Cycles for Low Carbon Dioxide Production

Conference Report and Summary

By: Riti Singh, John Horlock, and Tony Haslam
Cranfield University, Bedford, United Kingdom

Introduction

Environmental concern about greenhouse gas emissions has created a desire to move toward a sustainable energy future by using fuels in an increasingly clean and environmentally friendly manner for power generation. The UK government recently stated the goal that 20% of the nation's energy should be produced by renewable means by the year 2020. Even if this aspiration were to be achieved, it implies that up to 80% of energy in the UK would still be produced from thermal power. Combined cycle gas turbine plants are currently the most efficient means of producing thermal power and are likely to be so until 2020 and well beyond. Ways of mitigating greenhouse gas emissions, in particular CO_2, will therefore become increasingly important in these cycles. The Conference on Cycles for Low Carbon Dioxide Production, held at Cranfield University in March 2003 focused on CO_2 mitigation technologies, and on ways to move forward that might lead to the formation of governmental policy and its eventual implementation.

The Conference on Cycles for Low Carbon Dioxide Production brought together senior industrial engineers and academics with responsibility for new developments in power plant and power plant cycles in their organizations. The proceedings opened with an overview by Professor Riti Singh based on the report on "Key Components for CO_2 Abatement: Gas Turbines" that Cranfield University produced for the International Energy Agency in 1999. Following this, there were a number of presentations on gas turbine cycles suitable for CO_2 abatement and on CO_2 capture and storage. Representatives of major gas turbine manufacturing companies provided an industrial perspective, and there were also presentations from governmental agencies. The presentations and discussion on the cycles and the impact of low-CO_2 energy production on the gas turbine manufacturing and user industries formed the core of the two-day meeting. The conference had the involvement of the International Energy Agency, governmental agencies from the UK, the USA and the EU, representatives from the major gas turbine manufacturers in the UK, the USA, Japan and Europe, and European agencies/oil companies with an interest in CO_2 capture and storage. Numerous novel cycles were proposed to reduce CO_2 emissions from thermal power plants. Many of these cycles were considered in some detail at the Conference, mainly during the first day. The views of operators and practitioners were then considered on the second day, in an effort to establish a consensus on the best way forward.

This report provides an overview of the status of the technology and other factors required to achieve low carbon dioxide cycles. It also summarizes opinions expressed and questions raised by delegates at the March conference.

The Impetus for Low CO_2 Gas Turbine Technology

The amount of CO_2 produced by a thermal plant is now a major criterion of its performance, for environmental and therefore economic reasons. Thus in electrical power stations a new measure of the performance is the amount of CO_2 produced per unit of electricity generated, i.e., $\lambda = kg(CO_2)/kwh$. Fig.1 shows values of λ plotted against thermal efficiency for a high-carbon fuel (coal) and a lower-carbon fuel (natural gas). It illustrates that one obvious route toward a desired low production of this greenhouse gas is to seek higher thermal efficiency with natural gas. This was essentially the route preferred by those industrial companies consulted in compiling this report.

There is momentum in the academic community toward the design of low-CO_2 cycles. There is also a generally held belief that practical solutions to the problem can be derived through innovative cycle design. Some of the academic work is supported by funding from industry and governmental bodies (such as the U.S. Department of Energy and the European Union). Conference proceedings also bore evidence of the industrial perspective on the development of low-CO_2 technology. The industrial stance is that the technology should be in place, but is unlikely to be implemented until either a market need arises or legislation compels the adoption of the technology through CO_2 tax, credits, or other means. The companies would ensure that the technology was in place to meet environmental demands and they are involved in demonstrator technology programs. Manufacturers are active in undertaking and in supporting research; however, they do not influence government or public opinion. The role of the companies is to respond to demand by offering products that meet legislative requirements and, if possible, meet the performance targets required by the power generation industry.

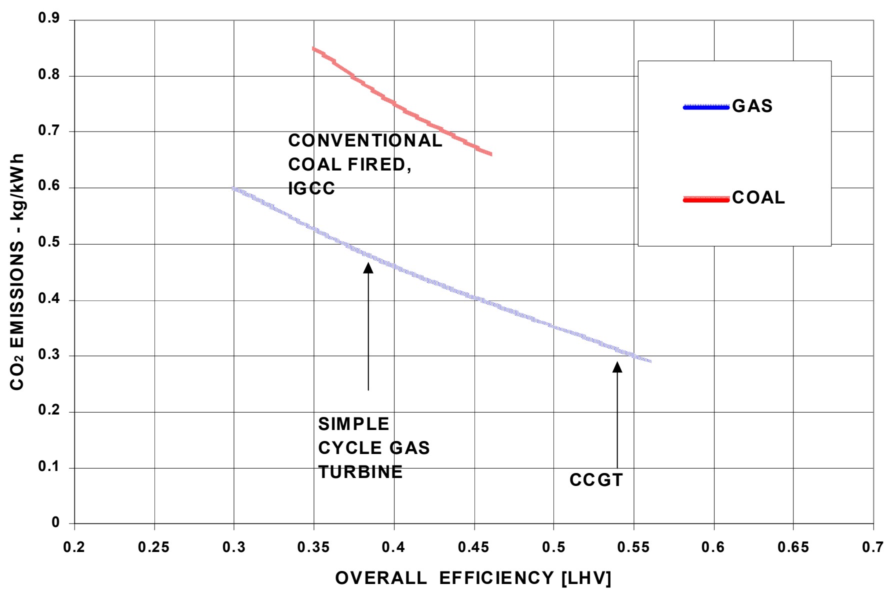

Fig. 1

It is recognized that CO_2 abatement technology will incur penalties in thermal efficiency that will lead to increases in the price of power. The requirement for CO_2 capture will need to be agreed upon internationally. Unilateral legislation to enforce CO_2 capture is unlikely to be viable and will have adverse implications for industrial success and national wealth. Companies operate in the global economy and will respond to international environmental requirements. At present, there is no market for CO_2 abatement technology to be incorporated into the current high-efficiency combined cycle power generation plant.

Storage of carbon dioxide from power plants will require substantial reservoirs capable of containing the gas. The obvious reservoirs are depleted oil or natural gas wells such as those in the North Sea and other parts of the world. These reservoirs have contained gaseous products and are therefore impervious to leaking gas. There is ample evidence that there is sufficient space for CO_2 storage for some considerable time. Although depleted oil/gas reservoirs are natural candidates for CO_2 storage, public opinion will need to change before they are put to use on a large scale. European reservoirs for CO_2 storage are available now; however, the cost of sequestration makes the technology uneconomic unless subsidies, probably raised from CO_2 taxes, become available. Countries that do not have access to depleted oil/gas reservoirs will also need to store CO_2, and therefore an international solution will be necessary. Reservoir owners may even resist the use of their facilities for CO_2 storage. In fact, owners may wish to exploit CO_2 storage as a commercial opportunity, thereby increasing the cost of the process.

The Way Forward

The cycles discussed at the Conference are not economically viable at present. Combined cycle gas turbine power generation plants are achieving increasing levels of thermal efficiency, and the cost of implementing new technology for CO_2 capture and storage is considerable. In the short to medium term, it is likely that effort will be concentrated on the development of highly efficient power generation plants with state-of-the-art technology. In the longer term, new technologies to remove, capture and sequester the carbon dioxide created in power plants will be developed to satisfy environmental and market-driven needs, which are likely to be manipulated through CO_2 taxes and credits.

Combined cycle gas turbine plants are currently the most efficient and will be used in future gas turbine applications for base-load power production. Stocks of coal are likely to outlive other fossil fuels and will become relatively cheaper as oil and other fuel stocks decline. The most promising and simplest scheme for the generation of CO_2-free power would be the addition of a syngas converter and water shift reactor to a gas-fired combined cycle plant. The converter produces synthesis gas (H_2, CO, CO_2 and H_2O). The addition of a water shift reactor converts the CO to CO_2, which could then be removed and stored. In time, as coal becomes cheaper than gas, a coal gasification plant could be added to maintain the production of syngas. Moreover, an air separation plant could also be added to enable the use of pure oxygen in the syngas converter and the removal of atmospheric nitrogen—and therefore NO_X gases—from the process.

The implementation of the process offers a clear route to the market. Although the production of syngas/hydrogen requires the addition of new plants, the gas turbine technology is essentially unchanged. Some modifications to combustion systems would be required for burning syngas/hydrogen. Modified machines would be sold to the same client base and there would be no reduction in the value of the machinery. Gas turbine manufacturers are not— and are unlikely to become—champions of CO_2 technology. However, under the right economic circumstances, there could be a synergy between gas turbine technology and the technologies required for CO_2 removal.

The Evolution of CO_2 Abatement Technology in Gas Turbines

CO_2 mitigation technology is likely to evolve in areas where the gas has an economic value. The oil and gas industry has a requirement for CO_2 to displace methane from coal in coal beds and for the enhanced recovery of oil from depleted wells. The technology is therefore likely to be of more immediate interest to the oil and gas industry than in the power production sector, particularly if the price of oil continues to rise in the near term. Moreover, the oil companies own the oil fields and therefore have immediate access to CO_2 storage facilities. Oil and gas companies have a history of generating power using gas turbine plants, and they are also used to dealing with large-scale chemical plants. The process of producing syngas/hydrogen is relatively straightforward for an oil/gas company. The electricity generated would be a by-product of the syngas/H_2 production process and could be sold into the national grid. Other products of the process could be district heating and other chemical by-products (maybe other fuels such as methanol) for which oil companies have immediate market access.

Without governmental/international pressure, it is unlikely that CO_2 sequestration technology will be incorporated into gas turbine plants. Gasification/syngas plant and shift reactors will be introduced only if the cost to the industry is offset by some other means. When economic conditions do become favorable, it is likely that for the first two to three decades it will remain a technology for large-scale base-load plants (big IGCC plants) near to CO_2 reservoirs, i.e., mainly coastal sites (probably with a few smaller pilot plants and demonstrators). Figure 2 shows a typical plant layout. After a time, the applications will likely increase to cover smaller power plants.

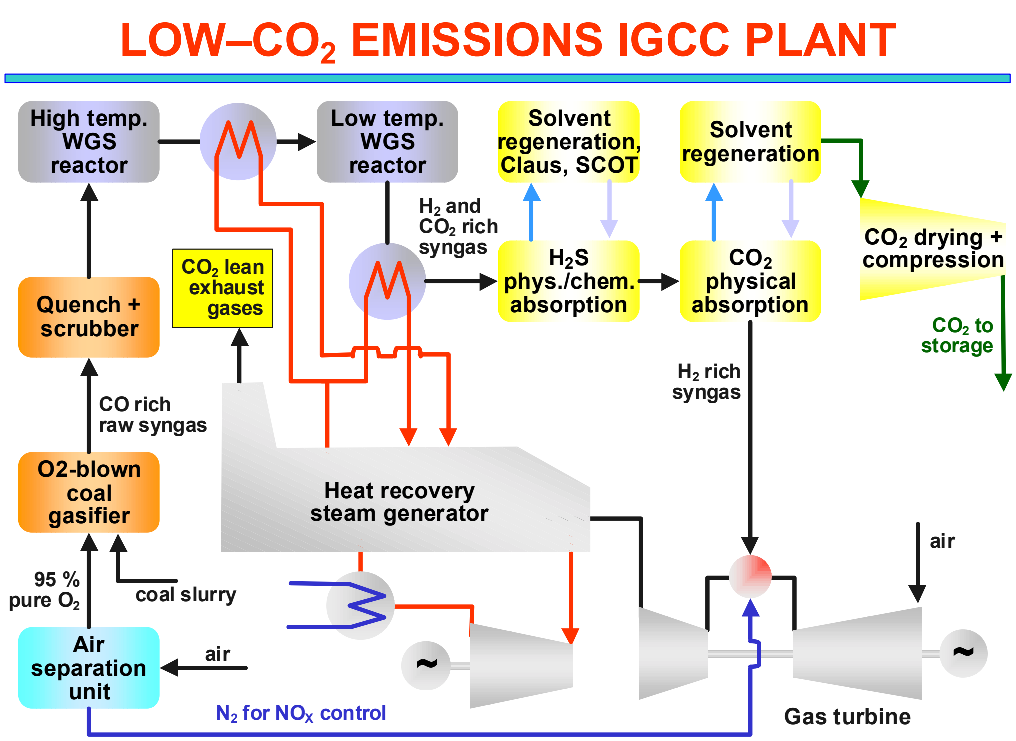

Fig 2.

Environmental Effects of the Technology

The incorporation of sequestration technology would imply a 5-10% points reduction in thermal efficiency at the machine level alone. This translates into a 10-20% increased fuel requirement to generate the same power. Inevitably, this means that fossil fuels will be consumed at a rate of 20% faster than previously; the acceptance of a degree of global warming might prove more acceptable to future generations than an increased rate of depletion of fuel stocks. The technology is available to reduce the increased rate of consumption of fossil fuels by a few percentage points. Membrane technology can be used to produce cheaper H_2 and O_2, and there are membranes that include a combustor. With proper cooling, cycle temperatures could be very high without producing NO_X.

Financial Issues

It is highly probable that legislation to reduce CO_2 emissions will be enacted in many countries during the next decade. The Kyoto Protocol resulted in various countries agreeing to certain reductions in emissions, including CO_2. Whilst some countries are moving toward the introduction of a carbon tax, others are recommending trading in carbon dioxide. Measures for abatement are likely to require further international agreement before substantive progress can be made. Generally speaking, however, new CO_2 abatement technologies will require several financially related issues to be properly addressed before the implementation of new technology is viable. Examples of these issues are:

- Economics of operation and competitiveness with other forms of renewables and natural gas-fired plants.
- Cost of CO_2 capture.
- Cost of transportation to the storage site.
- Legality of CO_2 storage in the North Sea and other reservoirs.
- Environmental aspects of geological storage and associated risks.
- Ownership of natural reservoirs for CO_2 storage.
- Cost of new infrastructure for CO_2 capture, transport and storage.

Conclusion

At present, CO_2 mitigation technology is relatively immature and the risks to industry are too large and protracted to make implementation a viable proposition. When economic conditions become favorable, the application of new technology for CO_2 abatement is expected to increase costs; in the early years, economy of scale suggests that applications will most likely occur in large plants, perhaps over 500MW. However, technology demonstrator plants will be smaller. Despite the belief that the new technologies will benefit only the large players in the power generation market, other market opportunities will arise for smaller players (requirements for new turbomachinery, transportation equipment, storage equipment, etc.).

Carbon taxation and CO_2 trading are possibilities, but these steps require much further work on the design of practical and effective procedures. As CO_2 abatement becomes more prevalent, the industries involved must remain competitive. It is inevitable that legislation will eventually emerge in many countries, as the issues become better understood.

In future the economics of electric power generation is likely to be affected considerably by the level of any environmental penalty imposed by a carbon or carbon dioxide tax. The cost of electricity produced by an efficient CCGT plant would be lower than that produced by either nuclear plant or by an on-shore wind farm. However, the price would probably rise above that of an on-shore wind-farm and a nuclear plant if representative values of carbon tax are applied (see Fig. 3).

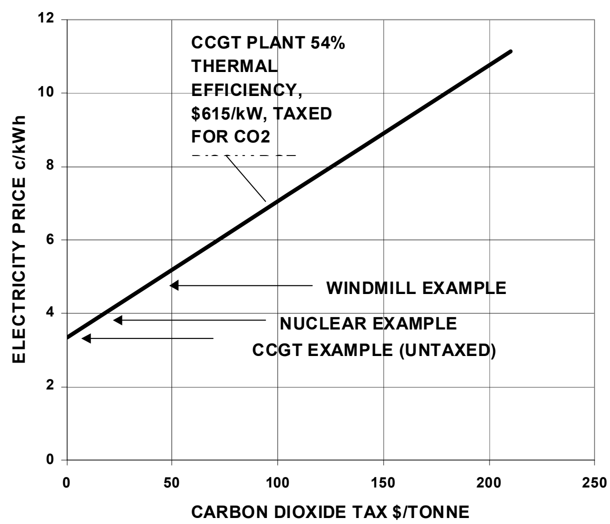

Fig. 3

The electricity cost for the CCGT power station with additional plant for ‘end of pipe’ sequestration would be comparable to the latter. Carbon tax of the order of 10$/t CO_2 are likely to produce energy price increases of about 10%. However, to promote the early replacement of fully depreciated coal fired power plant by carbon friendly means would require considerably higher carbon taxes in excess of 50$/t CO_2.

CO_2 removal is a medium term solution to the problem of global warming. It will allow a time window for renewable energy sources to mature and grow while maintaining an adequate level of power production. The ultimate objective, however, will be the production of hydrogen from renewable sources but this will only meet 20% of power needs at best.

Further details can be obtained from Tony Haslam, School of Engineering, Cranfield University, Cranfield, Bedford MK43 0AL, UK (a.haslam@cranfield.ac.uk).