UNITED
NATIONS

E

Economic and Social Council

Distr.
GENERAL

ENERGY/GE.1/2004/5
21 September 2004

Original: ENGLISH

ECONOMIC COMMISSION FOR EUROPE

COMMITTEE ON SUSTAINABLE ENERGY

Ad Hoc Group of Experts on Coal in Sustainable Development
Seventh session, 7-8 December 2004

CLEAN COAL – BUILDING A FUTURE THROUGH TECHNOLOGY

(Prepared by the World Coal Institute*)

I. INTRODUCTION

1. This paper examines in detail the environmental issues associated with coal use. It focuses in particular on greenhouse gases, and the potential provided by technological change to virtually eliminate CO_2 emissions from coal-based power and to position coal at the centre of an emissions-free energy future based on hydrogen.

2. The paper is a summary of the report *Clean Coal – Building a Future through Technology*, the latest in a series of reports by the World Coal Institute on the contribution of coal to global sustainable development. It complements the WCI report *The Role of Coal as an Energy Source*, which outlines the importance of coal as a low-cost source of power for economic and social development, and its role in maintaining global energy security [WCI 2003].

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GE.04-32061

II. COAL AND THE ENVIRONMENT

(a) The World Energy Scene

3. Coal plays a major part in the world's energy system and hence in global economic and social development. Coal currently supplies over 38% of the world's electricity and 23% of global primary energy needs. Coal-fired electricity drives the economies of the two most populous and fastest growing countries in the world today – China and India – as well as a number of key industrial economies, such as the United States and Germany (Table 1). Coal consumption is expected to grow by around 1.4% per year over the next thirty years.

Table 1: Coal-fired Power Generation as a Proportion of Total Electricity Consumption

Poland	94.8%	Greece	62.3%
South Africa	93.0%	Germany	52.0%
India	78.3%	United States	49.9%
Australia	76.9%	Denmark	47.3%
China	76.2%	United Kingdom	32.9%
Czech Republic	66.7%	EU15	27.2%

Source: International Energy Agency 2003

4. However, the industry recognises that it must also be able to meet the challenge of environmental sustainability. In particular, coal and other carbon-intensive energy sources must significantly reduce their potential greenhouse impacts if they are to claim a continuing and sustainable role in the global energy mix.

5. The coal industry is committed to this objective and believes it can be achieved, primarily through the development and deployment of clean coal technologies.

(b) The Environmental Challenge and Response

6. Most human activities have environmental consequences and all forms of energy, including renewable energy, raise their own environmental issues.

7. However, this paper is concerned solely with the environmental impacts of coal in power generation and the means by which those impacts have and are being reduced.

8. Coal's technical response to its environmental challenges is ongoing and multifaceted. However, it can be said to have three core elements:

- Eliminating emissions of pollutants such as particulate matter and oxides of sulphur and nitrogen. This has largely been achieved and the issue now is the application of “off-the-shelf” technology.

- Increasing thermal efficiency to reduce CO_2 and other emissions per unit of electricity generated. Major gains have already been achieved and further potential can be realised.
- Eliminating CO_2 emissions. The development of "zero emissions technologies" has commenced and is accelerating rapidly.

9. A fourth dimension is the potential for coal to provide an essential source of hydrogen for completely clean future energy systems for stationary and transport applications.

III. THE ROAD TO ENVIRONMENTAL SUSTAINABILITY

10. Different technology options are appropriate to different circumstances. In particular, the technologies that are viable in a developed country may not be as relevant to developing economies – typically, developing countries are unable to afford highly complex and expensive new technology and supporting infrastructure.

11. There is a road along which progress can be made towards better environmental performance, whatever the starting point. Already, in many developed countries, the technologies to deal with emissions of particulates, SOx and NOx not only exist, but also have been widely deployed. In other countries the focus may be on introducing the cleaner technologies already available, significantly reducing the environmental impacts of coal use.

12. This road continues forward into the future and offers an effective and realistic route to meeting the main challenge of the 21st century – reducing greenhouse gas emissions. The first step along this road is improvements in efficiency, which can reduce emissions of both pollutants and carbon dioxide per unit of power generated.

(a) Enhanced Take Up of Existing Options

13. Conventional coal-fired generation today is normally via pulverised coal combustion (PCC) – coal is pulverised into a powder, which is burnt in a high temperature furnace to heat water and produce steam to drive a steam turbine. Modern PCC technology is well developed, with thousands of units around the world, accounting for well over 90% of coal-fired capacity.

14. A range of options already exists to improve the environmental performance of conventional coal-fired power stations.

15. Coal cleaning by washing and beneficiation continues to play an important role in reducing emissions from coal-fired power stations. It can reduce the ash content of coal by over 50%, reduce SO_2 emissions and improve thermal efficiencies (leading to lower CO_2 emissions). Coal preparation is standard in many countries, but it could be usefully extended in developing countries as a low-cost way to improve the environmental performance of coal use. Only around 11% of thermal coal in China, for example, is currently washed. If a greater proportion of this coal were cleaned, there is the potential for thermal efficiency improvements of at least 2-3% and possibly up to 4-5%.

16. Particulate emissions can be reduced by methods such as electrostatic precipitators, fabric filters (also known as baghouses), wet particulate scrubbers and hot gas filtration systems. Both electrostatic precipitators and fabric filters can remove over 99% of particulate emissions.

17. Global concerns over the effects of acid rain have led to the widespread development and utilisation of technologies to reduce, and in some cases eliminate, emissions of SOx. Flue gas desulphurisation (FGD) technology, for example, employs a sorbent, usually lime or limestone, to remove sulphur dioxide from the flue gas. FGD systems are currently installed in 27 countries and have led to enormous reductions in emissions – wet scrubbers, the most widely used FGD technology, can achieve removal efficiencies as high as 99%. The cost of FGD units has also reduced significantly, now costing one-third of what they did in the 1970s.

18. NOx reduction technologies include the use of low NOx burners, selective catalytic reduction (SCR) and selective non-catalytic reduction (SNCR). Low NOx burners and burner optimisation techniques are used to minimize the formation of NOx during combustion.

19. Techniques such as SCR and SNCR lower NOx emissions by treating the NOx post-combustion in the flue gas. SCR technology achieves 80-90% NOx reduction and has been used commercially in Japan since 1980 and in Germany since 1986.

(b) Deployment of Advanced Technologies

Fluidised Bed Combustion

20. Fluidised bed combustion (FBC), in its various forms, can reduce SOx and NOx by 90% or more. In fluidised bed combustion systems, coal is burnt in a bed of heated particles suspended in flowing air. FBC systems are popular because of the technology's fuel flexibility; almost any combustible material can be burnt. In the USA, for example, FBC systems are increasingly utilised to burn abandoned piles of coal waste, turning what could otherwise be an environmental problem into a useful source of power.

Supercritical and Ultrasupercritical Power Plant Technology

21. Supercritical pulverised coal-fired power plant operate at higher steam temperatures and pressures than conventional subcritical PCC plant, and offer higher efficiencies – up to 45% - and hence lower emissions, including emissions of CO_2, for a given power output. Even higher efficiencies – up to 50% – can be expected in ultrasupercritical (USC) power plant, operating at very high temperatures and pressure.

22. More than 400 supercritical plant are in operation worldwide, including a number in developing countries. The 2x600MW supercritical Shanghai Shidongkou coal-fired power plant in China, for example, was put into operation in the early 1990s and China is now installing supercritical plant as standard for new plant. There are currently nine supercritical plant in operation in China, with 16 under construction and a further eight planned, altogether totalling over 21GW of coal-fired capacity.

Integrated Gasification Combined Cycle

23. In Integrated Gasification Combined Cycle (IGCC) systems, coal is not combusted directly, but reacted with oxygen and steam to produce a “syngas” composed mainly of hydrogen

and carbon monoxide. The syngas is cleaned of impurities and then burned in a gas turbine to generate electricity and to produce steam for a steam power cycle.

24. IGCC technology offers high efficiency levels, typically in the mid-40s – although plant designs offering close to 50% efficiencies are available – and as much as 95-99% of NOx and SOx emissions are removed. The further development and support of IGCC offers the prospect of net efficiencies of 56% in the future. There are around 160 IGCC plants worldwide.

25. The appeal of IGCC technology also extends beyond the potential for increased efficiencies and further reductions in pollutants. IGCC technology may also be the chosen pathway for the ultra low emissions system of the future, using carbon capture and storage, and as part of a future hydrogen economy. In IGCC, the syngas can be "shifted" to produce CO_2 and H_2, which can then be separated so that the hydrogen is available as a clean fuel product for use in power generation via gas turbines and fuel cells. The CO_2 is then available in a concentrated form for capture and storage.

26. At present, IGCC applications for power generation are considered by some to be less reliable than other clean coal technology options, such as supercritical PCC and CFBC. Further development in this area will be necessary if the technology is to become the chosen pathway.

(c) Exploiting Synergies with Renewables

27. Renewable energy technologies are set to account for an increasing share of the world's energy mix. However, there are a number of significant practical and economic barriers that limit the rate of penetration by renewables. The International Energy Agency estimates that new renewable technologies will still account for less than 5% of world electricity supply by 2030.

28. Renewable energy forms tend by their nature to be intermittent or unpredictable and to be "site dependent" – i.e. only available at particular suitable sites. Wind energy, for instance, depends on whether and how strongly the wind is blowing and even the best sites do not normally operate for more than about one-third of the time. Hydroelectric power similarly depends on the right sort of geographic conditions and on rainfall; a dry year may see shortages. Many forms of biomass are seasonal or difficult to transport.

29. Coal can be used to help overcome these difficulties, and hence support renewables use. Coal is widely available, easy to store and transport, and reliable coal-fired generation can balance the uncertainties introduced into the power grid by intermittent renewable energy. There are also operational synergies between coal and renewables that can significantly increase the efficiency of the renewable technologies and may be the most cost-effective way of increasing their use.

30. In particular, the economics and efficiency of biomass renewable fuels can be improved by co-firing with coal. Existing conventional coal-fired power stations can generally use between 10% and 20% biomass without modification, making it possible to reduce greenhouse emissions and use renewable resources, which would otherwise often go to waste.

31. Other renewables also offer similar synergies with coal – for instance, linking steam from solar thermal technology with the steam cycle of coal-fired power plant can be an effective way of

converting solar energy into electricity, at lower cost and with higher efficiencies than alternative routes, such as photovoltaics.

32. On a wider scale, coal-fired plant can complement wind or hydro generation providing the back-up needed when the renewable sources are not available.

(d) Development and Commercialisation of Next Generation Technologies

33. In the longer term, technologies for carbon capture and storage (CCS) have the potential not only to be an economic and environmentally acceptable route to a low carbon future but also to enable coal to form the basis of a future hydrogen economy.

34. These technologies enable emissions of carbon dioxide to be "captured" and "stored"; that is stripped out of the exhaust stream from coal combustion or gasification and disposed of in such a way that they do not enter the atmosphere. Carbon storage is not currently commercial but the required technologies are already proven and have been used in commercial applications in other contexts.

Storing and Using CO_2

35. A number of options for the storage of CO_2 are being researched at the present time, including geological storage and mineral storage.

36. **Geological Storage** – Injection of CO_2 into the earth's subsurface offers potential for the permanent storage of very large quantities of CO_2 and is the most comprehensively studied storage option. The CO_2 is compressed to a dense state, before being piped deep underground into natural geological "reservoirs". Provided the reservoir site is carefully chosen, the CO_2 will remain stored (trapped in the bedrock or dissolved in solution) for very long periods of time and can be monitored.

37. An obvious site for geological storage is depleted oil and gas reservoirs. In the USA, it is estimated by the US Department of Energy (DOE) that the storage capacity of depleted gas reservoirs is about 80-100 Gigatonnes, or enough to store US emissions of CO_2 from major stationary sources (e.g. power stations) for 50 years or more [Cook 2002].

38. **Saline Aquifers** – Storing large amounts of CO_2 in deep saline water-saturated reservoir rocks also offers great potential. One major project is already being conducted by the Norwegian company Statoil. This is at the Sleipner field in the Norwegian section of the North Sea, where about 1 million tonnes a year of CO_2 are being injected into the Utisira Formation at a depth of about 800-1000 metres below the sea floor.

39. Another option for permanent CO_2 storage is **Mineral Carbonation** – a process whereby CO_2 is reacted with naturally occurring substances to create a product chemically equivalent to naturally occurring carbonate minerals.

40. **Enhanced Oil Recovery** – CO_2 is already widely used in the oil industry to increase oil production – the CO_2 helps pump oil out of the underground strata, so increasing the level of recovery from the field. Without such methods of enhanced production, many oil fields can only

produce half or less of the original resource. The CO_2 therefore has a positive commercial value in such situations.

41. **Enhanced Coalbed Methane** – is a potential opportunity for storing CO_2 in unmineable coal seams and obtaining improved production of coalbed methane as a valuable by-product.

42. The capture and storage of CO_2 presents one of the most promising options for large-scale reductions in CO_2 emissions from energy use. The economics of CCS are likely to be broadly comparable with those of other options, such as renewables. The costs of renewables, of course, are expected to fall in future as the technology develops – but the same is true of carbon capture and storage.

Hydrogen from Coal

43. A key option for the longer term is the move towards hydrogen-based energy systems, in which hydrogen is used to produce electricity from gas turbines and, ultimately, fuel cells.

44. A key uncertainty surrounding the widespread uptake of fuel cells relates to the availability of hydrogen, which does not naturally occur in usable quantities. It would therefore have to be manufactured and fossil fuels are one likely source. Coal, with the biggest and most widespread reserves of any fossil fuel, is a prime candidate to provide hydrogen (via coal gasification) in the quantities needed and over the timeframe required. Several countries are starting to implement hydrogen programmes and many of them – Europe, USA, Japan and New Zealand – are considering coal as an option for the production of hydrogen. The European Commission's proposed Hypogen project – a €1.3 billion project to generate hydrogen and electricity produced from fossil energy sources including coal – is one such programme. Similarly, the US DOE FutureGen programme has a declared 10 year timescale to demonstrate hydrogen from coal gasification technology.

45. To become an attractive option in environmental terms, the production and use of hydrogen from coal would have to be combined with CO_2 capture and storage.

Integrated Gasification Fuel Cells

46. A hybrid system showing great promise is the integration of gasification with a fuel cell (IGFC). Fuel cells are capable of converting the chemical energy in a fuel, such as hydrogen, directly into electricity at high rates of efficiency and with almost no emissions. Emerging fuel cells have efficiency levels of 60%. They also produce very high-temperature exhaust gases that can either be used directly in combined-cycle or used to drive a gas turbine. IGFC hybrids have the potential to achieve near zero emissions, with the concentrated CO_2 lending itself to removal by separation or other capture means. The use of fuel cells has been demonstrated at the 2MWe size and plans are under way to use hydrogen from coal gasification in this and other technologies.

IV. REALISING THE VISION

(a) International R&D projects

47. Continued improvements in the performance of coal-fired power generation have been made possible by past research and development work undertaken in many countries and involving many organisations, in both government and industry. Such work continues, with the aim of leading us further down the road to lower emissions, towards the vision of an ultra low emissions future. Some of the projects involved are described in this section.

AD 700 Power Project – Europe

48. The AD 700 Power Plant involves collaboration between the European Commission and industry and is one of the projects financed by the EU's Fifth Framework R, D&D Programme. The focus is on establishing ultrasupercritical steam conditions, while at the same time developing improved power plant designs to minimise capital investment. The project aims to raise efficiencies to 55%, resulting in lower fuel consumption and a reduction in CO_2 emissions of almost 15%.

Canadian Clean Power Coalition (CCPC)

49. The Canadian Clean Power Coalition is a public-private partnership that aims to demonstrate CO_2 removal from an existing coal-fired power plant by 2007 and from a new power plant by 2010. CCPC comprises seven founding member companies representing over 90% of Canada's coal-fired electricity generation capacity, together with the Electric Power Research Institute, based in the USA. Phase I funding of C$5 million has allowed initial feasibility studies to proceed. The cost of the two plants will be around C$1 billion for CCPC over the next decade.

CANMET Energy Technology Centre – Canada

50. At the CANMET Energy Technology Centre – a key research arm of the Department of Natural Resources Canada – clean coal R&D focuses on a number of important areas. These include research into oxy-fuel combustion, so that flue gases from power stations might be made CO_2 rich (rather than diluted with nitrogen from the air) to eliminate the capture step prior to storage; fluidised bed combustion of steam coals for reduction of acid precursors; and mercury emission reductions from coal-fired power stations.

51. The research undertaken at CANMET – such as its bench- and pilot-scale R&D work on pressurised coal gasification, ceramic membranes for gas separation and catalysts – is enabling new responses to be developed to meet the environmental challenges facing coal use.

Carbon Sequestration Leadership Forum

52. The Carbon Sequestration Leadership Forum (CSLF) is an international initiative focusing on the development of carbon capture and storage technologies through collaboration. Some 15 countries, plus the European Commission, are involved in the Forum. The inaugural meeting was held in the USA in June 2003 and outlined the Forum's purpose: "To facilitate the development of improved cost-effective technologies for the separation and capture of carbon dioxide for its transport and long-term safe storage; to make these technologies broadly available internationally; and to identify and address wider issues relating to carbon capture and storage". The CSLF is important in that a structure has been put in place, recognising the importance of CCS

technologies and their future potential in meeting the environmental challenge of CO_2 emissions from coal-based electricity.

COAL21 – Australia

53. COAL21 is a major initiative of the Australian Coal Association, involving key stakeholders across industry, government and researchers, working to develop and initiate a strategy to move Australia along the road towards near-zero emission electricity production from coal. The programme started in early 2003 with an extensive 12-month consultative process. This culminated in the release in early 2004 of a zero-emissions coal technology roadmap and action plan for Australia focusing on the trial and demonstration of key technologies (see diagram on page 14). The second phase of the project will include the development of an implementation strategy to realise the action plan.

EAGLE Project – Japan

54. The New Energy and Industrial Technology Development Organization (NEDO) is undertaking a major project to develop coal gasification for use in fuel cells. The project is known as EAGLE (coal Energy Application for Gas, Liquid and Electricity). A pilot plant has been constructed, with a coal processing capacity of 150 tonnes/day, which aims to develop a coal gasifier suitable for IGFC.

55. The project, which started in 1998 and is due to run until 2006, is part of a broader initiative involving the incorporation of fuel cells within an integrated gasification combined cycle. The integrated coal gasification fuel cell combined cycle system should achieve efficiencies of at least 53-55%. Deployment of IGCC-fuel cells in Japan is expected to begin in 2010, with the introduction of 50MWe distributed power generation installations, followed by the introduction of a 600MWe system for utility use by 2020.

FutureGen – USA

56. The US$1 billion FutureGen project was launched in 2003 to demonstrate a near-zero emission 275MWe coal-fuelled IGCC plus hydrogen production plant, incorporating CO_2 separation together with geological storage. The project is intended to create the world's first zero-emissions fossil fuel plant which, when operational, will be the cleanest fossil fuel-fired power plant in the world. Cooperation between government, industry and international partners is a key element of the FutureGen project.

ZECA – USA/Canada

57. ZECA Corporation is the successor to the Zero Emission Coal Alliance, which was founded in 1999 by The Coal Association of Canada, Los Alamos National Laboratory and 16 other organisations. The ZECA Corporation is researching the development of the hydro-gasification process, whilst also cooperating with researchers who are looking into mineral carbonation as a route to CO_2 disposal.

V. CONCLUSION

58. Coal use need not be incompatible with environmental protection. In many areas – notably the reduction of particulates and acid emissions – this has already been achieved or is within reach.

59. Significant reductions in CO_2 emissions from coal-fired power stations have already been achieved through increasing efficiency. However, the road to sustainable coal consumption involves going further and achieving major reductions through the development and application of zero emissions technology. Zero emissions will not be achieved overnight, but a realistic pathway can be identified leading to substantial and sustained emissions reductions.

60. An ultra low emissions future is achievable with the development and deployment of the next generation technologies. It will require effort and commitment and may well also require specific incentives and support – it is unlikely that carbon capture and storage will be commercial activities in themselves, except in very specialised circumstances. However, if the world decides that it needs to make very substantial reductions in greenhouse gas emissions, the magnitude of the challenge means that it will need to ensure that it continues to explore and develop all the potential routes to this goal.

61. With a favourable policy environment to facilitate the continued deployment of existing clean coal technologies and the development of the next generation of technologies, the vision of an ultra low emissions energy production system for the 21st century can be realised. The coal industry is committed to working with others to achieve this goal.