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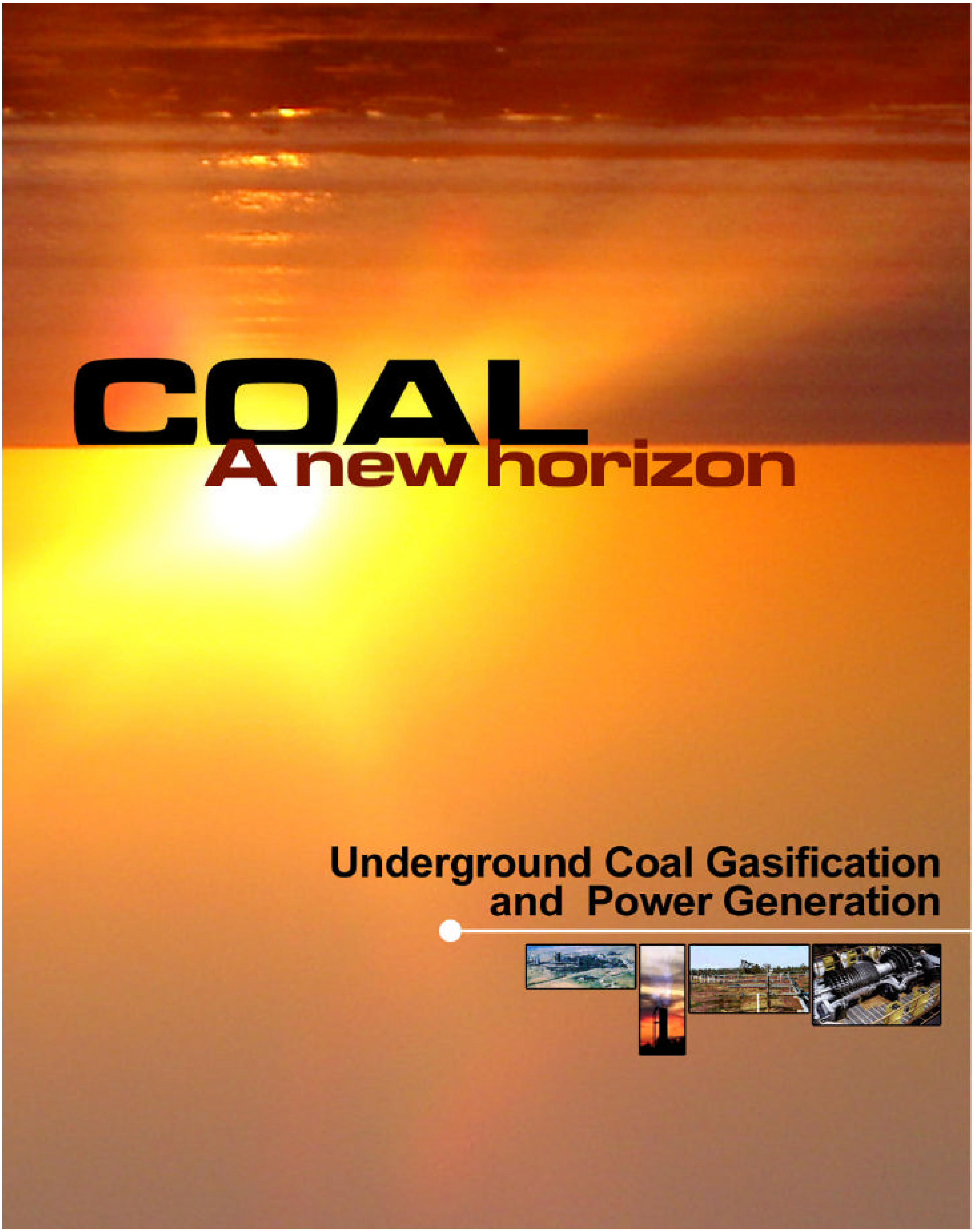


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# The Chinchilla IGCC Project to Date: Underground Coal Gasification and Environment

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**Abstract**

An IGCC project in Chinchilla, Australia (350 km west of Brisbane, Queensland) has been under development since July 1999. The project is the first to use Underground Coal Gasification as a syngas producer technology. Underground Coal Gasification (UCG) is a gasification process carried on in non-mined coal seams using injection and production wells drilled from the surface, which enables the coal to be converted into product gas. The process is flexible in operation, and is capable of producing commercial quantities of gas to be used as a chemical feedstock or as fuel for power generation.

Chinchilla IGCC project involves construction of the underground gasifier and demonstration of UCG technology, then progressive installation of the power island. The first phase started with the gas produced on December 26, 1999. Since then the plant has been making gas continuously, and its maximum capacity increased to about 80,000 $Nm^3$/h. Approximately 32,000 tonnes of coal have been gasified, and 100% availability of gas production has been demonstrated over 28 months of operation. The UCG operation in Chinchilla is by far the largest and the longest ever in the Western world. Ergo Exergy Technologies Inc. (Ergo Exergy) has provided UCG technology for the project and operated gas production site since the inception of the project.

The UCG facility at Chinchilla has used air injection, and produced a low BTU gas of about 5.0 $MJ/m^3$ at a pressure of 10 barg (145 psig) and temperature of $300^o$ C ($570^o$ F). It includes 9 process wells that have been producing gas manufactured from a 10 m thick coal seam at the depth of about 14 0 m. The process displayed high efficiency and consistency in providing gas of stable quality and quantity. The cost of the syngas produced proved to be comparable (on a per unit of energy basis) with very low cost of thermal coal in Australian market.

In anticipation of funding for gas turbine installation, and responding to the investor's need in demonstrating a safe and environmentally clean shutdown of the underground gasifier, a specially designed program of controllable shutdown has been implemented starting from mid-January 2002. It led to suspension of air injection into the underground gasifier in April 2002. An extensive environment management program has been further expanded to demonstrate environmental performance of the underground gasification facility in the conserved mode of operation. No contamination has been detected to date, thus confirming the benign nature of UCG process and effectiveness of the ground water protection methods.

Chinchilla project is being restructured and re-financed at the moment. Gas production is scheduled to be restored and further expanded by the end of 2002 to supply gas to a GT CC plant. A recently completed study has modeled efficiency and commercial viability of IGCC plants in Chinchilla (ranging from 5 to 400 MW) based on the following gas turbines: Typhoon (Alstom), Frame 6B, Frame 9E and Frame 9FA (General Electric). Performance of the GE turbines fueled by the UCG syngas has been evaluated with GE Power Systems, Schenectady, USA. Results have confirmed the high competitiveness of the UCG-IGCC process. Other options for applying UCG syngas for power generation have been studied, including co-firing with coal in existing boilers and re-powering of NG GT plants.

$CO_2$ emissions from the above plants have been estimated in another recent independent study. Complete life cycle analysis shows that a UCG-IGCC facility in Chinchilla would generate around 25% less $CO_2$ emissions than the most efficient of Australian coal-fired power stations.

The results of UCG operations in Chinchilla to date have demonstrated that UCG can consistently provide gas of stable quantity and quality for IGCC and other power projects at a very low cost enabling the UCG-IGCC plant to compete with coal-fired power stations. This has been done in full compliance with rigorous environmental regulations. The $CO_2$ emissions of the UCG-IGCC plant are considerably less than those of the best coal-fired power stations.

## Chinchilla IGCC Project

Chinchilla IGCC project is the first of its kind to utilize Underground Coal Gasification (UCG) as the technology for gas production [1]. It is located at Chinchilla, Australia (350 km west of Brisbane, Queensland). Ergo Exergy Technologies Inc, Canada (Ergo Exergy) has provided UCG technology for the project u nder an agreement with the developing company Linc Energy Ltd, Australia. Ergo Exergy has also designed and operated UCG plant at Chinchilla.

The conceptual design of Chinchilla IGCC project is illustrated in Figure 1. The process plant is used to condition the gas to satisfy strict requirements of the gas turbine. Raw gas produced at wellhead is cooled down to separate the liquids that are further processed and prepared either for sale or disposal. The gas then is cleaned up in sintered metal candle filters. Since candle filters require dry gas for normal functioning, the gas is reheated to the temperatures above dew point before entering the filters. A pilot cleanup plant simulating conditions of the full-scale process is being tested on site.

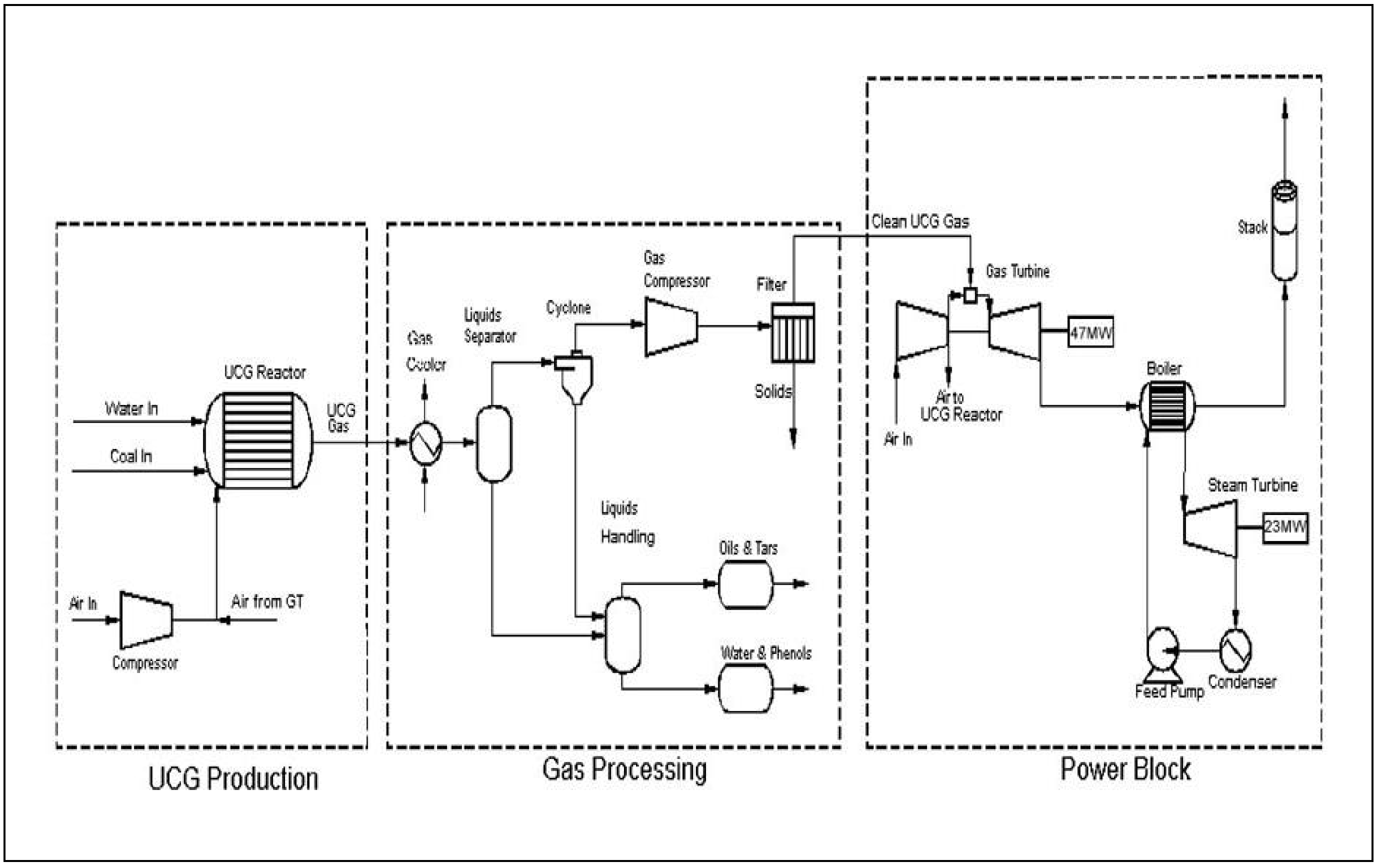



Fig. 1. Conceptual design of Chinchilla UCG-IGCC plant.

A gas compressor is required to bring the pressure of the gas to the level acceptable for the gas turbine. Water separated from the gas flow is used for cooling the raw gas in a heat exchanger and air in the air compressor intercoolers. It will also comprise a part of makeup water needed to operate the steam cycle once a steam turbine is installed.

The degree of integration in a UCG-IGCC plant is limited compared to modern IGCC projects since UCG gas production is distributed over a considerable area, and it is problematic to attain full integration of material and energy streams between gasification and power islands due to the length and variability of the gas gathering pipelines.

It must be noted that the need for the gas compressor is dictated only by the specific conditions of Chinchilla site, namely the thickness and permeability of the overburden. A deeper coal seam or less permeable rock in the overburden may allow gasification under m uch higher pressure, so that the gas can be supplied directly into the gas turbine avoiding the need in additional compression.

Fig. 1 depicts an example of a 70 MW IGCC plant. Chinchilla project has targeted this size of plant in an attempt to minimize capital investment required and to provide sufficient output to produce attractive commercial returns. The ultimate goal of IGCC development at Chinchilla is the scaling up of the initial plant to the size optimal for commercial performance, possibly 400 MW. The factors affecting the scale up are discussed later in this paper.

### Gas Production Process

A simplistic illustration of underground coal gasification process is given in Fig. 2. As in conventional gasification methods, during UCG coal in the ground reacts with an oxidant, and a part of released sensible heat is used in coal drying, pyrolysis and endothermic reactions that reduce the products of combustion. Resulting mixture is called UCG gas or UCG syngas. Obvious differences with a conventional gasifier include the following:

- Coal is not mined and chemical processes are arranged to occur in the virgin coal seam in situ.
- Contact between coal and oxidant is maintained through boreholes drilled from the surface into the coal seam while other boreholes are used to conduct the product gas to the surface. These boreholes are called injection and production wells, respectively, and collectively - process wells.
- Process wells must be connected within the coal seam by the links of low hydraulic resistance to allow production of commercial quantities of gas.
- Process water for gasification is usually coming from the coal itself and surrounding rocks, its influx must be carefully regulated.
- The process must be confined within a hydraulic system created in the coal seam so that no leakage of the product is possible and no contamination of the underground environment can occur. Such a hydraulic system is called an underground gasifier, and its design is the most crucial part of a UCG operation.

Process parameters, such as operating pressure, outlet temperature and flow, are governed by the coal and rock properties that vary with time and location. Information on the process conditions must be constantly monitored and updated as the gasifier develops. Process parameters should be adjusted accordingly to accommodate ever-variable conditions of gasification.

Advantages of operating a large underground gasifier include the following:

- A practically unlimited supply of coal is available for gasification, no coal and water supply is required to sustain the reaction.
- The UCG process creates an immense underground gas and heat storage capacity, which makes the gas supply very stable and robust.
- An underground gasifier is made up of a number of underground reactors with largely independent outputs. The gas streams from different reactors can be mixed as required to ensure consistency of overall gas quality. The outputs of reactors can be varied in order to optimise coal extraction and gas supply from the whole gasifier.
- No ash or slag removal and handling are necessary since they predominantly stay behind in the underground cavities.
- Ground water influx into the gasifier creates an effective “steam jacket” around the reactor making the heat loss in situ tolerably small.
- Optimal pressure in the underground gasifier promotes ground water flow into the cavity, thus confining the chemical process to the limits of the gasifier and preventing contamination in the area.

Unlike conventional gasification methods, UCG is not only a method of coal conversion; it is first of all a method of extracting coal from the underground beds, i.e. a mining technique. There are various similarities between UCG and underground mining techniques, e.g. UCG is concerned with typical mining issues such as sweeping efficiency, roof stability, ground water influx etc. As a coal recovery method, UCG supplements conventional mining by being capable of utilizing coal seams impossible or uneconomical to mine. E.g. it has been estimated that in the USA, there is 1.6 trillion tonnes of non-minable coal that is recoverable by UCG [2].

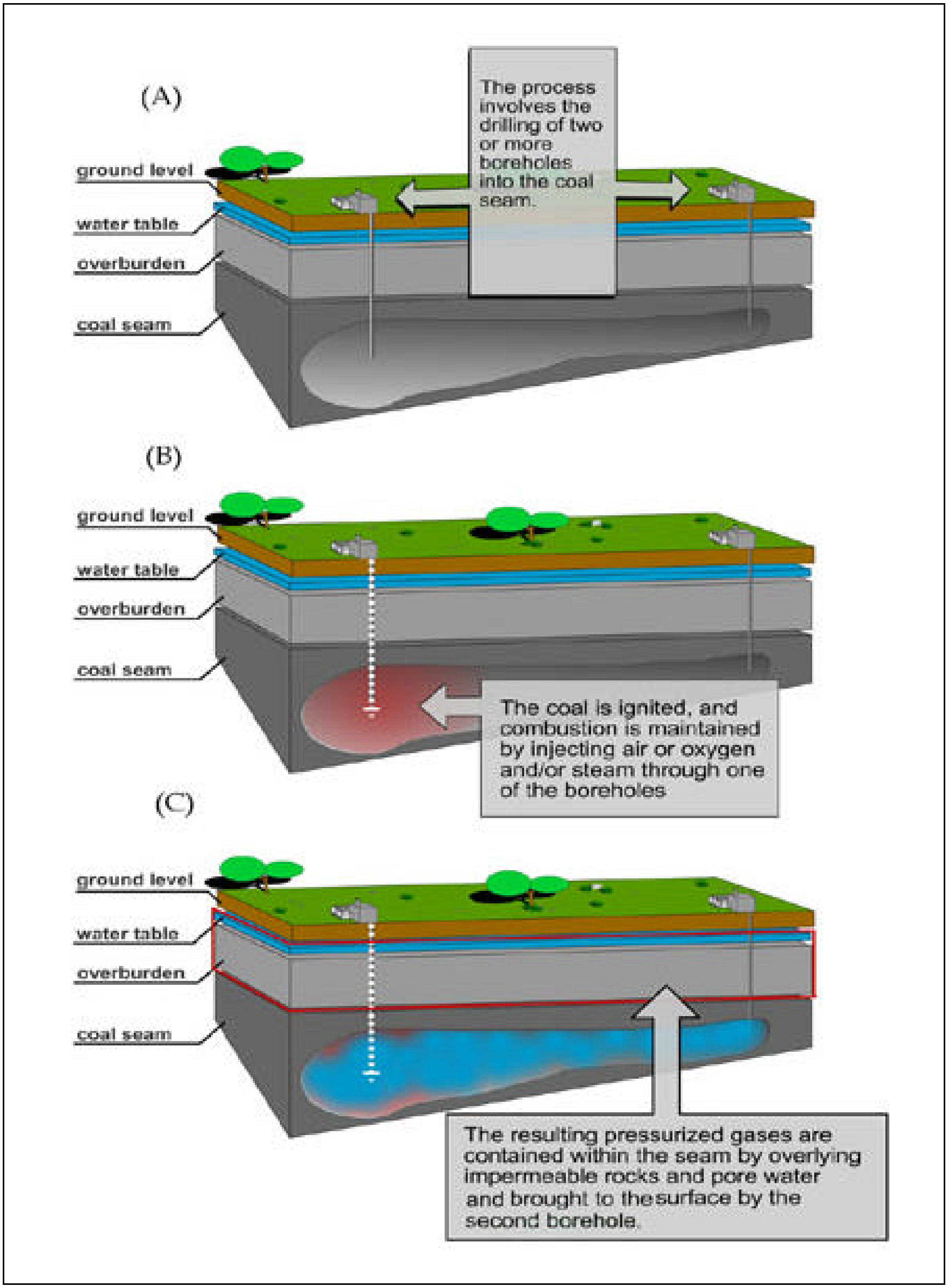



Fig. 2. A simple illustration of UCG process.

**Development to Date**

The project commenced by selection of Chinchilla UCG site and preparation of initial Pre-Feasibility Study in November 1997. Once sufficient funds had been secured, a site characterization program was initiated in June 1999 and concluded by the UCG-specific in situ testing in September 1999. Design and construction of the pilot plant were completed December 12, 1999. Gas production started December 26, 1999 using the initial three process wells. Since then the plant has been producing gas continuously, and its maximum capacity increased to about 80,000 $Nm^3/h$ (ref. Fig. 3). Approximately 32,000 tonnes of coal have been gasified, and 100% availability of gas production has been demonstrated over 28 months of operation. The UCG operation in Chinchilla is by far the largest and the longest ever in the Western world.

The UCG facility at Chinchilla has used air injection, and produced a low BTU gas of about 5.0 $MJ/Nm^3$ at a pressure of 10 barg (145 psig) and temperature of 300° C (570° F). It includes 9 process wells that have been producing gas manufactured from a 10 m thick coal seam at the depth of about 140 m. The process displayed high efficiency and consistency in providing gas of stable quality and quantity. The cost of the syngas produced proved to be comparable (on a per unit of energy basis) with very low cost of thermal coal in Australian market.

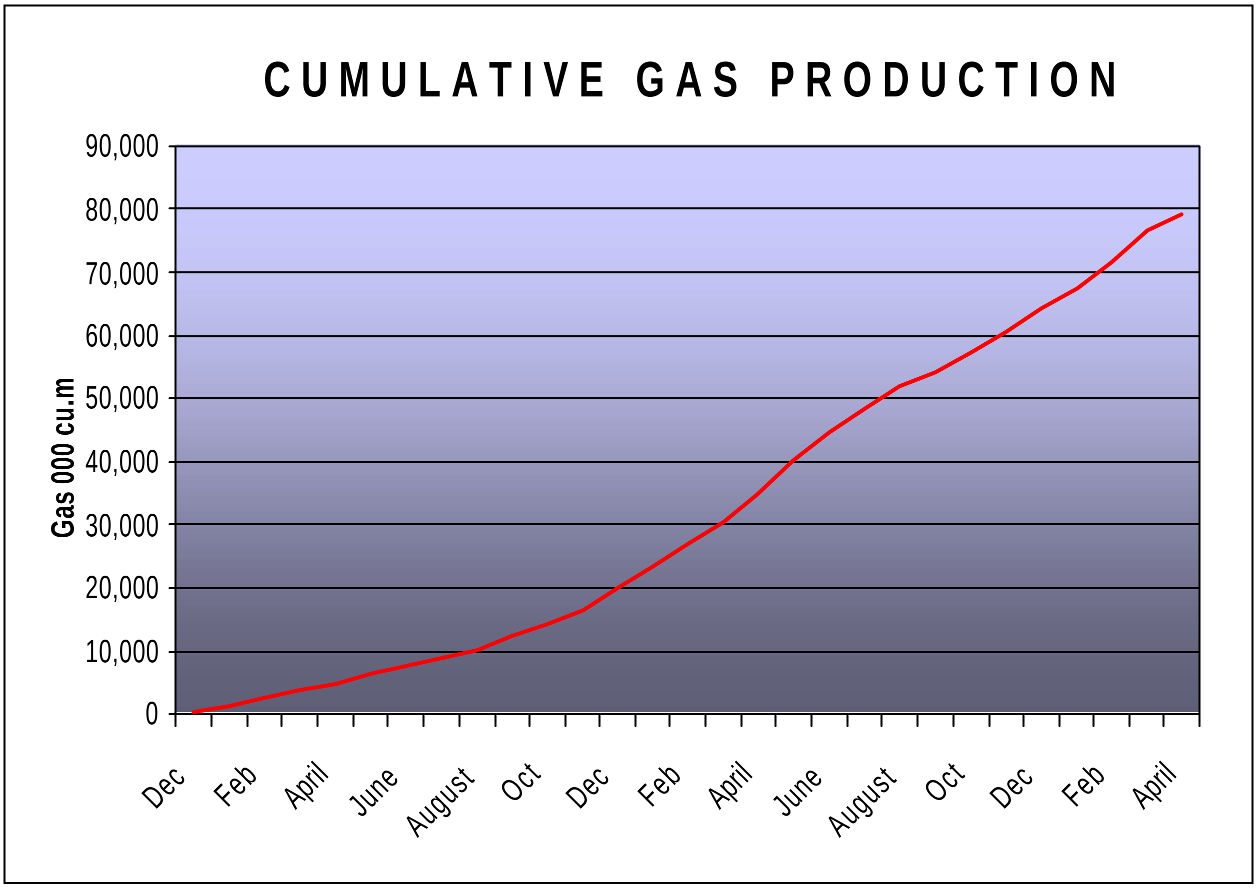



Fig. 3. Continuous gas production at Chinchilla has demonstrated 100% availability of UCG plant.

Technical achievements of gas production at Chinchilla include the following:

- Development of cheap and effective drilling techniques.
- Development of well linking techniques: connection of the process wells within the coal seam has demonstrably been the fastest and the most efficient in UCG history.
- The optimization of the spacing between the process wells: each well reaches over 37 thousand metric tonnes of coal.
- Production of gas of consistent quality and quantity with gas heating value well within requirements of a gas turbine manufacturer (within ± 10% of Wobbe index variation).
- Development of the gas cleanup techniques specific to UCG gas production conditions.

The gas produced in Chinchilla project was flared in anticipation of development of a gas turbine on site and construction of power plant. In the wake of the events of "September 11" and on the background of a sharp decline of pool prices in electricity market in Queensland, it became apparent that securing the gas turbine funding might take considerable time. Besides, investors and regulators both expressed a keen interest in demonstrating a safe and environmentally clean shutdown of the underground gasifier. A specially designed program of controlled shutdown has been implemented starting from mid-January 2002. It eventually led to suspension of air injection into the underground gasifier in mid-April 2002. An extensive environment management program on site has been further expanded to demonstrate environmental performance of the underground gasification facility in the conserved mode of operation.

Chinchilla UCG project is being restructured and re-financed at the moment. Gas production from the gasifier, which never stopped to date, is scheduled to be fully restored and further expanded by the end of 2002 to provide gas supply for a GT CC plant.

Fig. 4. The surface view of an underground gasifier in Chinchilla

## Environmental Performance

The environmental performance of the operation to date has been in full compliance with the Project Environmental Management Plan (EMP) and EPA regulations. In particular,

- No groundwater contamination has been registered.
- No subsidence has occurred.
- No surface contamination has been detected.
- No environmental issues have been identified to date in the controlled shutdown process.
- No complaints have been received from community.
- No non-compliance issues have been identified during independent annual environmental audits.

As part of the ground water monitoring process, the consulting hydrogeologists of Golder & Associates have been closely monitoring groundwater quality through a number of monitoring bores which include both piezometer bores for measuring ground water pressure, and bores for extraction of water samples for chemical analyses [3]. To date some 20 monitoring bores have been installed at strategic locations around the site and on neighbouring properties. According to the results of the monitoring program, underground gasifier seen in Fig. 4 has demonstrated exceptional environmental performance.

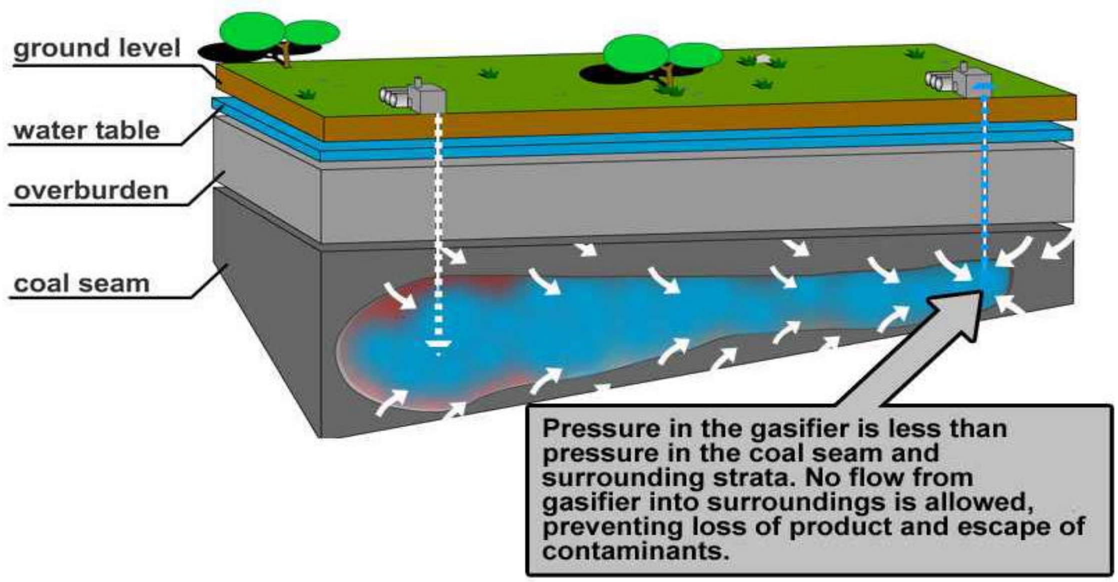



Fig. 5. Mechanism of protection of ground water during UCG.

The main principle of ground water protection during UCG operation is illustrated in Fig. 5. The process is conducted in such a way that gasification pressure in the gasifier is always slightly less than hydrostatic pressure of fluid in coal seam and surrounding strata. This creates pressure gradient directed towards the gasifier. As a result, no flow from gasifier into the surroundings is allowed, thus preventing the loss of valuable product as well as contamination of underground environment. Thorough knowledge of existing aquifers in the vicinity of underground gasifier and careful monitoring of hydrostatic pressure in the aquifers during UCG operations is an integral part of the ground water protection strategy.

## UCG and Power Generation

A recently completed study has modeled efficiency and commercial viability of IGCC plants in Chinchilla (ranging from 5 to 400 MW) based on the following gas turbines: Typhoon (Alstom), Frame 6B, Frame 9E and Frame 9FA (General Electric). Performance of the GE turbines fueled by the UCG syngas has been evaluated with GE Power Systems, Schenectady, USA.

GE pioneered syngas gas turbine technology nearly three decades ago and has developed a broad dedicated product line of gas turbines and matching steam turbines ranging from 10 to 300 MW for syngas applications. Syngas gas turbines are proven products with a total of 34 GE IGCC units sold of which 22 have accumulated over 360,000 hours of operation on syngas.

Gas turbines for syngas applications have basic technical and functional requirements that are different from those of a gas turbine operating on natural gas. Therefore, gas turbines must be modified with features that allow for efficient and reliable syngas service. These syngas specific features relate primarily to the combustion and fuel systems but also include some special fire protection, packaging, and controls modifications.

The core of a syngas gas turbine design is based on combustion system adaptation through laboratory testing. Combustors must be designed for a wide range of operating conditions with primary syngas, backup fuel, and possible co-firing of both fuels. The multiple can-annular combustor design of GE gas turbines results in excellent flame stability and mixing properties that produce very low emissions. This design also makes it possible to burn multiple fuels, including distillate, naphtha, syngas, propane and methane.

Due to the steady operational requirements of the gasification, syngas power plants perform best in base load applications. Syngas gas turbines require natural gas or distillate as a start-up fuel; i.e., all syngas gas turbines must be dual fuel capable. Consequently, syngas power plants can switch to the backup fuel when syngas is unavailable or co-fire when syngas is limited. This increases the plant's power availability to levels equivalent to natural gas fuelled power plants.

Because of the low heating value of syngas when compared to natural gas, significantly more fuel is required in an IGCC turbine than a natural gas turbine. As a consequence, the mass-flow, and thus the output power, of the gas turbine is much higher for an IGCC application. For the same reason, the gas turbine's output power is flat-rated up to very high temperatures.

GE has evaluated the syngas produced by the underground coal gasification facility in Chinchilla and has determined that it is an acceptable fuel for GE's syngas frame 6B heavy duty industrial gas turbine. At average ambient conditions of 25 degrees Celsius, the frame 6B produces at least 45 MW of simple cycle output power. Optimal performance is reached with the air extraction at about 15 tonnes per hour. This air will be used as a part of total injection duty of the plant.

GE Power Systems have also evaluated performance of larger gas turbines using UCG gas produced at Chinchilla. The results have shown that GE 9E gas turbine in a combined cycle configuration will generate over 177 MW at Chinchilla site conditions. Air extraction from the turbine compressor will be sufficient to cover most of the needs of UCG operation in compressed air.

GE 9FA gas turbine unit operating on UCG syngas fuel will generate 278 MW of simple cycle output. Combined cycle configuration would bring the output to about 400 MW. Further work is required to clarify air extraction potential of this particular gas turbine.

These results are very important for UCG based IGCC plants. They prove that there are large modern gas turbines available today that can successfully operate on UCG gas. As a result, the project has the potential to realize the significant economies of scale.

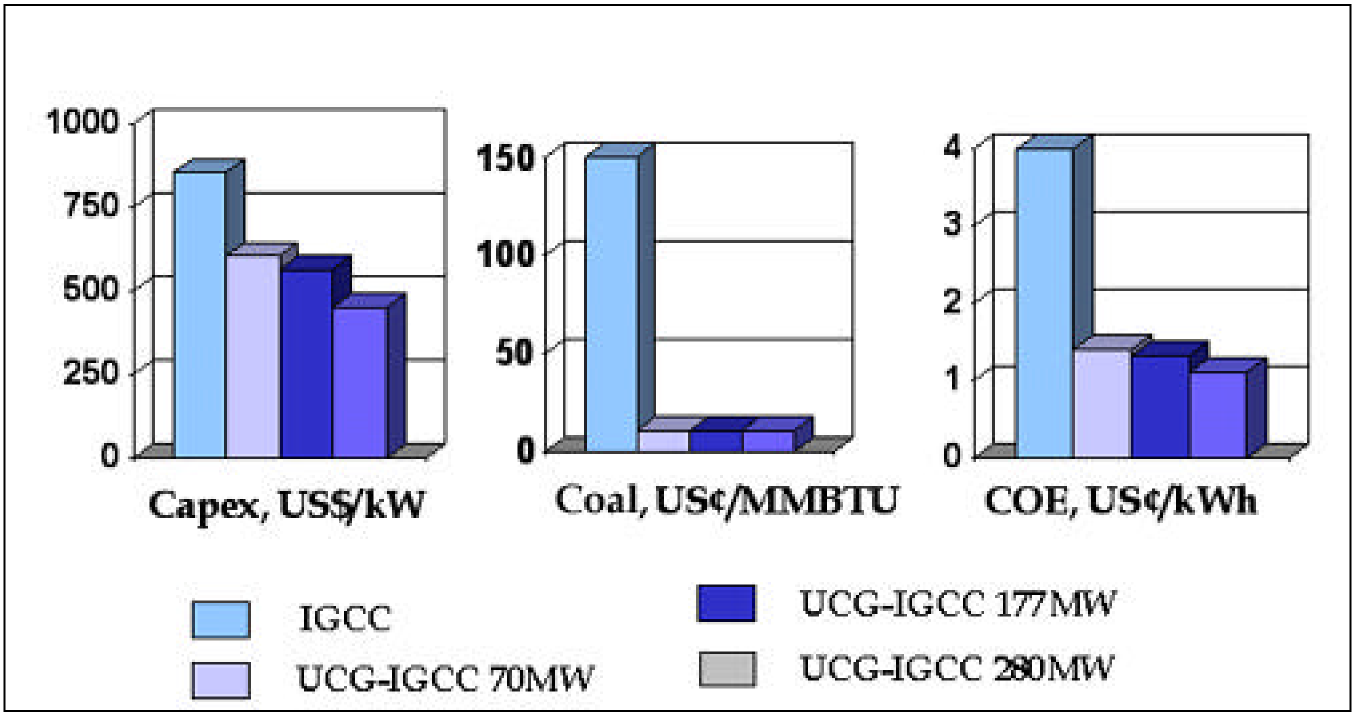
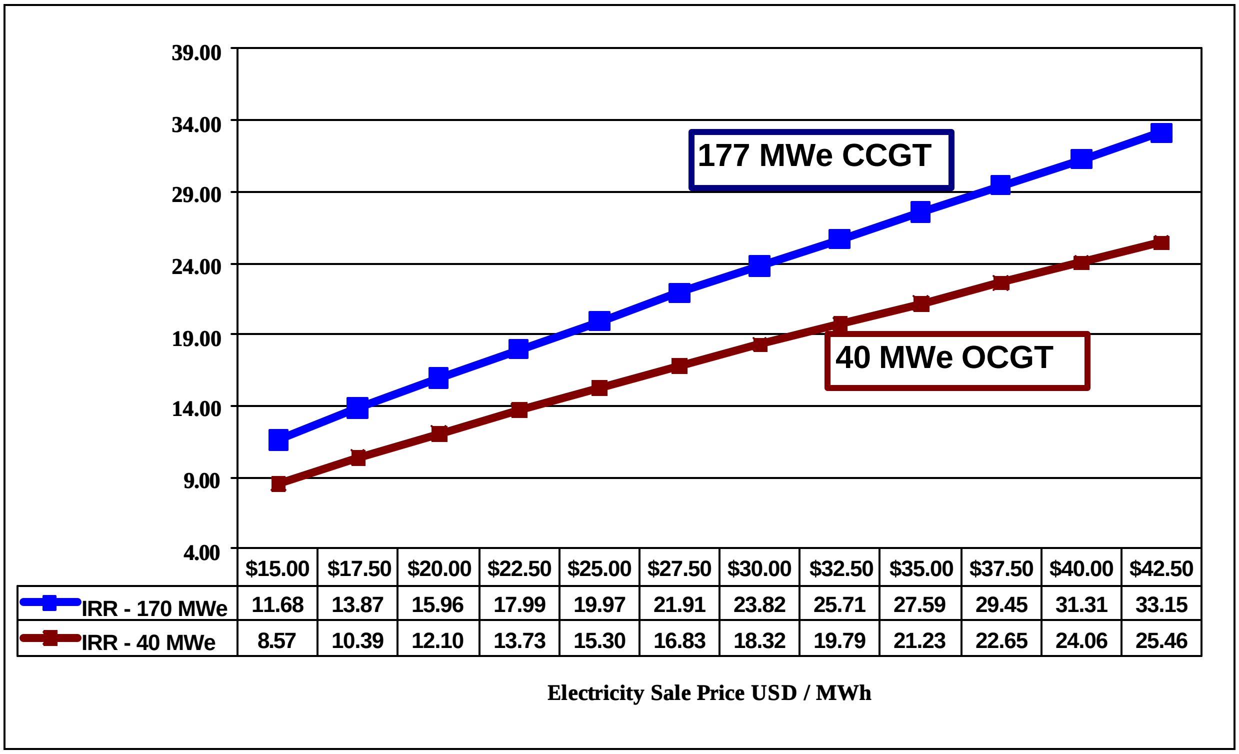



Fig. 6. Economic performance of UCG-IGCC plants

The economic analysis presented in Fig. 6 and Fig. 7 was performed on the following basis:

- Foreign exchange rate of USD $0.54 per AUD $1.00
- Project life of 25 years with no termination value
- Company income tax of 30% paid on profits
- Capex written off over 25 years: tax depreciation equals accounting depreciation
- Inflation effect of 2% per annum on revenues and 3% on costs
- Revenue sourced only from electricity sales and no value attributed to hydrocarbons and other by-products
- Labour rates and Insurance premiums based on Australian market conditions
- Gas Production Operational Performance
    - o 99 % plant availability
    - o Syngas calorific value 5.23 MJ / $Nm^3$
- Power Generation
    - o 84% availability for first 12 months
    - o 90% availability for next 12 months
    - o 94% availability for the rest of project life




| | $15.00 | $17.50 | $20.00 | $22.50 | $25.00 | $27.50 | $30.00 | $32.50 | $35.00 | $37.50 | $40.00 | $42.50 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| IRR - 170 MWe | 11.68 | 13.87 | 15.96 | 17.99 | 19.97 | 21.91 | 23.82 | 25.71 | 27.59 | 29.45 | 31.31 | 33.15 |
| IRR - 40 MWe | 8.57 | 10.39 | 12.10 | 13.73 | 15.30 | 16.83 | 18.32 | 19.79 | 21.23 | 22.65 | 24.06 | 25.46 |

Fig. 7. Internal Rate of Return for a 177 MW UCG-IGCC plant

Presented results of the financial modelling appear to be highly significant. Fig. 6 presents costs of the UCG-IGCC plant compared to target parameters of modern IGCC plants. Capital cost of UCG-IGCC is roughly half of that for IGCC, which is to be expected since expensive surface gasification facilities are not required for UCG. The cost of fuel supplied for IGCC plant is the market price of coal, whereas coal for UCG is acquired with the mining license and the only cost associated with it is the royalties payable to appropriate authorities. As a result, operating cost of an UCG-IGCC facility is much less than that of conventional IGCC. Combination of these factors leads to considerably lower cost of electricity: UCG-IGCC is capable of producing power at the cost as low as US$10.00 / MWh. As expected, a larger UCG-IGCC plant is producing better commercial results, but even a small 70 MW plant demonstrates attractive returns. Fig. 7 shows internal rates of return as a function of power selling price, modelled for two plants: an open cycle plant based on a Frame 6B and combined cycle plant based on a Frame 9E. High returns obtained at the power prices that are realistic in most power markets today, do provide an incentive necessary to introduce the new UCG-IGCC technology to traditionally conservative electricity industry.

Similar modelling has been recently carried out to evaluate the application of UCG gas for co-firing with coal in existing coal-fired plants. The results show that up to 100% of coal can be replaced in conventional boilers by UCG gas, bringing sizable savings from reduction of fuel price and elimination of coal preparation and ash handling costs. As attractive appears to be the option of repowering a NG GT plant with UCG gas. Detailed results are being published elsewhere.

## $CO_2$-emissions

A recent independent study conducted by BHP Billiton Newcastle Technology Centre (Australia) [4] dealt with Life Cycle Analysis of $CO_2$-emissions from a 400 MW UCG-IGCC plant. The power station was based on operating data p repared by Bernard Andersen, HRL technology (Melbourne) using an Aspen model of gas production from UCG and a GT Pro model of the combined cycle power plant. The latter comprised a single GE 9351FA gas turbine, one heat recovery steam generator and one condensing / reheat steam turbine. The overall specific greenhouse gas emissions were found to be 708 kg $CO_2$ / $MWh_e$ (exported).

BHP Billiton Newcastle Technology Centre has also conducted similar studies of Life Cycle Analysis of electricity production by other fossil fuel based power plants [5]. Comparative analysis of these results has led the researchers to the following conclusions:
"The main points from comparisons with other studies are:

- UCG-CCGT has the potential to be one of the lowest GGE coal-based technologies, and compares with the emerging IGCC and more radical ultra-supercritical developments - it would generate around 25% less GGE than the most efficient of Australian coal-fired power stations.
- UCG-CCGT has higher GGE than for natural gas CCGT due primarily to the higher C : H ratio of the gasified coal product.
- $NO_x$ values are equivalent to other combined cycle type power stations.
- UCG-CCGT requires smaller amounts of water compared to other combined cycle technologies, as gasification water requirement is provided by controlling ingress of water from aquifers surrounding the wells and gasification voids. Some of this water is extracted as condensate and reused for cooling purposes." [5]

Another independent study on the same subject was conducted by Dr Chris Spero from CS Energy Ltd, Australia and demonstrated similar results [6]. Information from [4-6] is summarized in Fig. 8.

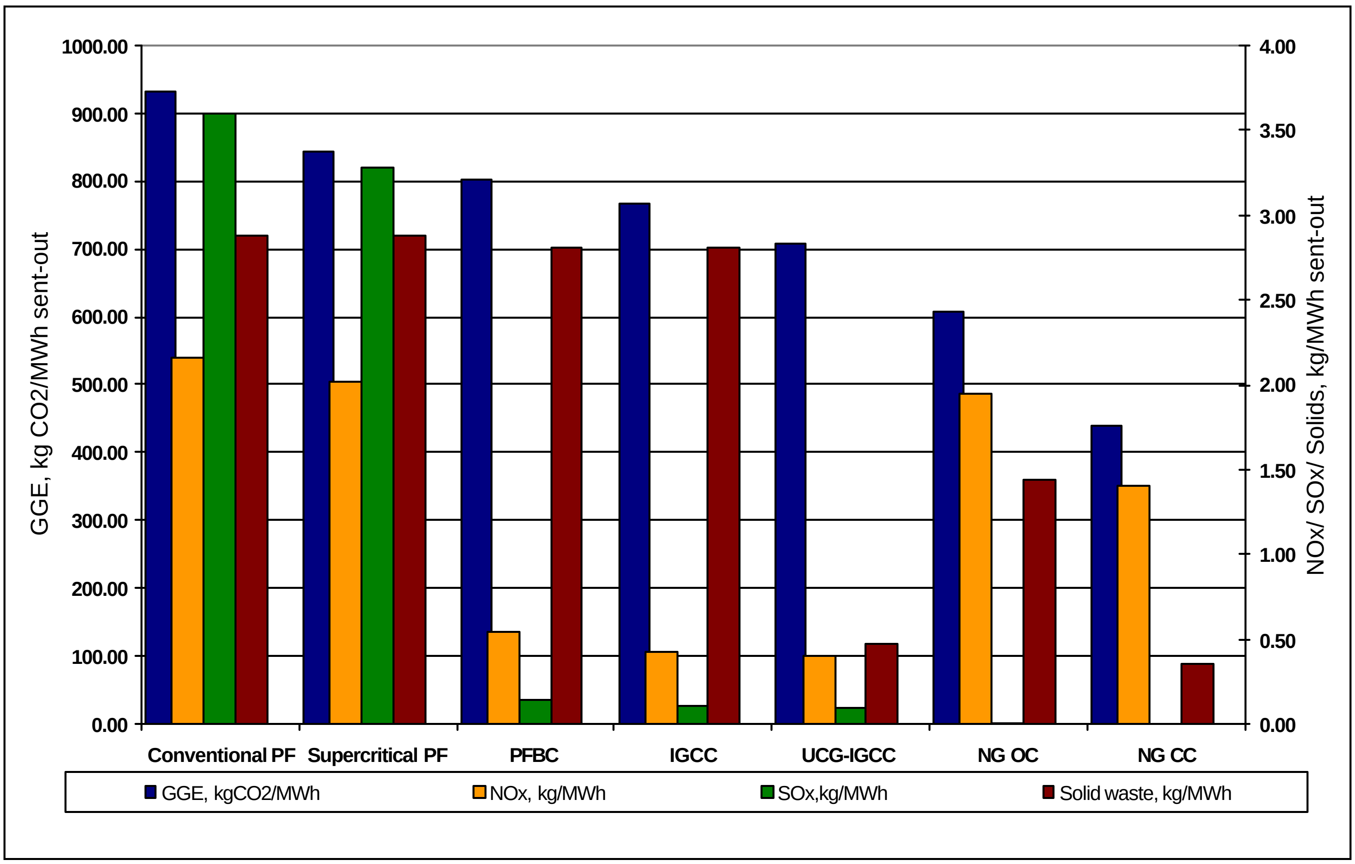



Fig. 8. Greenhouse Gas Emissions, $NO_x$, $SO_x$ and solid waste produced in life cycle of different coal-fired and NG power plants

It must be mentioned as well that UCG being essentially a mining technology, does create underground cavities that may be used for subsequent $CO_2$ sequestration. It is simple to estimate that removal of $CO_2$ from the syngas prior to gas turbine by one of many commercial methods (e.g. Rectisol®) would bring $CO_2$–emissions of UCG-IGCC plant (in the range of 350 kg $CO_2$ / MWh on a sent-out basis) to the level well under that for NGCC. The practical aspects of applying this method of $CO_2$ sequestration to conditions of Chinchilla UCG site are currently being investigated in further details.

## Conclusion

IGCC has proven to be an effective method of generating electricity from coal, which offers high efficiency, low greenhouse emissions and the capacity of cleaning the syngas stream from literally any contaminants. Unfortunately, IGCC today is too expensive to be adopted as a power generation method of choice. A cheaper IGCC would be a preferred alternative to the use of natural gas for power generation.

UCG-IGCC is an example of such cheaper IGCC method. While retaining major advantages of conventional IGCC schemes, i. e. high efficiency and low emissions, UCG-IGCC provides a source of cheaper electricity capable of competing in price with coal-fired power stations. Due to considerable versatility of UCG as a coal extraction method, there is an opportunity of introducing UCG-IGCC plants in the areas with coal deposits impossible to recover by conventional mining.

The results of UCG operations in Chinchilla to date have demonstrated that UCG can consistently provide gas of stable quantity and quality for IGCC and other power projects at a very low cost enabling the UCG-IGCC plant to compete with coal-fired power stations. This has been done in full compliance with rigorous environmental regulations. The $CO_2$ emissions of the UCG-IGCC plant will be considerably less than those of the best coal-fired power stations.

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