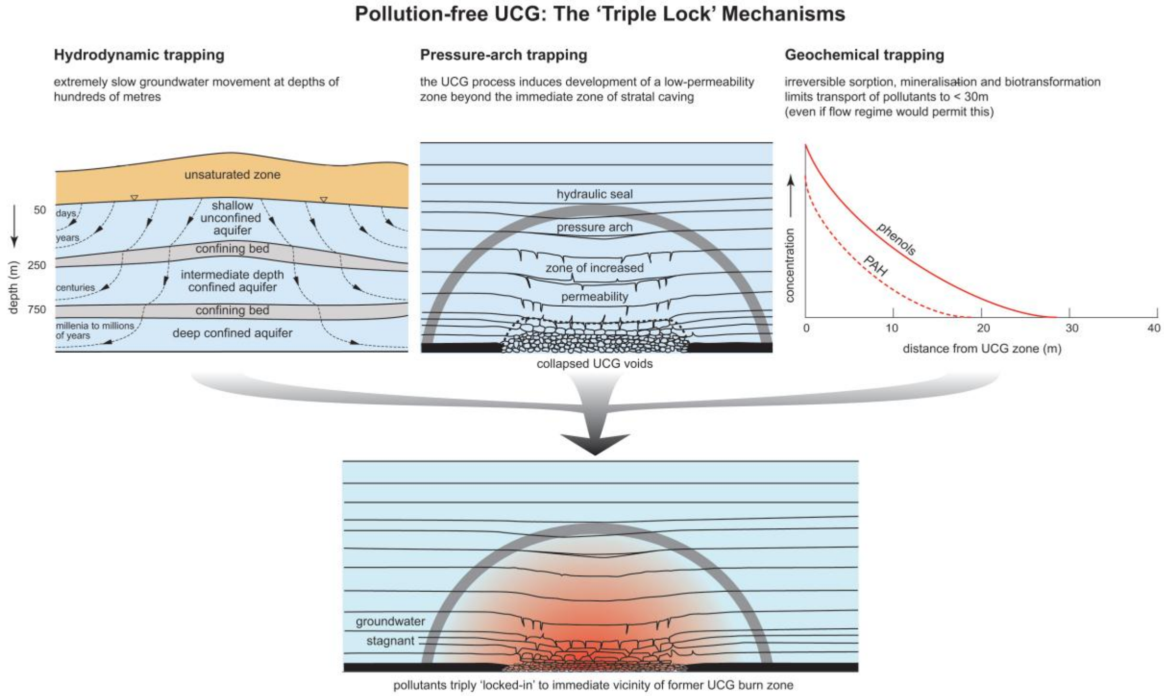
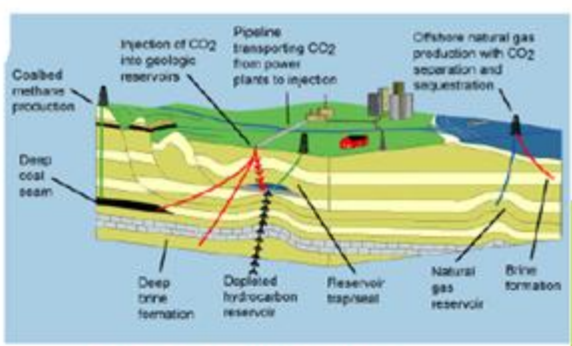
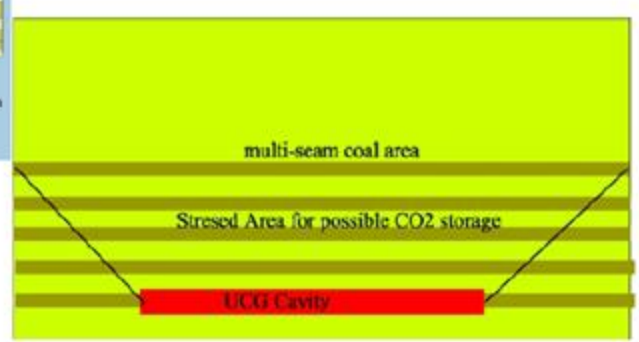


Fig 2.2. Triple Lock Mechanism



Multiple Storage Options



Storage in Abandoned Cavities

Fig 2.4. CO_2 Emission and Capturing

Collar Elevation=197.95m

Aquifer Depth(m) From Drill Collar		
Top	Bottom	Thickness
(1st) 54.51	57.51	3
(2nd) 104.51	108.51	4

Coal Intercepts(m) From Drill Collar		
Top	Bottom	Thickness
124.89	126.71	1.82
128.24	129.15	0.91
130.07	134.95	4.88
136.59	136.78	0.19
142.89	144.78	1.89
153.61	153.92	0.31
158.34	162.02	3.68
163.19	165.09	1.9
172.58	174	1.42

LEGEND	
	Recent
	Sub recent
	Bara
	Coal
	Aquifer

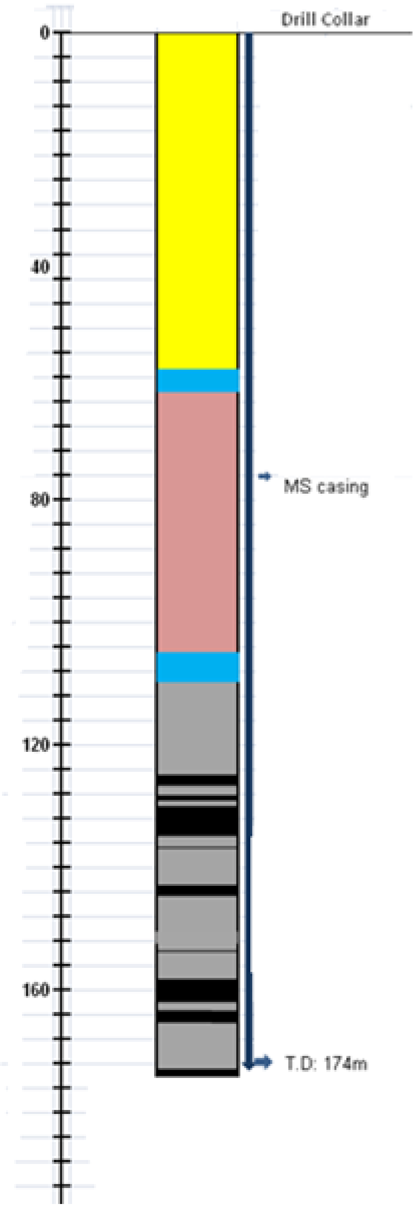


Fig 3.1. Litholog of Well Bore

Parameter	Desired Value	Imperial Units and Comments
Coal thickness (m)	2 - 15	5-50 ft
Thickness variation (% of seam thickness)	<25	
Depth (m)	92 - 460	300-1,500 ft
Dip (degrees)	0 - 70	
Dip variation (degrees/31 m, 100 ft)	<2	
Single parting thickness (m)	<1	<3 ft
Total parting thickness (% of seam thickness)	<20	
Fault displacement (% of seam thickness)	<25	
Fault density (Number of faults/31 m)	<1	Number of faults/100 ft
Coal rank	Low rank bituminous	≤ Bituminous
Coal moisture (wt %)	< 15	
Ash content (wt %)	< 50	
Coal sulfur (wt %)	< 1	
Thickness of consolidated overburden	>15	50 ft
Seam permeability (mD)	50-150	
Immediate overburden permeability (mD)	<5	15 m (50 ft) above the seam
Distance to nearest overlying water-bearing unit (m)	>31	>100 ft
Coal aquifer characteristics	Confined	
Nearest producing well completed in coal seam (km)	>1.6	≥1 mile
Available Coal Resources ($10^6 m^3$)	15.4	~$543x10^9$ cubic ft for 20 year-long operation

Source: Mastalerz et al., 2011

Fig 2.3. UCG Site Selection Criteria [21]

Table 1.1. The output of the fully developed chinchilla project

Product	Output	Energy
Electricity		67 MW
Gas	800 million Nm_3/annum	4.4 PJ/annum
Hydrocarbons	15000 tons/annum	0.6 PJ/annum
Phenols	3700 tons/annum	-
Anhydrous NH_3	1500 tons/annum	-
Clean water	200Megaliters/annum	-

Table 3.1. Water Quality of Shallow aquifer

Parameters	Unit	WHO	Results
pH	-	6.5-8.5	7.78
EC	ms/cm	-	8060
Sodium	mg/l	-	125
Magnesium	mg/l	-	140
Calcium	mg/l	-	230
Chloride	mg/l	250	191
Bicarbonate	mg/l	-	185
Silica Dioxide	mg/l	-	0.10
Total Hardness	mg/l	-	370
TDS	mg/l	1,000	4030
Turbidity	NTU	< 5	0.77

Table 3.2. Water Quality of Deep aquifers

Parameters	Unit	WHO	Results
pH	-	6.5-8.5	7.14
EC	MS/cm	-	10,170
Sodium	mg/l	-	177
Magnesium	mg/l	-	410
Calcium	mg/l		440
Chloride	mg/l	250	450
Bicarbonate	mg/l	-	815
Silica Dioxide	mg/l	-	4.8
Total Hardness	mg/l	-	580
TDS	mg/l	1,000	5080
Turbidity	NTU	< 5	37.2

Table 3.3. Results of Organic pollutants in Ground water samples

Parameter	**Results (ppm)**								
	W.H.O safe Limits	**MIJ-1**	**MIJ-2**	**MIJ-3**	**MIJ-4**	**MIJ-5**	**MIJ-6**	**MIJ-7**	**MIJ-8**
Benzene	**0.01**	**ND**	**ND**	**0.01**	**ND**	**0.01**	**ND**	**ND**	**ND**
Toluene	**0.7**	**ND**	**ND**	**0.02**	**ND**	**0.013**	**0.02**	**ND**	**ND**
Ethyl Benzene	**0.3**	**ND**	**ND**	**ND**	**ND**	**0.01**	**ND**	**ND**	**ND**
Xylene	**0.5**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**	**ND**

Table 3.4. the raw Syngas composition as follow at 2 bar and 300°C

Syn gas Components	Composition
H_2	(15-20%)
CO	(10-15%)
CO_2	(20-25%)
N_2	(40-60%)
H_2S	(1%)
H_2O	(0.4 kg of water/kg of Syngas)
Total Hydrocarbon	(<20 mg/Nm³)
Tar	(<1 mg/Nm³)
CH_4	(1-2%)

Table 3.5. Product gas specification after purification:

Syn Gas Components	Composition
Particulate content	≤50 mg/Nm³
Moisture content	≤50 mg/Nm³
Tar Content	≤50 mg/Nm³
H_2S	≤50 mg/Nm³
NH_3	≤20 mg/Nm³
Impurity Grain size	≤ 5μm
Impurity contents	≤30 mg/Nm³
Product gas temperature	<40°C
H_2	(15-20%)
CO	(10-15%)
CO_2	(20-25%)
CH_4	(1-2%)