ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 3, September 2012

# Underground Coal Gasification Techniques, Problems and its Solutions

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***Abstract-Underground coal gasification (UCG) is an industrial process, which converts coal into product gas. UCG is an in-situ gasification process carried out in non-mined coal seams using injection of oxidants, and bringing the product gas to surface through production wells drilled from the surface. The product gas could to be used as a chemical feedstock or as fuel for power generation. The technique can be applied to resources that are otherwise unprofitable or technically complicated to extract by traditional mining methods, and it also offers an alternative to conventional coal mining methods for some resources. The development work on UCG undertaken in the West over the past 20 years has focussed on technology improvements undertaken within an R&D framework. This, together with difficulties related to any underground process, may explain why industry has been reticent to embrace the technology for commercialisation. The Linc Energy/CS Energy Joint Venture has elected to return to the source of production experience, involving simple, proven techniques, in an effort to bridge this gap in understanding. If the current commercialisation program is successful, it will open up a huge energy resource for utilisation by industry, providing coal as a fuel which is still as competitive in price as it is now, but in a form which provides significant environmental advantages. The opportunities for gas utilisation in downstream industries are large, as is the potential for generation of export income. UCG may well be an old technology, but it's time for acceptance has arrived. This paper describes the coal gasification techniques, the problems and its solutions related to this. This also describes the future techniques can be applied for UGC.***

***Index terms* - Commercialization Programs, Product Gas, UGC.**

## I. INTRODUCTION

Underground Coal Gasification is the gasification of coal in-situ, which is achieved by drilling boreholes into the coal and injecting water/air or water/oxygen mixtures. It is both an extraction process (like coal mining) and a conversion process (gasification) in one step, producing a high quality, affordable synthetic gas ( Syngas) that can be processed to provide fuels for power generation, diesel fuels, jet fuels, hydrogen, fertilizers and chemical feedstock. Once processed, Syngas can be used for heating, power generation, hydrogen production, or the manufacturer of key liquid fuels such as diesel fuel or methanol. The technique offers many financial and social benefits over traditional extraction methods, most notably lower emissions, as no coal is brought to the surface and the gas can be processed to remove its Co2 content Interest in UCG as a secure and economic source of energy has increased over the past five years, most coal producing countries now have a comprehensive UCG program comprising of feasibility studies, planning demonstrations and commercial scale projects. In-seam and Directional Drilling technology, formulated for the oil and gas industry, has transformed the UCG process, making it easier, consistent and commercially viable, Commercial scale projects have started in Australia, China, South Africa and others such as India, Canada and the UK are not far behind Large-scale operations (>1GW) were developed by the Soviets in the 1970's and at least one plant in Uzbekistan still operates today. Low natural gas prices in the 1990's eliminated much of the ongoing development in US, although in Europe, a substantial program of development in deeper seams was maintained until the present day. Extensive trials in Europe, the US, Russia, Australia, have proven the technology on many occasions. UCG in combination with CCS (Co2 capture and storage) shows considerable promise as a low cost solution to carbon abatement) The composition of the syngas is particularly suited to Co2 capture and the high pressure from deep UCG will require smaller and less costly plant. The possibility of storing Co2 in nearby coal seams is a further option which is currently being researched, so far the results look very promising. UCGA is proud to be a member of the Global Roundtable on Climate Change (GROCC) and a Foundation Member of the Global Carbon Capture and Storage Institute (GCCSI).

## II. TECHNOLOGY BASED

The latest standard of the technology incorporates horizontal directional drilling. To obtain the gas two wells are drilled - an injection well which brings steam and oxygen or air underground to ignite the coal seam and maintain the process, and a production well which pumps out the raw syngas. Previously vertical wells were used which are difficult to connect and limit control over the formation of the underground cavity as they cannot be steered. Today's horizontal wells can be connected using a magnetic target and detector positioned in the tip of the wells. The injection well is retracted along the borehole to gasify the coal which flows to the production well. The process is monitored above ground based on measurements of pressure, temperature, gas flow rates, gas composition at the wells. These are informed by simulations carried out to model the process. The control of the process comes from the injection of the oxidant, as too low or a halting of flows will stop the process.

The produced syngas varies in composition depending on the coal quality and for a standard horizontal two well retractable injection point technique (CRIP) includes hydrogen (11-35%), carbon monoxide (2-16%), methane (1-8%), carbon dioxide (12-28%) and other smaller components. Specific alteration of the gasification system can also result in a variance of the syngas composition. Yang et al. (2008) published about a field test to manufacture hydrogen using a two-stage gasification process with multiple steam injection points to raise the temperature. In the test syngas was successfully produced with on average 50%+ hydrogen content with a range between 40% to 73%, and both CO and CH4 contents of over 6%.The process itself

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International Journal of Engineering and Innovative Technology (IJEIT)
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takes place in a coal seam normally saturated with water at hydrostatic pressure. There, several processes take place including evaporation, pyrolysis, steam gasification, CO2 gasification, and direct hydrogenation. To prevent the "reactor" from collapsing the process needs to take place in modules at a specified length, width, and depth, shown in figure 3. Thereby sufficient structural support is created both via the rock between the modules and by the under burden and overburden, similar to a large extent as the pillars created in room-and-pillar wall mining. Since the reactor is dynamic and its physical conditions depend on the type of coal and surrounding rocks these determine the possible size of a "module".

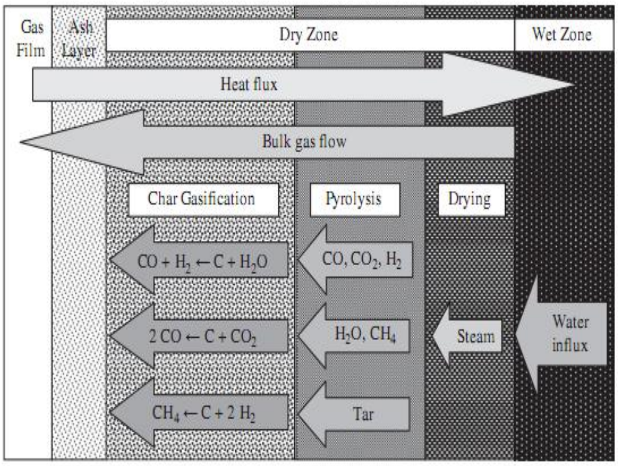


**Fig:1(Zones and By-Products Of Coal Gasification)**

## III. NEED OF GASIFICATION TECHNOLOGY

Coal production has been increasing over the past 10 years, despite calls for lower emissions and continued research into the development of alternative energy sources. The International Energy Association (IEA) predicts an increase in coal usage of 55% to 2030 as emerging nations develop industrial infrastructure and the world moves from reliance on depleting supplies of oil and gas. Coal will increasingly be used - but UCG offers, a cleaner, cheaper and safer method. However, nearly 85% of known coal reserves are deemed un-mineable with surface mining techniques, being too deep, too remote, and too uneconomical or of poor quality. The majority of countries with large coal reserves have few alternative indigenous energy sources, many of the poorest nations have low rank coals that emit noxious chemicals and low energy when conventionally mined. It is in these regions that UCG has much to offer. So many are now turning to UCG to fully utilize this valuable resource, which many experts believe could treble the availability of coal suitable for UCG globally,

UCG technology has less detrimental environmental impact, as all coal stays underground there are less emissions, less surface footprint as no surface gasifier is required and the gas is processed to remove harmful particulates, including CO2 capture.

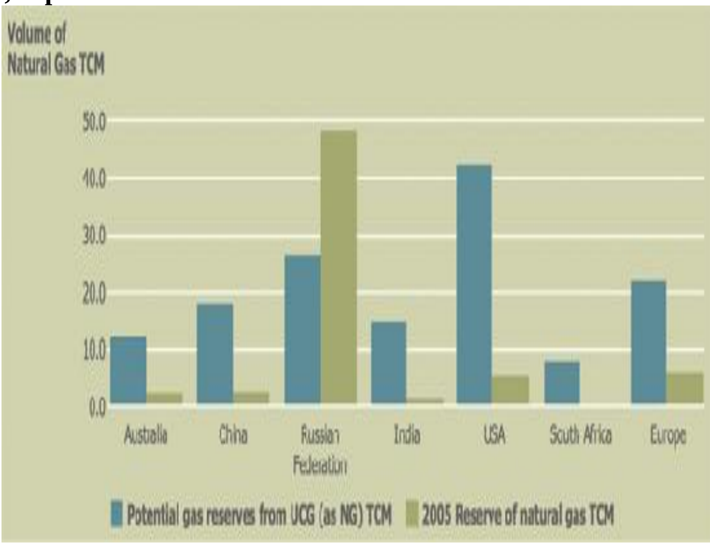


**Fig: 2(Chart Depicting Increased Quantities Of UCG Syngas Available - Compared To Natural Gas.)**

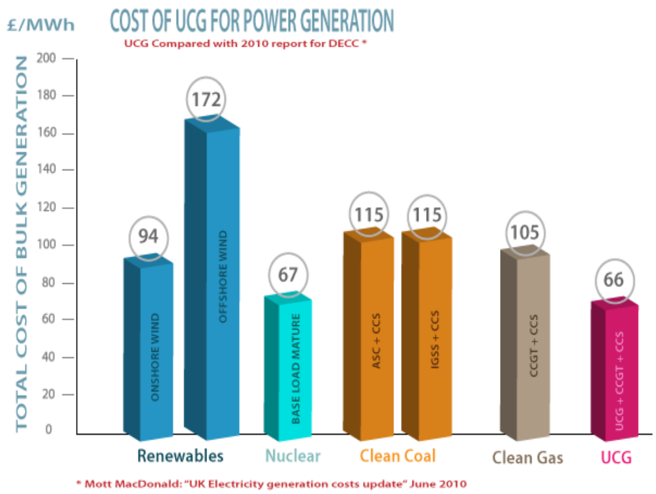


**Fig: 3 Graph Representations**

### A. *Worldwide UCG Projects and Developments:*

Renewed interest in UCG technology has recently occurred in most coal producing regions of the world, led largely by Australia where entrepreneurial companies are harnessing the potential for power generation and gas to liquids manufacturer. In India, high ash content of 35% to 50% has major technological limitations for coal development; UCG is especially suitable for low-rank coals like lignite's and sub-bituminous coal, which produce less heat and more Co2 when burned. In addition, the UCG process is an effective generator of large quantities of hydrogen, now in demand as a feedstock for the chemical industry and as an alternative fuel for vehicles. China is believed to have conducted more trials than any other country, at least 17 since 1991. India, meanwhile, plant use UCG for power generation and chemical feedstock, whilst South America plans to use UCG to produce fertilizers.

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ISO 9001:2008 Certified
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Australia has a number of trials in progress and as the map shows others are in various stages of planning in China, South Africa, India, UK, USA, Canada, Turkey, Vietnam, Hungary and Poland. In Britain, officials hope the process will provide access to vast coal reserves under the North Sea.

**APPLICATIONS:**

- Produce Heat
- Generate Power
- Hydrogen
- Methanol
- Synthesis of Chemical Products
- Synthetic Natural Gas

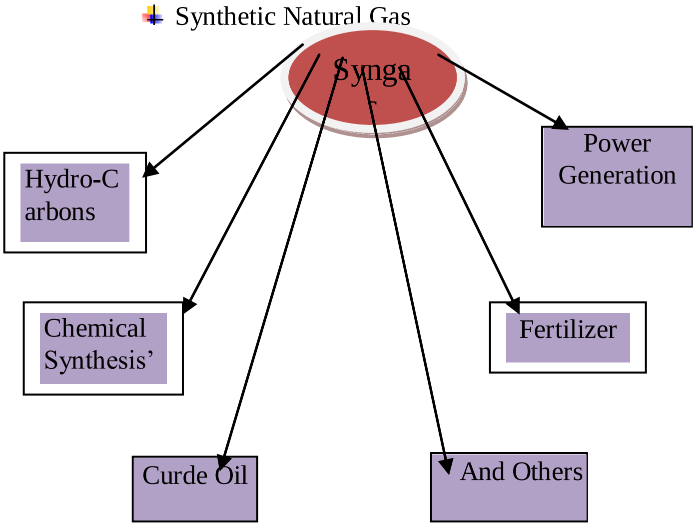


Fig.4: Systematic Diagram

**COMPONENT OF LAB SCALE MODEL:**

- Feed Gas Preheating System.
- Gasification Reactor.
- Gas Clean-up and Sampling System.

**COAL USED:**

| | |
|---|---|
| Percentage of Ash | 19.00 |
| Percentage of Moisture | 04.02 |
| Percentage of volatile matter | 27.06 |
| Percentage of Fixed Carbon | 49.92 |

Syngas is primarily made up of CO, $H_2$ and $CH_4$.

1. Partial Combustion $C + O_2 = 2CO$ exothermic
2. Combustion $C + O_2 = CO_2$ exothermic
3. $C + CO_2 = 2CO$ endothermic
4. Water-Gas $C + H_2O = CO + H_2$ endothermic
5. Hydro gasification $C + 2H_2 = CH_4$ exothermic
6. Shift $CO + H_2O = CO_2 + H_2$ exothermic
7. Reformation $CO + 3H_2 = CH_4 + H_2O$ exothermic

**Findings of Lab scale model**

With the oxidation zone at the thermocouple point I, indicated by maximum rise in temperature, the highest content of $CO_2$ in product gas was indicated. A significant decrease in the residual content of oxygen was shown at the same time.

- As the oxidation zone reached second thermocouple point lowest residual content of oxygen was obtained with the least amount of $CO_2$ content for a run.
- Also, steep increase in $CO_2$ and $H_2$ content in the product gas was obtained. Thereafter, $CO_2$ content in the product increased, rather moderately.
- It was found that addition of steam to the injection blast, generally, lowers the temperature of the reaction zones and thus improves the gasification efficiency.
- Large proportion of steam, however, slows the gasification due to further lowering of temperature in reaction zones.

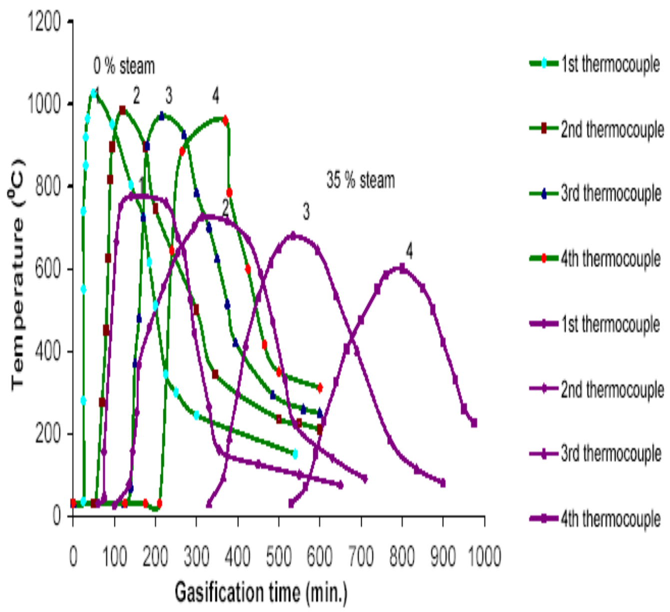


**Fig: 5 Graphs**

**ENVIRONMENTAL MERITS OF UCG**

***Merits:***

- No mining; no surface ash management
- Smaller footprint for surface facilities
- Fewer particulates, NOx, SOx
- Good coincidence between sites for carbon storage and UCG.
- Migration of VOCs in vapour phase into potable groundwater.
- Organic compounds derived from coal and solubilised metals from minerals contaminating coal seam groundwater Upward migration of contaminated groundwater to potable aquifers due to:

- Thermally-driven flow away from burn chamber.

ISSN: 2277-3754
ISO 9001:2008 Certified
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- Buoyancy effects from fluid density gradients resulting from changes in dissolved solids and temperature.
- Changes in permeability of reservoir rock due to UCG.

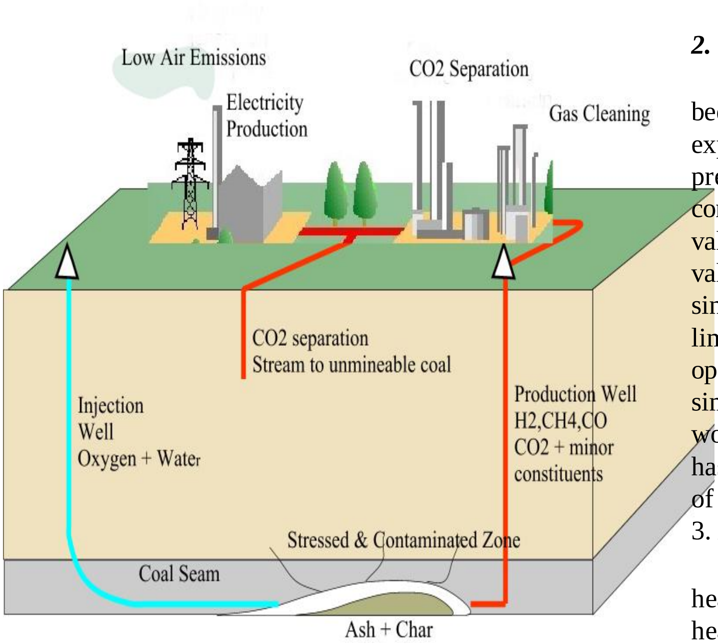


**Fig: 6 Diagram**

**PROBLEM SOLVED:**

***1. Decreasing Heating Value:***

In many field tests the gas produced started initially with a reasonable heating value which then declined gradually to unacceptable values. Two mechanisms are known which can cause this behaviour**:**

- Use of boreholes. One method of coal gasification involves the drilling of boreholes to connect the injection and the production well. The coal is ignited then and gasified along the length f the borehole. In t his process the coal burns radically outward, and the borehole increases in size. As the borehole grows in size, more gas by-passes the coal; and the gas heating value deteriorates correspondingly.

- Higher water influx for larger burned areas. Since many coal beds in the Vest are aquifers, water influx tends to increase as more and more surface is exposed by the combustion front. In addition, for larger burned out areas subsidence occurs establishing communication with overlying aquifers within the subsidence zone. With an exception discussed later in this paper, a drastic decline in gas heating value has not occurred during the field tests. The major reason is that the linked vertical well process used is not a borehole method but a permeation method, that is, it is essentially a packed bed process. Packed beds are widely used in the chemical process industries. A principle, well known among process chemists and engineers, is that for satisfactory results channelling must be avoided in packed bed equipment such as chemical reactors, liquid-liquid extraction columns, and distillation towers. None *of* the field tests have yielded any definite evidence that open channels have been created**.**

***2. Variability in Gas Quality and Gas Production Rates:***

A wide variability in gas quality and production rates has been observed on an hourly or daily basis in many field experiments. The need for a constant gas flow rate, however, presents no real problem. It is readily achieved with a constant air injection rate and with the use of a flow control valve on the production line. At variations in gas heating values on the order of 5 to 10 percent have been observed at a single well on a daily basis. This falls within the acceptable limits for the firing of large boilers. For a commercial operation, however, many production wells would be in use simultaneously and the variability in the gas composition would tend to average out. It i s also noted that gas variability has been more extreme in the borehole or streaming methods of UCG.

3. ***Low Thermal (Cold Gas) Efficiency:***

In this work thermal efficiency is defined as the upper heating value of dry gas and liquids produced divided by the heating value of the coal consumed. Consistent with this definition, sensible heat is not included nor is the latent heat of any water vapour in the gas. The instrumentation used during the field tests permits a accurate determination of the thermal efficiency. These efficiencies are the highest ever recorded. The Phase test achieved an efficiency of **89** percent for the entire 25 days of the test during which 2300 tonnes (2500 tons) of coal were consumed. Such high efficiencies are readily achieved under good operating conditions. There are many feet of earth overlying and l of is the coal seam, provide excellent insulation. In thick coal seams, therefore, the LiCG process operates nearly a diabolically. Most of the thermal energy Released from the combustion o f coal char and air must be produced a t the surface i n the form of sensible and latent heat and in the heating value of the gas produced, i.e., chemical heat. The sensible heat i s less convenient form o f energy because it can be transported only over very short distances.

In the borehole or streaming method o f **UCG** a substantial portion of the total energy released appears a t the surface in the form of sensible the hot combustion gases by-pass the coal and a considerable portion o f heat. In permeation processes only a small portion o f the energy goes into sensible heat. The combustion gases intimately contact the coal, and most o f the sensible heat i s used up f o r the highly endothermic steam-char reaction which produces a combustible gas. A number of conditions can lead to lower thermal efficiencies s as well as lower gas heating values.

- Thin coal seams. A larger portion o f the energy is lost to the surrounding rock format ions.

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- Very high ash coal (over 50 percent). A substantial portion of the thermal energy is taken up by the ash.
- Low air injection rates. Gas residence time underground i s longer, and a larger portion o f the energy is los t to the surroundings. Very low air flow rates also result in lower reaction zone temperatures.
- Gas channelling. This results in poor contact between gases and coal.
- Too high water in flux. Vaporization o f the water uses up much of the available thermal energy.
- Gas leakage.

***4. Site Specificity:***

The very favourable results obtained from UCG field tests, have not been duplicated anywhere else in the world. It might be concluded that success is specification the site. This is not the case, however. Most o f the parameters essential to successful UCG have been identified and of massive amounts of data acquired during four years of field testing. a number of favourable factors have contributed greatly to successful tests, several of these factors have been discussed already ( refer to item **1.** Low Gas Quality).These factors, however, are by no means unique to the coal field but occur in many if not most areas of the West.

***Problems Not Solved:***

Critical problems. These are problems which, if not resolved favourably, will have a major harmful impact on the commercialization of UCG. Only two problems of this type are known, subsidence and excessive water influx. Non - critical problems. These are problems which can have a major economic impact, but which will not prevent commercialization even if no favourable solution is found. Uncertainty concerning maximum well spacing is such a problem, Developmental problems. These are problems which require application of off-the-shelf technology, or are problems which may require new technology but will not have a major economic impact on the process. Gas clean.-up is such a problem.

***1. Subsidence:***

Subsidence is probably the most important single obstacle t o commercialization of UCG. Because of fiscally mutation, the tests have been limited to two and four well patterns with 60 foot spacing. With t h is spacing no subsidence has been observed a t the surface, although subsurface caving o f the roof has occurred directly over areas of burned out coal. When larger UCG patterns are used, subsidence of the surface will occur inevitably. At many locations in the western states this is not an insurmountable problem. Even with extensive subsidence, the surface is less disturbed than it would be by strip mining.

There are, however, three major problems associated with subsidence:

- Disruption of overlying aquifers. A very sensitive political issue in arid regions.
- Eatable basement of communication with overlying aquifers through subsidence and consequent flooding of the combustion zone.
- Gas leakage to aquifers and possibly to the surface.

***2. Maximum Well Spacing and Depth:***

Factors affecting maximum we11 spacing and depth are largely conjectural and have not been investigated in field tests. Maximum depth at which the process is workable is an important indicator of the amount of coal that may be suitable for UCG. Maximum well spacing is important because the drilling and completion of wells is a major cost item in the operation of a UCG project. Neither is a critical problem, however. There are vast deposits o f coal available at depths already tested successfully with UCG. Economic studies indicate that UCG even with the close spacing used may be competitive already with some intrastate natural gas prices etc.

**TECHNICAL RISKS IN UCG COMMERCIALIZATION**

Figure: illustrates the phases in development of UCG projects, with the gas being utilised either for power generation or for synthetic fuel production. The process for producing the gas has been established on a commercial scale at the Angren site in Uzbekistan. Procedures for cleaning the gas for later use have been developed in the US by several companies, such that the product gas can be utilised in currently available gas turbines, or in Fischer- Tropsch plant for diesel fuel production. These end uses for coal gas have been utilised for many years using similar gas produced from surface gasification plants. Given the above discussion, the main risk associated with development of a UCG project in Australia would appear to be economic viability, an issue which is the subject of some debate when data from more recent US work is set against conclusions drawn from studies of the Soviet experience. Resolution of this issue has been a central part in the current assessment of UCG potential.

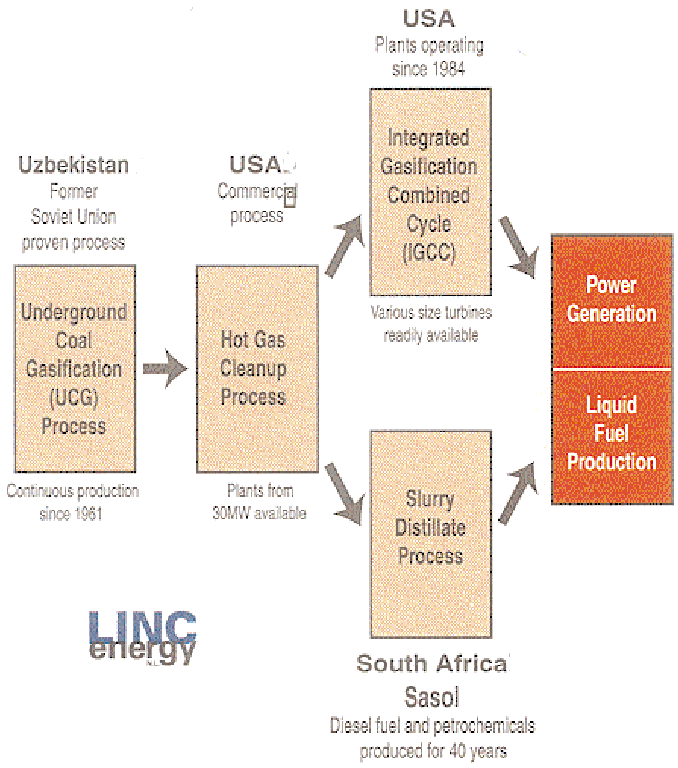


**Fig: 7 DEVELOPMENTS PHASES OF UCG**

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ISO 9001:2008 Certified
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## THE FUTURE OF UNDER GROUND COAL GASIFICATION:

Between 2000 and 2010 world energy use increased by 2.6 billion metric tons of oil equivalent per year. Of this increase, a little over half came from coal, and 72% of the coal increase came from China. The vast exploitation of Chinese coal, the cheapest source of electricity in the world, enabled western nations to benefit from both cheaper goods and outsourcing environmental issues, and for China to benefit from increasing goods exports and rising domestic consumption. Substantial doubt has risen, however, about the possible duration of this economic miracle since China now produces 48% of global coal and consumes around 3% of its reserves every year. How long will Chinese coal last?

The reserve limits for coal, for China as well as the rest of the world, can be postponed for several generations if the technology to gasify coal underground can be commercialized. Underground Coal Gasification (UCG) enables the access of deeper coal layers hitherto unavailable through conventional mining. Several modern pilot projects have been successfully completed in recent years and commercial projects are underway. This article gives an overview of present developments, the technology of the process, costs to produce electricity and liquid fuels from the syngas, and discusses environmental concerns.

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