UNITED NATIONS

E

Economic and Social Council

Distr.
GENERAL

ENERGY/GE.1/2002/8
4 September 2002

Original: ENGLISH

ECONOMIC COMMISSION FOR EUROPE

COMMITTEE ON SUSTAINABLE ENERGY

Ad Hoc Group of Experts on Coal and Thermal Power
Fifth session, 18-19 November 2002

CARBON SEQUESTRATION – AVOIDING CO_2 EMISSIONS FROM FOSSIL FUELS
An Overview of Technology Options and International Initiatives

Note by the secretariat

I. INTRODUCTION

1. The objective of this paper is to provide a non-technical overview of the concept of carbon sequestration. A brief introduction to a selection of the current array of international collaborative R,D&D (research, development and deployment) efforts and initiatives, involving both the public and private sector, to develop carbon sequestration technologies is also included. The paper, additionally, serves to highlight a number of publications, reports and websites that provide more in-depth information and reviews of sequestration initiatives worldwide as well as specific projects.

2. It is intended that the paper serve as a background document for the UNECE Workshop on 'Carbon Sequestration', organised jointly by the Committee on Sustainable Energy and the Ad Hoc Group of Experts on Coal and Thermal Power, in Geneva, 19 November 2002.

3. The focus of the paper is on carbon dioxide (CO_2). Estimates indicate that the production and use of fossil fuels contributes to 64% of anthropogenic greenhouse gas (GHG) emissions worldwide and that power generation from fossil fuels is responsible for over one-third of global annual CO_2 emissions. Despite CO_2 having a lower Global Warming Potential (GWP) than other GHGs, its sheer abundance combined with its increasing emission levels indicate that if concentrations of GHGs in the atmosphere are to be decreased, significant reductions in fossil fuel generated CO_2 emissions would be needed. For public and policy acceptance fossil fuels need to respond to the challenge of today's increasingly carbon constrained world. Coal, as the most carbon intensive of all the fossil fuels, has the greatest opportunity to make a difference in providing a solution to reducing CO_2 emissions.

GE.02-32376

4. Given the forecast increases in global population and energy demand, one of the most pressing and challenging issues facing the international community is how to simultaneously achieve energy security, economic growth, poverty alleviation and environmental protection for all. Fossil fuels (coal, natural gas and oil) currently supply nearly 80% of the world's commercial and non-commercial primary energy needs – see Table 1. However, this figure rises to 85% if just commercial energy is examined. Fossil fuels additionally account for just under 65% of global electricity generation (coal, 38.1%; gas, 17.1%; and oil, 8.5%) and 97% of the energy for transportation. In response to a burgeoning population global energy use is forecast to increase by 75% by 2020, with most of the demand met by abundant and affordable fossil fuels. Despite the urgent desire of the international community to shift to a low carbon economy, fundamental changes to the world's energy system cannot take place rapidly. It is recognised that extensive research and development programmes on a wide range of technologies will be necessary if the world is to look to achieve the massive reduction in GHGs currently being sought.

Table 1: Total World Primary Energy Consumption (% by fuel, 1999)

FUEL SOURCE	**%**
Coal	23.5
Natural Gas	20.7
Oil	35
Nuclear	6.8
Hydro	2.3
Combustible Renewables and Waste	11.1
Other, including Geothermal, Solar, Wind and Heat	0.6

Source: International Energy Agency Key World Energy Statistics, 2001 Edition

5. There are a limited number of options currently available for reducing GHGs arising from the generation of energy, notably (i) improving efficiency of energy conversion and utilisation thereby reducing energy consumption; (ii) use of low-carbon fuels e.g. fuel switching from coal to natural gas; (iii) enhancing the natural 'sinks' for CO_2, e.g. forests, soil and ocean, which all draw down CO_2 from the atmosphere, and (iv) use of energy sources with very low CO_2 emission, such as renewable or nuclear energy. Carbon sequestration of CO_2 from fossil fuel combustion has now emerged as a fifth option.

6. Carbon sequestration, sometimes referred to more broadly as carbon management, is commonly defined as "the capture and secure storage of carbon emitted from the global energy system". Carbon sequestration offers significant potential to reduce GHGs at costs and impacts that are economically and environmentally acceptable.

7. Although only in its infancy, due to the potential of carbon sequestration to sustain the use of fossil fuels by reducing GHGs, carbon sequestration technologies are being aggressively explored, technologies ranging from CO_2 injection into geologic formations or the deep ocean, stimulation of natural biological terrestrial and oceanic CO_2 sinks, air extraction of CO_2, mineral carbonation, and novel methods to generate fossil fuel-based energy that facilitate CO_2 recovery. All are at various stages of development ranging from being operational on a small scale, to field-experimentation, to laboratory prototypes, to conceptual designs. However, notwithstanding the potential they offer, significant work still needs to be undertaken to examine and understand the feasibility, scalability, environmental impacts and risks, and implementation costs and time-constants of these technologies.

8. The potential importance of capture and storage of CO_2 in mitigating climate change has now been acknowledged by the International Panel on Climate Change (IPCC), which is convening a Workshop on Carbon Capture and Storage in Regina, Canada, 19-21 November 2002. The IPCC was established jointly by the World Meteorological Organization (WMO) and the United Nations Environment Programme to: (i) assess all available factual information on the science, the impacts and the economics of climate change and on the adaptation/mitigation options to address climate change; (ii) assess, and if necessary develop, methodologies such as the IPCC Guidelines for National GHG Inventories and (iii) provide, on request, scientific/technical/socio-economic advice to the Conference of the Parties to the United Nations Framework Convention on Climate Change and its bodies. The issue of carbon capture and storage has, however, received little attention in the IPCC's Third Assessment Report (TAR) due to limited published scientific information, hence, the IPCC's recent decision to hold a workshop, which will result in a scoping paper defining future action on the issue.

9. The IPCC Workshop is extremely comprehensive in its coverage addressing issues including: sources of CO_2 and technologies for CO_2 capture; transport of CO_2 from capture to storage; geographical potential of the technology; re-use of captured CO_2 in industrial applications; CO_2 storage options, including: deep saline water-bearing formations (saline aquifers), depleted oil and gas reservoirs, oil reservoirs that may be used for CO_2 Enhanced Oil Recovery (EOR), deep coal seems containing methane (Enhanced Coal Bed Methane Recovery, ECBM), and deep ocean storage; costs and energy efficiency of CO_2 capture and storage in comparison with the costs of other large-scale options, especially in the area of electricity generation and use; implications of large-scale introduction; long-term technological and economic implications of carbon storage technologies (e.g. hydrogen, H_2); environmental impacts; risks and risk management during capture, transport and storage; monitoring of CO_2 storage; impediments and barriers to the implementation of geologic carbon storage; modelling of CO_2 storage in energy and climate models; implications for national and international emission inventories; and legal aspects.

II. CAPTURE OF CO_2

10. Capture and storage are best suited to large point sources of CO_2 such as fossil fuel-fired power stations, which currently account for around one-third of global CO_2 emissions. The following fossil fuel based power generation technologies have been considered for CO_2 capture:

- Pulverized coal fired plant equipped with flue gas desulphurisation (PC + FGD)
- Natural gas combined cycle power plant (NGCC)
- Integrated Coal Gasification Combined Cycle (ICGCC)
- Pulverized coal-fired plant incorporating O_2/CO_2 flue gas recycling combustion (O_2/CO_2 Recycle

11. There are currently three main approaches to CO_2 capture: flue gas approach, oxygen combustion approach and Hydrogen/syngas approach. A fourth approach, Novel Concepts, is under exploration.

(i) **Flue Gas Approach**: in this approach, also known as Post-Combustion Capture, the CO_2 is captured from combustion products in power plant flue gas or industrial exhaust. The selection of capture technology depends on the properties of the flue gas. Flue gas separation and capture methods include:

Absorption – CO_2 can be removed from flue gases using solvents that rely on chemical or physical absorption – this method is also known as solvent or amine scrubbing. The most common solvents used for neutralizing the CO_2 in chemical absorption systems are alkanolamines, such as monethanolamine (MEA).

Adsorption – solid absorbents (materials with high surface areas) such as zeolites and activated carbon, can separate CO_2 from gas mixtures.

Cryogenics/CO_2 Recycle – CO_2 can be separated from other gases by cooling and condensation. Cryogenic separation is widely used commercially for purification of CO_2 from streams that already have high CO_2 concentrations.

Membranes – gas separation membranes rely on differences in physical or chemical interactions between gases and a membrane material, causing one component to pass through the membrane faster than another. With regard to CO_2 capture, two types of membrane systems are applicable: gas separation membranes (ceramic and polymeric) and gas absorption membranes.

(ii) **Oxygen Combustion Approach**: also known as O_2/CO_2 recycle or flue gas recycle combustion. In this approach the nitrogen (N_2), the major component of flue gas, enters with the combustion air and limits CO_2 concentrations.

(iii) **Hydrogen/Syngas Approach**: this is considered a pre-combustion capture technology that removes the carbon content of fossil fuels (decarbonization) and produces a CO_2-rich by-product stream. It is an approach used for both H_2 production and electricity generation.

(iv) **Novel Concepts**: this by definition is a dynamic category and includes innovative approaches to carbon sequestration. These concepts have not yet been proven, but may offer potential breakthroughs in a technology that is in its infancy. Novel concepts include: new power cycles; chemical looping; dry ice co-generation; biological CO_2 fixation with algae, hydrate formation; direct capture of CO_2 from air; and, zero emissions coal (ZEC) power plant.

Pre-Combustion Capture

12. The low concentrations of CO_2 in power station flue gas mean that a large volume gas needs to be handled resulting in large equipment sites and high capital costs. The low CO_2 concentration also poses an added disadvantage in that powerful solvents have to be used to capture the CO_2 and regeneration of the solvents, to release the CO_2, requires a large amount of energy. If the CO_2 concentration and pressure could be increased, the CO_2 capture equipment required would be much smaller and different solvents could be used, with lower energy penalties for regeneration. This can be achieved by pre-combustion capture, when the fuel is reacted with oxygen or air, and in some cases steam, to produce carbon monoxide (CO) and hydrogen. The CO is reacted with steam in a catalytic reactor, called a shift converter, which results in more CO_2 and H_2. The CO_2 is separated and the H_2 is used as fuel in a gas turbine combined cycle plant. The process is, in principle, the same for coal, oil and natural gas.

III. TRANSPORTATION OF CO_2

13. Following capture, the CO_2 needs to be transported either by high pressure pipeline or by tanker to its future storage location, a long-term geological site on land or offshore to the deep ocean. CO_2 is largely inert and easily handled. Additionally, considerable existing offshore oil and gas pipeline infrastructure offers the potential to support offshore CO_2 storage sites. The IEA Greenhouse Gas R&D Programme (IEAGHG) currently compiles CO_2 pipeline design data.

14. Although CO_2 is not currently transported by ships, tankers similar to those used for liquefied petroleum gas (LPG) could be used and there are plans to commercialise larger volume tankers, up to one million tonnes (Mt), if the vessel can be used solely for CO_2 transportation.

IV. UTILIZATION OF CO_2

15. Following capture, the CO_2 can then be utilized or stored so avoiding its release into the atmosphere. Currently the largest use of CO_2 is for approximately 70 active enhanced oil recovery (EOR) operations, located predominantly in Canada and the United States. Other current uses for CO_2 include: chemical feedstock, food production, fish farms, agricultural greenhouses, conversion to fuels, and manufacture of stable products such as carbonate minerals. Commercial markets for CO_2 are, however, limited compared to the volume of CO_2 emitted annually. For example, it is estimated that in the United States approximately 40 Mt of CO_2 are used per annum by industry, which represents only about 2% of the total annual emissions from power plants in the United States. Hence, the reuse of CO_2 from power plants is a very limited option.

V. STORAGE OF CO_2

16. Following capture, the other option to avoid release of the CO_2 to the atmosphere is storage. Storage options range from geologic formations, the deep ocean to natural sinks, such as the ocean and terrestrial ecosystems. The preliminary estimates of the worldwide capacity of potential CO_2 sites are presented in Table 2. Total global anthropogenic CO_2 emissions amount to the equivalent of 7 GtC – with this figure in mind, Table 2 clearly demonstrates that the potential global CO_2 storage capacity is massive.

Table 2: Global Capacity of Potential CO_2 Storage Sites, Gigatons of Carbon (GtC)

Sequestration Option	Global Capacity (GtC)
Ocean	10,002
Deep Saline Formations	100s - 1,000s
Depleted Oil and Gas Reservoirs	100s
Deep Unmineable Coal Seams	10s - 100s
Terrestrial Ecosystems	10s
Utilization	Less than 1 GtC per annum

Source: Solutions for the 21st Century, Zero Emissions Technologies for Fossil Fuels, Technology Status Report, May 2002, IEA WPFFF (from Herzog, H., 1999 and United States Department of Energy, 1999)

17. The overriding objective of CO_2 sequestration is the development of effective, verifiably safe and environmentally sound CO_2 storage sites that meet public approval. The future viability of sequestration is dependent upon this objective being met.

18. Whilst the storage of CO_2 in terrestrial ecosystems poses no health, safety or environmental risks, the potential environmental and safety impacts of CO_2 storage in geologic formations and the ocean are not yet fully understood predicating further investigation and study.

19. Storage options for CO_2 include:

A. GEOLOGIC FORMATIONS

Depending upon the formation used, the CO_2 can be sequestered by a combination of three main mechanisms: hydrodynamic trapping, where the CO_2 is trapped as a gas or supercritical fluid; solubility trapping, where the CO_2 dissolves into the fluids; and, mineral trapping, where the CO_2 reacts directly or indirectly with minerals and organic matter in the formation to become part of the solid mineral matrix.

(i) Oil and Gas Reservoirs:

Abandoned or active and uneconomical oil and gas reservoirs, in particular where EOR is an option, offer storage options. In EOR operations, CO_2 is injected into oil reservoirs to increase the mobility of the oil and hence increase the productivity of the reservoir. The majority of the CO_2 remains in the reservoir, but that which is produced along with the oil is generally separated, recompressed and injected back into the reservoir. Natural gas fields have also demonstrated the ability to store gases for millions of years and could potentially offer another CO_2 storage option; however, unlike oil reservoirs CO_2 is not currently used to enhance the recovery of natural gas.

Due to their attributes and the extent of current knowledge and experience, oil reservoirs requiring EOR are leading contenders for near-term CO_2 sequestration. The PanCanadian Weyburn EOR CO_2 Monitoring Project in Saskatchewan, Canada, which involves the first commercial injection of CO_2 captured from the Great Plains Synfuels (coal gasification) Plant in North Dakota, United States, will be the largest CO_2 flood in Canada. About 20 Mt of CO_2 will be injected and permanently stored into the reservoir over the project's life and at least 130 million additional barrels of incremental oil are projected to be recovered. Although a number of commercial EOR projects have been undertaken, the Weyburn EOR project is unique because of the oil field's extensive historical database, which is currently being used to gain an improved understanding of the site's storage potential.

(ii) Deep Saline Aquifers:

These aquifers are widely dispersed below the continents and the ocean floor and are within close proximity to a number of power plants. Aquifers are typically formed in carbonate or sandstone formations and the aquifers that are filled with unpotable (e.g., brackish or saline) water and have a low permeability cap rock (i.e. an impermeable rock that will not allow fluids through) are considered suitable for CO_2 storage. The aquifer's pore structure allows gases and liquids to flow through the bed. When CO_2 is injected into a water filled saline aquifer, it displaces the water without mixing together to form a single fluid phase. Because CO_2 is soluble in water, some of the CO_2 dissolves. In some formations, CO_2 can react slowly with minerals to form carbonates, permanently sequestering the CO_2. Injecting CO_2 into deep saline reservoirs involves techniques similar to those used in EOR. A current example of deep aquifer sequestration that has proved to be technically feasible, and the only commercial CO_2 geologic sequestration facility worldwide, is Statoil's Sleipner CO_2 Storage Project. Since October 1996, approximately one Mt of CO_2 from Norway's Sleipner West gas field have been injected annually into the Utsira Sand formation, a saline aquifer located around 1,000 metres below the floor of the North Sea and associated with the Sleipner West Heimdel gas reservoir. The CO_2 is a natural part of the hydrocarbon gas that needs to be separated prior to pipeline export. Instead of being vented to the atmosphere the CO_2 is captured, compressed, dried and injected into the Utsira formation.

(iii) Deep Unmineable Coal Beds:

These coal beds offer a potential storage medium for CO_2, but with added value. Coalbed methane (CBM) is a naturally occurring gas found in coal seams worldwide. CBM reserves can be exploited commercially by the drilling of CO_2 injection and production wells, after which the methane (CH_4) produced is purified prior to sale. Such CH_4 production can be enhanced by injection of CO_2 into coal formations, a technique known as enhanced coalbed methane extraction (ECBM). At least two to three molecules of CO_2 are sequestered for each molecule of CH_4 produced. Provided the coal seam is never mined the CO_2 will be permanently sequestered. Favourable geology is the key technical criteria for successful implementation of ECBM.

(v) Mineralization:

It is possible to react CO_2 with naturally occurring minerals such as magnesium silicate to form stable, environmentally benign carbonates. This is a process that occurs naturally over long time periods; however, in order to sequester CO_2, the objective is to accelerate the reaction rate of the process. Los Alamos National Laboratory (LANL), United States, is currently studying the feasibility of designing the conditions that will allow the transformation to occur at sufficiently rapid rates.

20. The range of geologic storage options potentially offer effective, safe and environmentally acceptable CO_2 storage sites. However, ongoing R&D is required to answer a range of uncertainties as to whether underground CO_2 storage is, reliable, safe and effective; how quickly and under what conditions the CO_2 might migrate to the surface; and, how long the CO_2 can in fact be stored underground.

B. OCEAN STORAGE

21. The transfer of CO_2 from the atmosphere to oceans is a natural process that occurs as part of the carbon cycle. In certain cold water areas CO_2 can also be transferred to the deep ocean – the lower the temperature of the water the more soluble the gas. The ocean holds an estimated 40,000 GtC, which is equivalent to around 50 times that of the atmosphere – its capacity is also much larger than that of the atmosphere. Two approaches are being considered for ocean sequestration: direct CO_2 injection and indirect sequestration via the enhancement of CO_2 uptake from the atmosphere using iron fertilization.

(i) Direct CO_2 Injection into Deep Oceans:

In this approach, CO_2 captured from large point sources is transported to the injection site by sub-sea pipeline or tanker. The CO_2 is injected at various depths in gaseous, liquid or solid form, where it will behave differently according to its form and the depth of discharge. The retention time of CO_2 injected into oceans depends on the depth at which it is injected. This is because water temperatures decrease significantly with depth and, cooler, denser water moves more slowly. The direct injection approach is best suited to large, stationary sources of CO_2 with access to deep ocean sequestration sites. Model simulations and studies indicate that deep injection of CO_2 offers a potentially effective way of sequestering CO_2 in the ocean for hundreds of years of more. However, R&D is still required to fully understand the environmental and biological implications of this approach.

(i) Ocean Fertilization:

There is a naturally occurring process, known as the 'biological pump', by which phytoplankton growing in the surface waters of the ocean are consumed by larger plant life, which are in turn consumed by fish. An estimated 70-80% of the fixed carbon is recycled to surface waters with the remaining organic matter being remineralised to CO_2 by bacteria on the ocean floor. Introducing iron, which acts as a fertilizer, into areas with relatively low phytoplankton growth leads to increased storage of CO_2 in the ocean floor. General understanding of small-scale ocean fertilization is in its infancy.

C. TERRESTRIAL ECOSYSTEMS

22. Terrestrial ecosystems cover vegetation, plants, trees and soils, microbial and invertebrate communities. The transfer of carbon to terrestrial ecosystems is known as the terrestrial carbon cycle. During this cycle carbon enters the system in a variety of ways, including photosynthesis and decomposition of animal manure, and is then stored either above aground (in trees and plants) or below ground (in soils, roots and microorganisms). The carbon can, however, be released as a result of overgrazing, poor land management practices, soil erosion and deforestation.

23. The objective of terrestrial carbon sequestration is to increase the levels of atmospheric CO_2 that are stored in terrestrial ecosystems, through practices such as enhanced plant growth, reforestation and land restoration. An additional approach is to protect existing ecosystems that store carbon so that sequestration can be maintained or increased. The near-term benefits of carbon sequestration in terrestrial ecosystems are manifold: increased atmospheric CO_2 uptake; improved soil quality; enhanced efficiency of water use and storage; improved crop and biomass yields; decreased risk of soil erosion, and rehabilitation of degraded land.

24. In order to maximise the storage potential of terrestrial ecosystems additional R&D is required, particularly in the areas of storage capacity measurement and verification of storage rates.

VI. ECONOMIC CONSIDERATIONS

25. One of the key challenges facing carbon sequestration is the issue of economics. In order to play a key and full role in GHG mitigation strategies the technologies must be cost competitive.

26. The strategic objective of carbon sequestration for the fossil fuel industry is to develop technologies that allow the economically viable separation, capture, transportation and sequestration of CO_2 from flue gases. The specific objectives are to reduce costs by one-half over today's best available technology for existing facilities, and by three-quarters for new facilities, by the end of 2003.

27. Under present technology, the cost of CO_2 capture and storage in new power plant is currently about US$100-300 per ton of carbon emissions avoided and costs are expected to fall in future as the sequestration technologies mature. The United States Department of Energy (DOE) has a long-term goal of reducing total sequestration costs to US$10 or less per net ton of carbon emissions avoided and is seeking to accomplish this by 2015. Achieving this goal would save the United States trillions of dollars.

VII. OTHER CONSIDERATIONS

28. A number of other issues need to be addressed on the pathway to maximising the full potential of carbon sequestration. These issues include: legal aspects, there is currently no legal framework for carbon sequestration projects and areas such as liability, licensing and leakage will need to be addressed; environmental, health and safety concerns, there are a number of potential environmental, health and safety risks associated with carbon sequestration that predicate a full risk assessment, particularly with regard to geologic storage; and, public education and community dialogue, the viability of carbon sequestration as a tool to mitigate GHGs is largely dependent on public and policy acceptance and to achieve this will require early engagement through open and public dialogue.

VIII. INTERNATIONAL INITIATIVES AND RESEARCH PROGRAMMES

29. The significant potential offered by carbon sequestration to mitigate CO_2 emissions from the use of fossil fuels is clearly acknowledged by the extent of the international attention it is receiving. A number of countries have now established broad national research programmes on carbon sequestration with impressive budgets. These countries, the majority of which are also involved in international collaborative initiatives, include: Australia, Canada, Denmark, Japan, Netherlands, Norway, United Kingdom and United States. The European Commission through its Research Directorate General 'Preserving the Ecosystem Research Actions for Energy' is also a strong supporter in a number of international collaborative carbon sequestration research projects.

Australia: the Commonwealth Scientific & Industrial Research Organization (CSIRO) undertakes activities relating to zero emissions technologies for power generation and assessments of technical and economical feasibility of CO_2 sequestration from domestic coal and gas-fired power stations. Additionally, a joint Australian Petroleum Cooperative Research Center (APRC), government and industry research project called GEODISC (Geological Disposal of Carbon Dioxide), is assessing the feasibility of sequestering large volumes of CO_2 into geological formations within Australia.

Canada: there has been a long term interest in Canada in CO_2 capture, storage and utilization technologies, with early work focussing on EOR by CO_2 injection. Canada established a national initiative on CO_2 capture and storage in 1998. A wide range of organisations and research bodies are active in the field, including: Alberta Geological Survey, Alberta Research Council, Geological Survey of Canada, National Coal Inventory, Natural Resources Canada CANMET Energy Technology Center, Petroleum Technology Research Center, and ZECA Corporation. A selection of the vast array of current domestic and international collaborative initiatives, involving public and private sector partnerships, is highlighted below:

- Assessment of CO_2 Storage Capacity of Deep Coal Seams in the Vicinity of Large CO_2 Point Sources in Central Alberta
- CANMET CO_2 Consortium
- Canadian Clean Power Coalition
- Enhanced Coalbed Methane Recovery for Zero Greenhouse Gas Emissions
- International Test Center for CO_2 Capture
- Oxy-Fuel Field Demonstration Project
- Sequestration of Carbon Dioxide in Alberta's Oil and Gas Reservoirs

- Sequestration of Carbon Dioxide in Oil Sands Tailings Streams
- Weyburn CO_2 Monitoring and Storage Project
- Zero Emissions Coal Alliance

Denmark: although there are currently no domestic carbon sequestration projects, the Danish Geological Survey is active in a number of international projects, in which it is assessing geologic storage capacity and sites.

European Commission: the European Commission's Research Directorate General 'Preserving the Ecosystem Research Actions for Energy' is a strong supporter in a number of international collaborative research projects, including:

- SACS (Saline Aquifer Storage)
- CO_2 Store
- GESTCO (European Potential for Geological Storage of CO_2 from Fossil Fuel Combustion)
- CO_2 Net and its successor CO_2Net2
- Weyburn CO_2 Monitoring and Storage Project
- NASCENT (Natural Geologic Analogues Research)
- AZEP (Advanced Zero Emission Power Plant)
- GRACE (CO_2 capture from refinery H_2 generation and from oxyfuel combustion with subsequent CO_2 storage in saline aquifers, coal beds, or EOR)
- RECOPOL (Reduction of CO_2 emission by means of CO_2 storage in coal seams in the Silesian Coal Basin of Poland); and
- NGCAS (optimisation of geologic storage and assessment of long-term risks)

Japan: Japan has the largest and longest running carbon sequestration programme. Significant CO_2 capture and storage research activities first commenced in Japan in 1989 as part of the Government's New Earth 21 Programme, following which the Research Institute of Innovative Technology (RITE) was founded. RITE's programme of work in this area largely focuses on CO_2 sinks and capture options including biological fixation. Two such projects are: Biological CO_2 Fixation and Utilization and CO_2 Fixation in Desert Area using Biological Function. A number of large projects on CO_2 storage in deep oceans and deep saline reservoirs are also underway in Japan. Additionally, the Japan Coal Energy Center (JCOAL) is promoting CO_2 sequestration technology. JCOAL is a member of the Japan Forum on CO_2 Sequestration in Coal Seams, which aims to demonstrate and industrialize an economical, stable and safe coal seam CO_2 sequestration technology by 2010.

Netherlands: a number of projects are underway, including: development of a membrane gas absorber for capture of CO_2 in cogeneration plants; a study on the technical and economic feasibility of domestic ECBM by the Netherlands Agency for Energy and the Environment (NOVEM); and, preparation of an R&D Inventory of CO_2 Removal.

Norway: in 1997 the Norwegian Research Council established the Norwegian National Climate Technology Programme (KLIMATEK). KLIMATEK is a five year US$70 million programme to promote the R,D&D of technologies for reducing GHGs. Some 50 projects are included in KLIMATEK's current portfolio and these largely involve offshore petroleum production, process industry, gas-fired power production with CO_2 capture and CO_2 storage. KLIMATEK has and is supporting a wide range of zero emissions projects. Norwegian companies are also involved in international collaborative carbon sequestration projects.

United Kingdom: the United Kingdom Department of Trade and Industry (DTI) maintains several programmes that develop technologies and processes that seek to improve environmental performance and sustainable development whilst maintaining fossil fuels as part of the power generation mix. One of DTI's most important projects is the Cleaner Coal Programme, a six-year collaborative programme of activities linking R&D with technology transfer and export promotion. In addition to its national activities, such as Alstom Power's GAS-Zero Emissions Plant (GAS-ZEP), the UK is very active in the IEA GHG R&D Programme and international collaborative carbon sequestration projects including: SACS, GESTCO, Weyburn CO_2 Monitoring and Storage Project, and NASCENT.

United States: the United States Department of Energy (DOE) has an extensive Carbon Sequestration Program, which is administered by the DOE's Office of Fossil Energy (www.fe.doe.gov/coal_power/sequestration/index.shtml) and the National Energy Technology Laboratory (NETL; www.netl.doe.gov/coalpower/sequestration). The program's portfolio covers the entire carbon sequestration 'life cycle' of capture, separation, transportation, and storage or reuse, as well as research needs for the two other major energy related greenhouse gases of concern, CH_4 and nitrous oxides (N_2O).

Specifically, the US Carbon Sequestration Program has six elements: (i) cost-effective CO_2 capture and separation processes; (ii) CO_2 sequestration into geologic formations; (iii) direct injection of CO_2 into the deep ocean and stimulation of phytoplankton growth; (iv) improved full life-cycle uptake of terrestrial ecosystems; (v) advanced chemical, biological, and decarbonization concepts; and, (vi) models and assessments of costs, risks and potential of carbon sequestration technologies. The programme, with total funding of about US$100 million, sponsors some 60 projects. Industry's share is equivalent to 40% of the total. In the 2002 financial year (FY) the programme was funded at US$30 million and there is a request of some US$50 for the FY 2003. The vision of the programme is to bring the carbon sequestration concept to commercial deployment by 2010.

30. A vast array of international R&D collaborative projects and programmes are underway worldwide, which are sponsored by a combination of national R&D programmes, international organizations and industrial companies. Three of the leading initiatives are highlighted below.

IEA Greenhouse Gas R&D Programme (IEAGHG)

31. IEAGHG is the leading international collaborative programme on technologies for reducing GHG emissions from the use of fossil fuels. It conducts technical and engineering evaluations of technology options as well as identifying targets for research, development and demonstration and then facilitating the progress of such activities. It promotes and disseminates the knowledge and results of this work so as to enable decisions on mitigation options to be made with the best available information. Established in 1991, IEAGHG operates under an Implementing Agreement provided by the International Energy Agency (IEA). In recognition of the need for global action on abatement/mitigation technologies, membership of the IEAGHG Programme is open to countries both inside and outside the IEA. There are currently 16 member countries, together with eight major and multi-national companies as industrial sponsors.

32. IEAGHG has conducted around 90 separate investigations of technologies, the results of which form the basis for much of the current understanding and published literature on the potential for CO_2 capture and storage to mitigate climate change. IEAGHG's published range of

technical reports, includes: ‘Putting Carbon Back into the Ground’, ‘Ocean Storage of CO_2’, ‘Greenhouse Gas Emissions from Power Stations’, ‘Carbon Dioxide from Power Stations’, Carbon Dioxide Capture from Power Stations’, and ‘Carbon Dioxide Utilisation’.

33. Further information on IEAGHG, its activities and publications is available at: www.ieagreen.demon.co.uk

Zero Emissions Technologies Strategy Initiative for Fossil Fuels (ZETs)

34. Preparations for the Zero Emissions Technologies Strategy Initiative for Fossil Fuel (ZETS) were launched in October 2001 by the International Energy Agency’s Working Party on Fossil Fuels (IEA WPFF) as its key strategic activity in recognition of the importance carbon sequestration and zero emissions technologies and the potential significant contribution they can make to stabilizing global CO_2 emissions if sufficient investments in R&D are made.

35. The development of the ZETs Initiative has been based on the following thinking: zero emissions technologies for fossil fuels concept may be new to many, but relevant R&D that builds on a wealth of industry experience has been underway throughout the world for a little more than a decade. For example, CO_2 capture technologies are routinely used by the oil, gas, and chemical industries. These technologies were not initially developed for carbon sequestration, but both the public and private sectors recognize the contribution they can make to achieve deep reductions in GHG emissions.

36. While CO_2 capture and sequestration is still in its infancy and receives substantially less R&D funding than other mitigation options, a number of research programmes have been established and initial R&D investments have been made by both government and industry. Added to which, a diverse and expanding array of technical processes are in different stages of development, a handful of demonstration projects are underway or being planned and some commercial success has been achieved. The most important issues facing the R&D community and industry are reducing costs and developing effective, verifiably safe and environmentally sound storage options that are acceptable to the public. Another major issue is the limited and declining investments in energy R&D.

37. Given the long term challenge of stabilizing GHG concentrations and the technologies that are required to meet that challenge, a significantly more robust and coordinated R&D effort is essential. International collaborative RD&D with an emphasis on large-scale demonstration projects through partnerships with industry, government and academia can leverage global efforts in advancing technological progress and to a certain extent offset the shortage of necessary public investments in relevant science and technology. On the other hand, an active dialogue with the public and policy makers is needed to identify the policy challenges in progressing technology at an increasing rate.

38. The overall objective of the ZETS Initiative is to facilitate the RD&D of zero emissions technologies for fossil fuels. This objective will be achieved by activities in four broad categories:

(i) **Communications:** Inform key decision-makers and the public throughout the world about the importance of zero emissions technologies for fossil fuels.

(ii) **Collaboration and Deployment:** Forge and implement WPFF member commitments to collaborate and develop and deploy zero emissions technologies for fossil fuels.

(iii) **Cooperation:** Facilitate cooperation with non-WPFF member countries to help them improve the efficiency and environmental performance of fossil fuel facilities.

(iv) **Safety and Security:** Explore how to enhance the safety and security of fossil energy systems and determine the technical implications, R&D needs and solutions.

39. The activities of the ZETS Initiative will complement the IEAGHG Programme, the Greenhouse Gas Technologies Information Exchange as well as the activities of the various IEA WPFF Implementing Agreements. They will work collectively to contribute to and build on industry and country activity to further advance the RD&D required to recognize the goal of zero emissions from fossil fuels.

40. The first products of the ZETs Initiative are the WPFF's Strategic Plan and a Technology Status Report (TSR). The ZETs TSR has been written with the aim of providing members of the scientific, technical and policy community, as well as non-governmental organizations and related stake holders, with easily accessible information about zero emissions technologies for fossil fuels and also the array of RD&D activity underway by both the private and public sectors worldwide. In order to convey these challenging concepts to a broader audience, the TSR is relatively non-technical in nature. Although zero emissions technologies for fossil fuels encompass removal of a range of emissions, the focus of the TSR is on technologies that primarily address CO_2. The report includes basic descriptions of both CO_2 capture technologies and the various storage options, provides the current status of each technology and then assesses the cost issues. Additionally, the report outlines R&D requirements, highlights some of the legal and environmental, public health and safety issues that must be addressed and finally catalogues international efforts in this important technology area.

41. <u>In view of its coverage and non-technical nature, the ZETs TSR is highly recommended to anyone seeking further information on zero emissions technologies for fossil fuels.</u>

42. Further information on ZETs, including downloadable copies of its Strategy and the first TSR, is available at: www.iea.org/impagr/zets/

<u>CO_2 Capture Project (CCP)</u>

43. The CCP is an international effort formed in 2000 that seeks to address the issue of reducing emissions in a manner that will contribute to an environmentally acceptable and competitively priced continuous energy supply for the world. With a current membership comprising nine of the world's leading energy companies (BP, ChevronTexaco, Eni, Norsk Hydro, PanCanadian, Royal Dutch Shell, Statoil and Suncor Energy), the CCP's primary objective is to develop new, breakthrough technologies to reduce the cost of CO_2 separation, capture, and geologic storage from combustion sources such as turbines, heaters, and boilers. The CCP will accomplish this objective by: performing benchtop research and development (engineering studies, computer modelling, laboratory experiments) to prove the feasibility of advanced CO_2 separation and capture technologies, specifically targeting post-combustion methods, pre-combustion decarbonization, and oxyfuel; developing guidelines for maximizing safe geologic storage, for measuring and verifying stored volumes, and for assessing and

mitigating storage risks; developing an economic model to establish lifecycle CO_2 separation, capture and sequestration costs for current and best technologies to compare alternatives and direct the research and development towards the most promising technologies; and, actively transferring and making available the new technologies to industry via publications, presentations, conferences, an Internet website, patent licenses and commercial services.

44. A distinctive aspect of CCP is its emphasis on collaboration and partnership with governments, industry, NGO's and other stakeholders. The members of the project recognize that the challenges associated with global climate change require solutions that are economically and socially acceptable to all. The CCP is currently leveraging an international commitment totalling approximately US$28 million over a two-year period from the European Union, IEAGHG, the Government of Norway (KLIMATEK Programme) and the United States (Department of Energy).

IX. CONCLUSIONS

45. Fossil fuels will remain the mainstay of energy production well into the twenty-first century. Availability of these fuels to provide clean and affordable energy is essential to achieve environmental protection and sustainable development at the global level. However, increased concentrations of CO_2 due to carbon emissions are expected unless energy systems reduce the levels of carbon emissions released to the atmosphere.

46. In order to achieve meaningful and deep reductions in global CO_2 emissions it will be necessary to fully exploit the potential offered by carbon sequestration, encompassing CO_2 capture, separation and storage or reuse. Carbon sequestration, together with reduced carbon content of fuels and improved efficiency of energy production and use, must play major roles if the world is to continue to enjoy the economic and energy security benefits that fossil fuels brings to the global energy mix.

47. By enabling the capture and permanent storage of CO_2 from fossil energy systems, carbon sequestration technologies offer pathways to the sustainable use of fossil fuels – and solutions to the goal of sustainable energy development. While many technical and engineering challenges lie ahead, the focus must be on (i) reducing costs to ensure the technologies are economically viable and cost-competitive, and (ii) developing effective, safe, long-term and environmentally benign storage options. In addition to addressing these challenges, legal issues need to be considered together with public health and safety aspects. Finally, the viability of carbon sequestration as a GHG mitigation strategy depends on public and policy acceptance, which will require an informed global community that is engaged in an open dialogue on the issues at both local and international levels.

48. The pathway to full deployment of carbon sequestration technologies will only be attained by sustained international collaborative R,D&D initiatives that include partnerships with industry, government and research bodies.

49. Carbon sequestration offers significant potential to reduce GHGs at costs and impacts that are economically and environmentally acceptable.

X. RESOURCE MATERIAL

50. During the preparation of this paper, the following reports and website were used as key resource material:

(i) IEA Committee on Energy Research and Technology Working Party on Fossil Fuels 2002, '***Solutions for the 21st Century, Zero Emissions Technologies for Fossil Fuels, Technology Status Report***'

(ii) IEA/UK Department of Trade and Industry 2000, '***Carbon Dioxide Capture and Storage***', DTI, London.

(iii) United States DOE National Energy Technology Laboratory Carbon Sequestration website, ***http://www.netl.doe.gov/coalpower/sequestration/index.html***.