
# Cleaner Fossil Energy Task Force

## Action Plan

Contents

# Introduction

The seven countries of the Asia-Pacific Partnership on Clean Development and Climate—Australia, Canada, China, India, Japan, the Republic of Korea, and the United States of America—are cooperating to meet both their increased energy needs and associated challenges, including those related to air pollution, energy security, and greenhouse gas intensities.

The Partnership has established public-private Task Forces in eight key sectors: (1) cleaner fossil energy; (2) renewable energy and distributed generation; (3) power generation and transmission; (4) steel; (5) aluminium; (6) cement; (7) coal mining; and (8) buildings and appliances. The Task Forces are designed to meet Partnership goals through international cooperation to facilitate the development, diffusion, deployment, and transfer of existing, emerging, and longer term cost-effective, cleaner, more efficient technologies and practices among the Partners through concrete and substantial cooperation to achieve practical results.

As a product of its first stage of collaboration, each Task Force has created an Action Plan which has been endorsed by the Policy and Implementation Committee. The Action Plans contain an initial set of priority activities for implementation. Some projects contained within the Action Plans may need to be refined or elaborated. Financial resources are needed for the implementation of the Action Plans. Some initial funding from some government and industry sources has already been identified for the implementation of projects. Partner countries will continue to work to mobilize further funding from both public and private sectors in order to bring about full implementation of the practical projects identified in the Action Plans and will continually develop new projects and add them to this set of activities.

# Sector Review

Coal, oil and gas will remain critical fuels for all seven Partner countries. Against a background of increasing energy demand in the Asia-Pacific region, there is a need to improve the efficiency and environmental performance of fossil fuel use. Significant opportunities exist today to achieve efficiencies and performance improvements in the stationary use of coal, oil and gas. The development and deployment of lower emissions technologies will be a key in delivering clean development and climate outcomes associated with fossil fuel use.

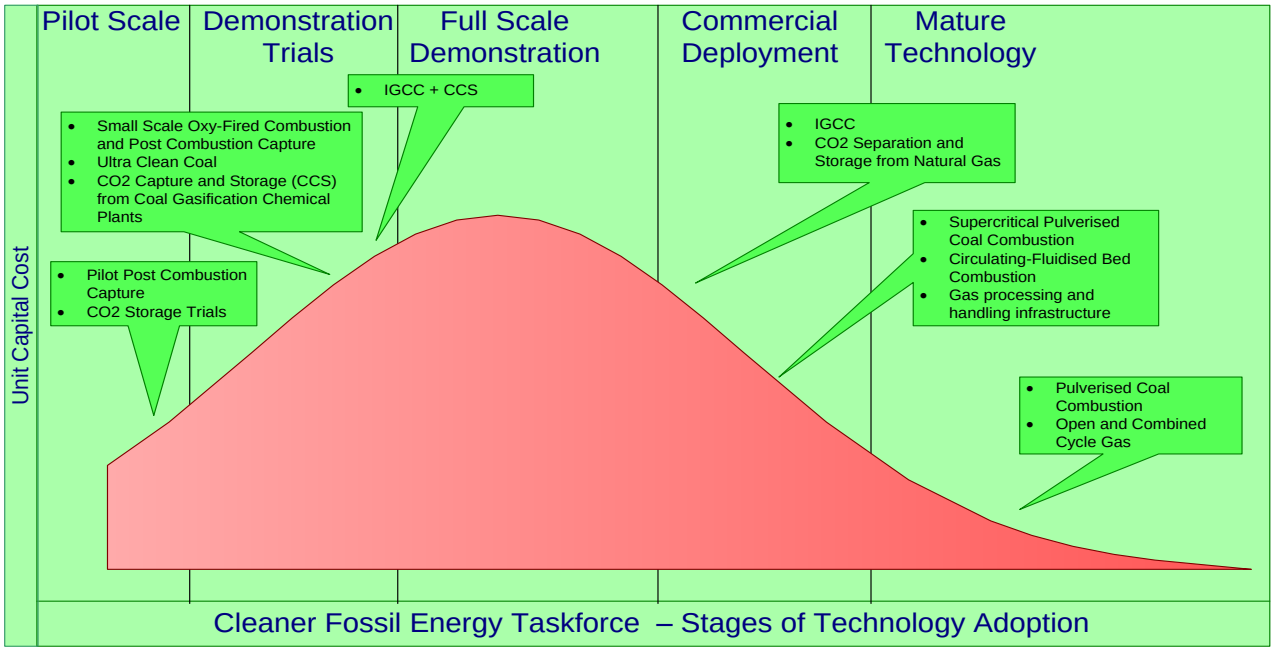
There is a range of key advanced coal, oil and gas technologies identified with the potential to significantly reduce greenhouse gas emission levels, air-borne pollutants and other environmental impacts. The use of carbon dioxide ($CO_2$) capture and storage (CCS) will be important in delivering significant greenhouse gas emission reductions from the use of fossil energy. These capture-enabling technologies include integrated coal gasification combined cycle (IGCC), oxy-fuel combustion, and post-combustion $CO_2$ capture. Other technologies, such as ultra-supercritical pulverized fuel, coal upgrading, gas hydrates and hydrogen technologies, coal bed methane, coal and gas liquefaction including poly-generation, co-gasification of coal/pet coke/residues/biomass are also important elements that need to be considered in developing a cleaner fossil energy strategy. A summary of key technologies is contained in Appendix D.

These technologies are at different stages of development. Relatively new technologies, such as post-combustion capture of $CO_2$ and oxy-fuel combustion, need to be trialed in pilot plants or small-scale demonstration plants. Other technologies, such as IGCC, are being demonstrated commercially and are now being planned by several utilities on a commercial basis. Supercritical power generation is a mature technology and development and deployment efforts are now focused on ultra-supercritical boilers, which are capable of achieving even higher efficiencies. For gas-fired power generation and city gas uses, small incremental improvements

in the technologies related to gas processing, handling and transportation are probably easy to achieve and may have significant benefit in reducing fugitive emissions.

**Figure 1** provides a general overview of the current stage of development for some of the key cleaner fossil energy technologies. This figure also illustrates the relatively high cost of developing and deploying new technologies compared to the cost of mature technologies. The unit cost of new technologies generally declines with increased market penetration and operating experience. However, significant cost differentials exist between plants that do not capture and store $CO_2$ and those that do. This cost differential needs to be reduced. A major mission for the Task Force is to support collaboration that reduces cost barriers and facilitates the deployment of low emissions technologies. Technologies need to be developed and deployed so that they enhance energy access and security, taking into account mature and efficient processes, such as those used in supercritical power stations.

**Figure 1 Technologies and Stages of Development/Diffusion**




In addition to technology solutions, the Task Force will consider opportunities to support the greater uptake of natural gas in Partner countries through market mechanisms. This will include identifying and addressing potential barriers to the delivery of liquefied natural gas (LNG) and cross-border pipeline gas, to help meet the rapidly growing need for high-quality, affordable and lower emission fuel for both stationary energy and transportation in Asia-Pacific Partnership countries.

The Task Force will develop a cleaner fossil energy work program that builds on and adds value to existing and prospective programs in each country. As can be seen from the overview of most Partner countries' clean fossil energy policies and activities in Appendix C, each Partner country has its own technology development and energy market access strategies. The Task Force will draw on industry and government participation from each country to help ensure that its activities are responsive to the sustainable development needs and priorities of each Partner.

## Objectives

The key objectives for the Task Force include:

- Accelerate demonstration, deployment and transfer of key technologies to improve environmental and economic performance of fossil fuel use.
- Build capacity, expertise and the research base in Partner countries needed to sustainably support development and deployment of cleaner fossil energy technologies.
- Share best practices and cleaner fossil energy technologies to increase their utilization and improve on their efficiency.
- Identify and, where possible, reduce and eliminate barriers to the uptake of cleaner fossil energy technologies and practices in Partner countries—including technology, policy, market, economic and regulatory barriers, barriers, and other barriers, such as those related to planning, approvals and licensing, finance, public acceptance, lack of appropriate information, and market structures and incentives.

## Partnership Actions

The responsibilities of the Cleaner Fossil Energy Task Force can be grouped under the five broad thematic areas contained in Table 1 below, which are the priorities for the Task Force. Further detail on the strategies to progress the objectives of the Task Force in relation to each of these thematic areas is contained in Appendix B.

**Table 1 Priority Thematic Areas for Task Force Actions**

| Themes | Possible Goals | Areas of Focus for Possible Projects and Activities |
|---|---|---|
| 1. **$CO_2$ Capture and Storage**: This covers capture and storage of $CO_2$ from natural gas production and fossil energy use, with geological storage to include enhanced oil and methane recovery. This theme is linked to technologies under themes 2 and 3 that enable the capture of $CO_2$ for storage. | • To develop commercial storage sites by 2015. | • Undertake measures including capacity building, general exchanges and information sharing, joint research to improve the development of $CO_2$ capture and storage technologies in Partner countries.<br>• Undertake evaluation of potential $CO_2$ capture & storage sites in Partner countries.<br>• Pilot $CO_2$ storage projects in Partner countries, if needed. |
| 2. **Post-Combustion Capture, Oxy-Fuel Combustion and Other Advanced Technologies**: This includes research, development, demonstration and commercial deployment of advanced combustion technologies, such as ultra clean coal and hyper coal, oxy-fuel combustion, post combustion capture and the application of CO2 capture to super/ultra-supercritical pulverized-coal power plants, and a range of advanced fluidized bed technologies that reduce emissions and support more efficient use of lower grade fuels. | • Commercial deployment of large-scale oxy-fuel and post-combustion capture technologies by 2015.<br>• Commercial deployment of advanced coal processing technologies for advanced combustion processes by 2015. | • Progress development of oxy-fuel combustion technology by facilitating and supporting medium- to large-scale demonstration projects.<br>• Progress development of post-combustion $CO_2$ capture technology by supporting pilot demonstration trials covering a range of different power stations and flue gas combinations.<br>• Support demonstration projects which progress the development of technologies (e.g., ultra clean coal, hyper coal) that allow the direct firing of coal in combined-cycle power stations.<br>• Identify barriers to supercritical and combined cycle gas technologies being the minimum standard for future power stations.<br>• Facilitate large-scale demonstrations of ultra supercritical, high performance turbines and fluidized beds. |
| 3. **Coal Gasification and Liquefaction**: This covers coal-based IGCC, with CCS and chemical plants with capture of pure $CO_2$. | • Commercial deployment of large-scale IGCC technology by 2015.<br>• $CO_2$ capture from chemical plants by 2015.<br>• Commence operation of large-scale demonstration of IGCC with CCS by 2015. | • Capture existing $CO_2$ streams from existing coal gasification plant and link in with a possible pilot $CO_2$ storage project.<br>• Facilitate deployment of IGCC power plants to improve the environmental performance of coal power.<br>• Build on and add value to proposed zero emission coal gasification power stations (e.g., FutureGen, GreenGen, ZeroGen).<br>• Facilitate gasification trials of alternative fuels, like pet coke, residues from refineries |
| 4. **Energy Market Access for Gas**: This involves identifying and addressing barriers to natural gas and LNG market penetration and growth. | • Reduce or remove significant barriers to domestic and cross-border natural gas trade to increase energy security of member countries by 2012. | • Technology improvements for natural gas usage<br>• Increased efficiency of natural gas-fired combined cycle electricity generation Gas/LNG market growth in Partner country economies.<br>• LNG interchangeability<br>• LNG public education |
| 5. **Gas Infrastructure & Utilization Improvements**: This includes efficiency gains and emissions reductions through application of improved or advanced gas processing, transport and utilization technology. | • Improved energy efficiency and environmental performance is achieved while enhancing energy security of member countries by 2012. | • Technology efficiency gains from gas processing and transportation.<br>• Reduced methane emissions from natural gas processing facilities and pipelines and LNG facilities.<br>• Increased efficiency of natural-gas fired cogeneration and district heating facilities.<br>• Increased efficiency of natural gas-fired industrial end-users,(e.g., brick kilns, glass/ceramics, and other materials and products) not included under Steel, Aluminum, and Cement Task Forces.. |

The identified themes highlight initial areas of focus for the Task Force and indicate the strategic basis for selecting and developing projects. The projects identified in this Action Plan reflect the focus of the themes, the stage of development of specific technologies, and the current capability to progress a project or activity. Additional projects will be identified and undertaken as the work of the Task Force progresses. The Task Force may establish working groups to provide guidance and advice and to support the implementation of activities and projects.

The Task Force recognizes the suite of international initiatives currently in place and the contribution Asia-Pacific Partnership countries are making to those efforts, including the Carbon Sequestration Leadership Forum and the Methane to Markets Partnership. In addition to these international activities, there are substantial domestic programs currently being progressed in member countries (see Appendix C). The activities and projects occurring under the auspices of this Task Force are intended to link, enhance and build on the substantial activities currently occurring through other international and domestic initiatives and programs.

In addition, there is considerable economic and technical work that cuts across the five areas which will use data from demonstration projects to add value to techno-economic evaluations of low emission technology, address gaps and add value to low emission technology R&D programs, and develop incentives to support demonstration and deployment of low emission technologies.

Appendix A contains project plan summaries proposed by Partner countries and endorsed by the Policy Implementation Committee in Korea on 11-13 October 2006.

# Appendix A: Project Proposals

## CFE-06-01: CO2 Capture and Storage Program

***Project Description***

The project focuses on capacity building and research in geological storage of $CO_2$ in China through a multi-faceted capacity building program and a significant basic and applied research program. The project will include workshops, study tours, exchanges, and research into geological storage of $CO_2$. In addition, the project will incorporate collaboration and coordination of activities with other CCS-enabling efforts in China.

Key milestones of the project include:

- A capacity building program comprising of a series of technical workshops in both Australia and China; international conferences and meetings; student and researcher exchanges and a Study Tour;
- Basic and applied research in geological storage of CO2; and
- Operational component including the development of a CAGS project website, other publications, attendance at project meetings and related workshops and Project launch and technical symposium wrap up events to aid network and capacity building.

***Participation***

Lead Partner: Australia;

Geoscience Australia

Australian Government Department of Resource, Energy and Tourism

Participating Partners/Organisations: China;

Chinese Ministry of Science and Technology

Chinese Academy of Sciences

China University of Petroleum

***Objectives***

To reduce $CO_2$ emissions to the atmosphere by helping to accelerate the development and deployment of carbon capture and geological storage (CCS) technology in China and Australia. It will encourage and facilitate knowledge sharing between China and Australia in the field of the geological storage of carbon dioxide.

***Status (as at March 2009)***

Not Complete

Preliminary work on the project commenced in November 2007. Since that time, a Letter of Intent regarding CAGS was signed on 17 October 2008 by Australia and China, and the CAGS work plan (MOST and GA) was finalised in October, 2008. Later stages of the project's work are being finalised.

***Project Location***

Australia

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## CFE-06-02: Ultra-Supercritical Pulverized Coal and Carbon Capture and Storage (USC PC/CCS) Near Zero Emissions Workshop and Design Guides for APP Countries

***Project Description***

Planned and conducted a workshop, developed user-based plant design guidelines, and transferred information for Ultra-supercritical (USC) pulverized coal (PC) with near-zero pollutant emissions plus post-combustion $CO_2$ Capture and Storage (CCS) Technology applied to coals in Partner countries. The research and development needs and guidelines for Partner countries, as well as specialized technology transfer and training has been added into the ongoing CoalFleet for Tomorrow® USC/CCS Program.

Participants in current CoalFleet for Tomorrow® work access combustion system design results, tech transfer, and expert advice when they join the ongoing international program on design guidelines, permitting, etc.

The content of the workshop 1) highlighted the major demonstrations of USC PC and/or CCS being planned and the design progress in reducing energy and cost for post-combustion capture; 2) Exchanged information on other major demonstration and deployment experience and information on USC PC and of design studies for CCS; and 3) Refined needs for the development of plant design guidelines based on user input.

Follow-on activities now that the APP project is complete involve expanding ongoing CoalFleet for Tomorrow® work, which has created three version of user developed design guidelines for a number of USC PC configurations and design guidelines for USC PC with Carbon Capture and Storage. This includes integration studies.

It is anticipated that this planned Partnership project will broaden the coal types and designs covered to include additional merchant and in-country coals (e.g., major coals traded in the Partnership region). Design guidelines have been developed for several U.S. coals and CoalFleet for Tomorrow® has developed information to consolidate worldwide USC PC lessons learned. In ongoing separately funded work case studies of actual plant retrofits with advanced amine technology is also being studied

***Participation***

Management of workshops and organization of CoalFleet for Tomorrow® activities will be by the United States/Electric Power Research Institute (EPRI). Cosponsors have been obtained in partner countries. CoalFleet is an ongoing international collaboration that has over 66 organizations involved including firms in United States, Australia, Japan, South Korea, and Canada but participation is open to all firms. Most participants are coal-based firms owning a total of over 200,000 MWe of coal-fired generation on five continents and four Partner countries. Supplier and engineering firms, coal companies and government entities are also participants.

This will expand deployment in Partner countries by providing international design information, lessons learned and guidelines for the technology, thereby reducing risk.

***Objectives***

Goals and outcomes sought from the Workshop—Design guidance and lessons learned on PC and CCS for a variety of coal types encountered in Partner countries. Additional designs (including country specific) evaluated and reviewed to match appropriate technology with various coals and evaluate how designs can be integrated with CCS. Currently, many PC plant designs exist, but only *selected* international merchant coals are being included in design guidelines from both the CoalFleet for Tomorrow® Program and “standard designs” by

suppliers. But coals vary extremely widely within and between Partner countries. This is expanding deployment in Partner countries by providing international design information, lessons learned and guidelines for the technology, thereby reducing risk.

Initial workshop assured that all potential participants are aware of coal differences and designs that are being developed and demonstrated worldwide and their applicability to Partner countries' coals.

Partner exchange broadened the types of coals considered for USC PC with low emissions and options for $CO_2$ capture and design information for these coals.

This expands on leverage for funders as the additional participation and adds cases relevant to the country coals. It brings in user experience and expertise and provides training and updates on the world state of the art.

Special guidelines, case studies and economic studies to be developed under this program could serve to reduce technology uncertainty and risk in application to Partner countries' coals.

Participation in CoalFleet for Tomorrow® is open to all via annual fees based on MWe coal capacity (with a minimum for non-generating entities).

***Status (as at March 2009)***

Complete

After initial delays the workshop was held March 31 2008 in Melbourne, Australia in conjunction with the APP join meeting of Power generation and transmission TF and Cleaner Fossil Energy TF. This was attended by approximately 100 delegates, Summary material and presentations are available as the deliverable from the APP project .

As a result of this input and separate CoalFleet for Tomorrow® efforts, three revisions of guidelines have been created and are available to CoalFleet for Tomorrow® Participants. Follow-on plant design guidelines—separate milestone chart is available for CoalFleet for Tomorrow®—all participants are eligible to attend five meetings per year plus specially crafted web conferences and Partnership meetings.

***Project Location***

The Workshop was held in Melbourne Australia . Project work done in USA and Australia

***Resources***

EPRI and Rio Tinto co-sponsors shared the cost of the seminar/workshop.

Follow-on via CoalFleet for Tomorrow® has been entirely voluntarily funded by participants to date and it would continue to be funded via set fees. Intellectual property is usable by the funders and not redistributed, but all participants are welcome.

***Project Contacts***

Project Manager Information

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## CFE-06-03: Ultra Clean Coal (UCC)

### *Project Description*

The project is comprised of a UCC production campaign through a process that removes nearly all the incombustible impurities from coal. The resulting product is to be used for long duration turbine erosion/corrosion trials and testing in gas turbine and diesel engines. These trials and tests are being devised so as to provide data and experience for the engineering design of a semi-commercial scale demonstration plant. An integral part of the project is the technical exchange and demonstration to Partner countries hosted and facilitated by the project proponent.

Key Milestones of the project include:

- Recommissioning of the Cessnock Pilot Plant to produce UCC;
- Laboratory testing and research and development;
- Test UCC as a replacement fuel in diesel engines and gas turbines;
- Engineering study for demonstration scale UCC plant; and
- Engineering study for demonstration scale power plant

### *Participation*

Lead country: Australia;

Ultra Clean Coal Energy Limited (UCC Energy Ltd) - Australia

Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Participating countries: United States, Japan;

Mitsubishi Heavy Industries (MHI) – Japan

### *Objectives*

To develop Ultra Clean Coal (UCC) technology to a stage where it can be commercially deployed for electricity generation using direct coal firing. The project is expected to contribute to improved fuel preparation and production through trialing UCC fuels in specially modified electricity generation systems. It will also build the capacity, expertise and research base in Partner countries to support the development and deployment of UCC technologies.

### *Status (as at March 2009)*

Not Complete

The UCC Pilot Plant has been successfully recommissioned and production of UCC for Coal Water Fuel (CWF) has commenced with operating hours increasing in line with production needs. A detailed analysis and testing program has been developed and laboratory testing and micronisation tests on CWF have commenced. A diesel engine on which to demonstrate the potential for using UCC CWF as a power generation fuel has been delivered and a contract has been agreed to perform a preliminary engineering study for the proposed UCC Demonstration Plant.

### *Project Location*

Australia, New South Wales, Cessnock

***Project Contacts***

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## CFE-06-04: Oxy-fuel Combustion and Working Group

***Project Description***

An ad-hoc working group will be established to develop a work program which will include undertaking a broad review of the status of oxy-fuel combustion technology and proposed demonstration projects. It will build on the research and development base, and the market and institutional foundations of Partners through technology supporting initiatives including oxy-fuel demonstration trials, education, training and skills transfer.

Key project Milestones include:

- Appointment of personnel for the OFWG Management Team;
- The development of an Asia Pacific Partnership cleaner fossil energy roadmap that builds on the range of existing national (and other international) measures and initiatives that exist in Partner countries;
- A broad review of the status of oxy-fuel combustion technology and existing demonstration projects;
- Identifying barriers to the commercialisation of oxy-fuel technology and develop oxy-fuel projects that could address these issues and;
- Facilitating and supporting implementation of oxy-fuel demonstration trials.

***Participation***

Lead Partner: Australia

Participating countries/organisations: All APP member countries

***Objectives***

To facilitate, support and add value to oxy-fuel combustion demonstration projects. The project will support the development, demonstration, and commercial deployment of oxy-fuel combustion technology in Partner countries.

***Status (as at March 2009)***

Not Complete

The interim personnel of the OFWG Management Team have been appointed and the initial meeting of the OFWH was convened in Yokohama in February 2008. An Oxy-fuel Capacity Building Course, primarily for SE Asian Countries including Korea, China and India, was organised in Korea in February 2008. The OFWG website was established at http://newcastle.edu.au/project/oxy-fuel-working-group/ and the Broad Review of oxy-fuel technology status commenced. The proponent also participated as a keynote speaker in the International Oxy-fuel Combustion Seminar and workshop in Daejeon, Korea, on 27-29 August 2008.

***Project Location***

All APP member countries

***Project Contacts***

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## CFE-06-05: Callide-A Oxy-Fuel Demonstration Project

***Project Description***

The Callide Oxyfuel Project is short-term initiative concerned with the demonstration of low emission electricity generation from a coal fired boiler. The project is being conducted as part of an international effort to develop clean coal technologies and will involve retrofit of oxyfuel technology to Callide A Unit No. 4, capture of around 70 t/day of CO2 from a flue gas side stream, and transport and storage of up to 20,000 t CO2 pa for about 2 years.

***Participation***

The Project Participants are CS Energy, IHI Corporation (IHI), Electric Power Development Co., Ltd (J-Power), Mitsui & Co. Ltd (Mitsui), Schlumberger and Xstrata Coal. The Australian Coal Association Low Emission Technology Pty Ltd (ACALET) is a special contributor. JCOAL (Japan) is a supporting collaborator. Key technology suppliers to the Project include: IHI Engineering Australia and IHI Corporation, Air Liquide, Gas Liquid Processing Pty Ltd and Siemens.

***Objectives***

The project has three broad goals, namely to:

Demonstrate a complete and integrated process of oxy-fuel combustion of pulverised coal within a National Electricity Market facility, incorporating oxygen production, oxy-fuel combustion, $CO_2$ processing and liquefaction, and $CO_2$ transport and geological storage;

Obtain detailed engineering design and costing data and operational experience to under-pin the commercial development and deployment of new and retrofit oxy-fuel boiler applications for electricity generation; and

Obtain detailed geotechnical design and costing data and operational experience to support the development of geological storage projects in excess of 1 million tonne of $CO_2$ per year.

***Status (as at March 2009)***

Not Complete

| ***Key Milestones*** | ***Status*** |
|---|---|
| Joint Venture established | Completed - Mar 2008 |
| Plant supply contracts awarded | Completed - Aug 2008 |
| Refurbishment of Callide A unit 4 completed and returned to service | Completed – Feb 2009 |
| Finalize $CO_2$ site selection | Jun 2009 |
| Earthworks for oxygen and $CO_2$ plant | Jul 2009 |
| Complete detailed engineering design of all plant and equipment | Dec 2009 |
| Commence construction works at Callide site | Jan 2010 |
| Commence drilling and installation works for $CO_2$ storage | Oct 2010 |
| Commence Oxyfiring | Apr 2011 |
| Commence $CO_2$ capture, transport and storage | Sep 2011 |
| Conclude oxyfuel test program at Callide A and $CO_2$ injection | Sep 2013 |
| Conclude post $CO_2$ injection monitoring | Dec 2015 |

***Project Location***

Stage 1 - Callide A Power Station, Biloela Queensland Australia

Stage 2 – Near Springsure, 300 km west of Biloela

***Project Contacts***

Project Manager Information

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## CFE-06-06: Assessing Post Combustion Capture (PCC) for Coal Fired Power Stations in APP Countries – Stage 1 and 2

***Project Description***

The project consists of two components: The Australian component of the project will establish two mobile PCC pilot plants and a research laboratory that will test novel PCC processes and a range of different solvents to capture $CO_2$.

The Chinese component of the project will involve Australian and Chinese technologists working together to deploy a mobile PCC pilot plant in China and carry out further PCC trials and research under different conditions at Chinese power stations. The technology transfer of current PCC technology and an enabling program for ongoing technical development will support the future concept design of a demonstration plant and full scale plants in China.

Key milestones of the Australian component (Stage 1) of the project include:

- Establishing a PCC test program at Delta Electricity's Munmorah power station for two years;
- Establishing a second PCC test program involving short campaigns on different solvents and operating parameters;
- Laboratory testing and research program before and during large scale PCC deployment;
- Process engineering and design for integration with power station energy systems;
- Technology transfer program among APP participants;
- Supporting possible trials in other APP countries based on the foundations of the trials conducted in Australia.

The key milestones of the Chinese component (Stage 2) of the project include:

- PCC pilot plant demonstration at Gaobeidian Power Station;
- Pilot plant demonstration at a second site;
- Technology scale up and international industry implementation with workshops focusing on the customisation and adoption of a PCC roadmap in China; and
- An outreach program (Technical Development Program).

***Participation***

Lead Partner: Australia;

Australian Commonwealth Scientific and Industrial Research Organisation (CSIRO)

Delta Electricity - Australia

Tarong Energy Corporation – Australia

Participating Partners/Organisations: China;

Chinese Thermal Power Research Institute

China Huaneng Group

***Objectives***

To demonstrate Post-Combustion Capture (PCC) technologies by using purpose built mobile pilot plants to trial post-combustion capture technologies at existing coal fired power stations.

The outcomes of this project will enable the economics of PCC technology to be determined and provide a roadmap for the demonstration and deployment of PCC technology.

***Status (as at March 2009)***

Not Complete

The construction of the first pilot plant at Munmorah Power Station was completed in October 2008 with tenders for the construction of the second pilot plant at Tarong A Power Station now being evaluated. Carbon dioxide was first captured by the pilot plant from the Munmorah Power Station flue gas in February 2009. The first Chinese Pilot Plant has also been constructed and commissioned with 1000 tonne $CO_2$ captured so far. The research program for the Australian Pilot Plant has progressed with work continuing on:

- solvent development through solvent characterisation experiments and speciation studies;
- further investigation into the use of enzymes for efficiency improvement of PCC;
- development of dedicated ionic liquids and process engineering and integration has resulted in the definition of baseline power plants with $CO_2$ capture for the Australian conditions;
- a patent application for use of enzymes for facilitation of the desorption reactions has been provisionally granted;
- process engineering and integration has resulted in the definition of baseline power plants with CO2 capture;
- holding discussions on the possibility of establishing a second pilot plant in China utilising flue gas with less stringent emissions controls, thus providing an additional challenge for PCC-technologies; and
- Six researchers were involved in the project presented papers at the ninth Greenhouse Gas Control Technologies Conference (GHGT-9) held in Washington in November 2008.

***Project Location***

Australia

***Project Contacts***

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# CFE-06-07: Integrated Gasification Combined Cycle with Carbon Capture and Storage (IGCC/CCS) Workshop, and Design Information for APP Country Coals

### *Project Description*

Planned and conducted a workshop cosponsored by J-Coal and EPRI, and EPRI prepared User Design Basis Guidelines on Integrated Gasification Combined Cycle (IGCC) plus $CO_2$ Capture and Storage (CCS). The Workshop results were delivered in October 2006. The research and development needs, including design guidelines and information for Partner country coals and 50-Hz machines, have been delivered by expanding the ongoing CoalFleet for Tomorrow® IGCC/CCS Program using this input. This workshop was combined with the Japanese l "Clean Coal Day in Japan" "Advanced Clean Coal Technology International Symposium 2006 and Expert Group Meeting for APP" CFE-06-09 based on discussion in the Tokyo Task Force meeting in July 2006.

Initial information was exchanged in the September 4th 2006 meeting held at the Capital Tokyu hotel. Follow-up Information including many updates (6 so far) of user design guidelines have been delivered through additional reports, seminars, and regional meetings, training sessions and webcasts conducted in the CoalFleet for Tomorrow® program.

The content of the workshop held in Japan September 4th 2006 included 1) Highlights of the major demos of IGCC/CCS being planned (e.g. FutureGen and GreenGen; 2) Exchange of other major demonstration and deployment experience and information on IGCC and of design studies for CCS; 3) Needs for development of design guides based on user input (CoalFleet for Tomorrow® has created guidelines for a number of IGCC configurations and is continuing updates to incorporate global results and design needs).

CoalFleet for Tomorrow® work now includes a number of include additional merchant and in-country coals (e.g. major coals traded in Partnership region), and has added 50-Hz designs. Design guidelines include information to consolidate worldwide IGCC lessons learned.

### *Participation*

Management of workshop was jointly sponsored by JCOAL (Japan) and the Electric Power Research Institute (EPRI USA) and organization of CoalFleet activities have been coordinated by EPRI. Presentations were provided from China. India, Japan, United States; with coverage of United States' FutureGen Project, Japan's EAGLE Project, Australia's Stanwell Project, and China's GreenGen Project and other projects.

The workshop was open to all and attended by 45 people. New work on guidelines is accessible to paid participants. Follow-on is being conducted as an expansion on CoalFleet for Tomorrow® collaborative research project. CoalFleet has currently over 65 organizations involved, including firms in United States, Australia, Japan, and Korea, and Canada as well as non- APP countries but participation is open to all firms. Most participants are coal-based firms owning a total of over 400,000 MWe of coal-fired generation on six continents. Supplier and engineering firms, coal companies, and government entities are also participants

This expands deployment in Partner countries by providing international design information, lessons learned and guidelines for the technology, thereby reducing risk. It will open opportunities for cross training, exchange, and participation in large projects.

### *Objectives*

Insights into the needs and differences unique to Partner countries' coals and the integration issues of IGCC/CCS. Later guidelines provide design guidance and lessons learned on IGCC

and CCS for a variety of coal types encountered in Partner countries. Additional designs (including country specific) have been evaluated and reviewed to match appropriate technology with various coals and evaluate how designs could be integrated with CCS.

This will expand deployment in Partner countries by providing international design information, lessons learned and guidelines for the technology, thereby reducing risk. Early IGCC design guidelines developed in CoalFleet for Tomorrow® have been in use at several U.S. and European locations planning and refining designs for IGCC projects.

Technology transfer and information will also be highlighted as they have been in CoalFleet for Tomorrow® and can include appropriate exchange arrangements, such as recorded web-based information sessions to overcome travel and other issues.

Partnership exchanges have broadened the types of coals considered for IGCC/CCS and design information for these coals. This expanded FutureGen, GreenGen, and CoalFleet for Tomorrow® understanding for additional firms.

Participation in GreenGen, FutureGen, Zerogen and CoalFleet for Tomorrow® will continue to be determined by sponsoring organizations. Participation in CoalFleet for Tomorrow® is via annual fees based on MWe coal capacity (with a minimum for non-generating entities).

***Status (as at March 2009)***

Complete

Completed, workshop results distributed and reported in Japan's Clean Coal Day. RD&D plans published for IGCC and IGCC/CCS are available.

Participants in CoalFleet for Tomorrow® after the workshop have access to all current-year deliverables when they are funding, to training information, web-based information.

***Project Location***

The venue for the IGCC CCS Workshop was in Tokyo at the Capital Tokyu hotel to take advantage of participation by a number of firms in the Japan Clean Coal Days sponsored by JCOAL.

***Resources***

JCOAL and EPRI co-sponsored the cost of the workshop September 4$^{th}$ 2006. CoalFleet for Tomorrow® has been entirely voluntarily funded by participants to date and it would continue to be funded via set voluntary fees. Intellectual property from CoalFleet for Tomorrow® is usable by the funders and is not public or redistributed broadly but all participants are welcome to fund and have access.

***Project Contacts***

Project Manager Information

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## CFE-06-08: Asia-Pacific Gas Market Growth Project

***Project Description***

The project will analyse the Asia-Pacific gas market conditions, identify impediments to and provide solutions for improving market conditions. It will also assess the skills required to improve the regional gas market conditions and determine the magnitude of private and/or public investment required for the Asia-Pacific Regional Gas Market to reach its potential.

Key milestones of the project include:

- An analysis of the Asia-Pacific gas market;
- Determining the magnitude of private/public sector investment required across the APP economies to achieve the objectives of the Regional Gas Market Plan;
- Determining the consistency of best practice principles;
- Determining an approach for the Asia-Pacific Gas market to align with International projections;
- Identify areas of capacity building and information and data gathering necessary to underpin the project's objectives; and
- Develop an Asia-Pacific Regional Gas Market Plan.

***Participation***

Lead Partner: Australia;

The Australian Petroleum Production and Exploration Association (APPEA)

Australian Government Department of Resources, Energy and Tourism.

Participating Partners/Organisations: USA;

US Department of Energy

US Energy Association

American Petroleum Institute.

***Objectives***

To improve energy security while reducing environmental impacts of fossil fuel use by increasing the utilisation of gas within the Asia-Pacific Region. The project will help ensure that the burgeoning energy demand of the Asia-Pacific region is met while reducing the rate of growth in greenhouse gas emissions.

***Status (as at March 2009)***

Not Complete

An analysis of the Asia-Pacific gas market was conducted that identified impediments to improving the Asia-Pacific gas market. It also determined the magnitude of investment required and how to align the Asia-Pacific Gas market with International projections. Findings are being collated into a Draft Report for consideration by members of the CFE Task Force.

***Project Location***

Australia

***Project Contacts***

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# CFE-06-09: (Methodology Development Track): Developing Consistent Methodology for Estimation and Evaluating Greenhouse Gas Emissions Reductions Potential for the Liquefied Natural Gas Sector

### *Project Description*

Consistent and comprehensive internationally accepted methodologies will be developed to estimate methane, carbon dioxide, and other greenhouse gas (GHG) emissions from the entire LNG value chain, including: liquefaction facilities, transportation, loading/off-loading, and regassification.

Adoption of these methodologies will be promoted within Partner countries and other interested countries. Use of these consistent methodologies will enable comparability and assessment of potential gas wastage areas and will facilitate cost-effective investments to reduce natural gas losses, improve energy efficiency and increase the amount of gas delivered to market.

### *Participation*

**Lead:** American Petroleum Institute (API)

**Other US Participants**: U.S. Environmental Protection Agency, Department of Transportation/Office of Pipeline Safety; U.S. Energy Association.

**International Support**: Australia Department of Industry, Tourism and Resources; the Department of Environment and Heritage; the Australian Petroleum Production and Exploration Association (APPEA); and the Australian Energy Alliance.

### *Objectives*

- Develop and publish technically sound and transparent methods to estimate GHG emissions from LNG operations accounting for the diversity of operations and natural gas origins;
- Estimate GHG emissions for select case-study examples to highlight key contributing sources to overall GHG emissions from LNG operations;
- Identify cost-effective best management practices and technologies to achieve reductions from key sources identified;
- Compare the potential for GHG emission reductions from identified technologies and practices as compared to medium-term business as-usual emission projections.

### *Status (as at March 2009)*

<u>Not Complete</u>

1. Establish working group of interested companies and compile relevant background literature – ***COMPLETED***
2. Identify and undertake necessary technical work – ***IN PROGRESS***
3. Develop and test comprehensive emissions estimation methodology appropriate for LNG facilities – ***3rd - 4th QTR 2009***

4. Publish emissions methodology and reach out to partners for implementation of these methods in their regions – ***4th QTR 2009 or 1st QTR 2010***
5. Develop case studies examples to test the impact of new technologies and best-management practices and quantify emission reduction opportunities – ***CY 2010***.

***Project Location***

Initial effort is to be conducted in the U.S. by API and its member companies in collaboration with the Center for LNG (CLNG), the U.S. EPA Natural Gas Star and other organizations.

Future tasks will entail reaching out to partner countries for their input and testing of developed methods.

Partners will be requested to provide case study examples to enable broad representation of LNG projects and operations throughout the APP countries.

***Project Contacts***

**Project Manager Information**

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## CFE-06-10: Information Exchange on LNG Public Education Campaigns

***Project Description***

Goal: A regional public education workshop on liquefied natural gas (LNG) will be held to exchange information among governments and private sector with the aim of reducing public opposition to new LNG shipping and receiving terminals. The project will help to increase LNG trade and investment in the Asia-Pacific Region to:

- Enhance energy security.
- Reduce air pollution.
- Reduce greenhouse gas emissions.
- Enhance economic growth.

Taking account of the environmental benefits of natural gas over other fossil fuels and the increase in energy security through fuel diversification, the project will help to ensure that new LNG facilities in the region are safely developed and operated with the consent of the informed general public. Public opposition to LNG shipping and receiving terminal can block or delay their development. Such problems can arise when project developers do not fully engage the local population, who may not be well educated or understand the actual history of successful operation of LNG terminals around the workshop, prior to start of construction or during operations, especially if a problem arises. The workshop will build from three successful regional LNG public education workshops organized by the Department of Energy in the United States in early 2006.

*Phase 1:*
Interface with the APEC Gas Forum (APGAS), which will hold its second meeting in Perth, Australia, from August 31-September 1, 2006.

APEC/APP LNG Public Education Workshop to be conducted in November 2007 timeframe.

Proceedings including conclusions and recommendations to be available by mid-2007.

*Phase II:*
Develop case studies of both successful and unsuccessful LNG public education campaigns to share lessons learned among APEC/APP member economies (pending approval of APEC proposal for implementation in 2007).

***Participation***

Lead: *United States*

Organizers: APEC Expert Group on Clean Fossil Energy.

Participants: representatives from the public and private sectors from all Partner countries as well as financial institutions.

***Objectives***

This workshop was developed in direct response for cooperative activities spelled out in the final declaration of the 6$^{th}$ Meeting of APEC Energy Ministers, held in Manila in June 2004:

"…strengthen economic infrastructure to eliminate bottlenecks to economic growth, especially in such areas as telecommunications, transportation, and energy, in order to further integrate members into the regional economy, and the region into the global economy. The project will expand the capacity of APEC members to absorb LNG technologies and promote a free flow of information on these technologies to the public, thereby enhancing public acceptance and encouraging natural gas trade and investment."

The APEC Workshop is being organized to exchange information on public education campaigns related to LNG in APEC economies. The workshop will be expanded under the Partnership by inviting India's participation (after receiving APEC approval for inclusion of a non-member economy).

***Status***

Not Complete

***Project Location***

The location of the 2-day LNG Public Education Workshop is still to be finalized in one of the Partner countries.

***Resources***

US$120,000, including US$100,000 from APEC to support event organization and invitational travel from APEC member economies.

## CFE-06-11: Asia-Pacific Gas Hydrate Cooperation

***Project Description***

Goal: Several Partner countries are conducting significant R&D programs to develop gas hydrates as a clean energy source. The goal of this project is share information on Partner countries' national programs, which will help to better inform policy makers and researchers, and to conduct cost-shared joint projects that will allow gas hydrates to become a viable commercial energy source sooner.

Gas hydrates represent a huge potential resource—as much as 400 million trillion cubic feet (tcf), a staggering figure compared to the 5,500 tcf that make up the world's currently proven gas reserves. Natural gas is expected to take on a greater role in power generation, largely because of increasing pressure for clean fuels, and gas hydrates could provide a vast new supply of affordable gas for power generation for centuries. In addition, because hydrates occur adjacent to the coasts of most countries this resource, if developed, has the potential to change the world energy and energy security balance.

Goal: Accelerate the development of technologies to allow the production of methane from gas hydrates while protecting the environment to:

- Enhance energy security.
- Reduce air pollution.
- Reduce greenhouse gas emissions.
- Enhance economic growth.

Taking account of the environmental benefits of gas, the extensive gas hydrate research and development (R&D) being conducted by Partner countries, particularly the United States, Japan, India, and Australia, and the regional desire to increase energy security, the project will help to ensure that the energy demand growth aspirations of the Asia-Pacific region are met.

Specifically, the project will focus on:

- Exchanging information about gas hydrate R&D to better inform policy makers.
- Exchanging gas hydrate research data to better inform researchers.
- Developing a plan of cooperation for joint projects.
- Public education on the benefits and environmental implications of gas hydrates.
- Skills enhancement.

Production of methane from hydrate, although shown to be feasible, still requires significant research to validate detection technology and test and refine potential production technologies. Because of the diversity of hydrate deposits and possible extraction techniques, each country has a slightly different approach, but will benefit from information about others' efforts.

*Phase 1:*

- Enlist involvement of government and industry of Japan, China, Korea and India.
- Informal discussions on cooperation during 2006-2007 at Partnership and other multi-national meetings.
- CODATA-Hydrates meeting tentatively scheduled October 21-22, 2006 in Beijing.
- Planning meeting mid-2007.
- Complete plan for cooperation and joint projects by end 2007.

*Phase 2:*

- Implementation phase—commencing 2008.
- Possibly including multinational production test in 2010-2012.
- Commercialization of methane production from hydrates expected by 2015.

***Participation***

Lead: United States.

Participants: Representatives from the public and private sectors from United States, Japan, India and Australia.

***Objectives***

As articulated in the project description above.
Project will enhance all participants' understanding of the geologic and engineering complexities of gas hydrates by sharing each participant's unique experiences with their resource. Shared information will reduce risk and accelerate technology for commercial production of methane from hydrates.
The U.S. Department of Energy has a US$12 million/year methane hydrate program dedicated to realizing hydrate's energy supply potential, while continuing to address important hydrate research questions such as sea floor stability, drilling safety, and environmental issues associated with naturally-occurring methane hydrate. The program aims to develop the knowledge and technology necessary to allow commercial production of methane from hydrates by 2015.
In order to inform policy makers in participating countries of cooperative efforts, the plan includes informal discussions between government agencies and a planning meeting involving government policy makers.
In order to increase data exchange to better inform the research community, DOE supports and invites others to support CODATA (International Council for Science: Committee for Data for Science for Science and Technology) Task Group for Data on Natural Gas Hydrates.

***Status***

Not Complete

***Project Location***

TBD

***Resources***

*Phase 1:* Funds for travel, report, meetings, report production etc will be required (e.g., US$80,000 for CODATA.).

*Phase 2:* Dependent on implementation plan.

## CFE-06-12: Costs and Diffusion Barriers to the Deployment of Low-Emission Technologies

***Project Description***

Partner countries are endowed with different resources and energy systems and face different clean development challenges indicating that deployment of clean energy technologies will likely be non-uniform across the region. Additionally, cost estimates are changing for all technology options as new technologies enter the portfolio mix and operating conditions change.

The project seeks to assess and estimate the levelized cost of electricity for a range of fossil fuel and renewable Low Emission Technologies (LETs) specifically in Australia. The project uses EPRI's proprietary methodologies, and where possible, the International Energy Agency's Greenhouse Gas (IEAGHG) R&D Programme's set of standard technical and economic assessment criteria.

Cost estimates for technology options are changing over time and across regions, and as new technologies enter the portfolio mix and as operating conditions change, a consistent methodology is needed to evaluate new options. To support a goal of increasing the uptake of low emission technologies (LETs) within the APP region, policy makers and technology investors need updates on LET cost information based on a broadly accepted analytical methodology.

This information is critical for both policy makers and technology investors. The majority of LETs are characterized as either being immature, relatively costly and/or unintegrated. This project will enhance the understanding of LETs and explore the enabling infrastructure or systems required to deploy these technologies in the region. Identifying the costs and other barriers to the take up of different energy technologies is an important first step and the Partnership Work Plan, agreed at the Ministerial meeting in January 2006, identified this exercise as a priority Task Force consideration (referred to as "Stage 1 Road-mapping").

***Participation***

Australia will manage the project with support from the United States.

An experienced high-profile technology and modeling organization (Electric Power Research Institute (EPRI)) was contracted to undertake the project.

This project was jointly undertaken with the Renewable Energy and Distributed Generation Task Force and covers both renewable and fossil fuel generation technologies.

The project needed to be coordinated with other ongoing studies being progressed through other fora (e.g., APEC and IEA) and incorporate learnings from other related Partnership projects (e.g. CFE 06-e8 Asia-Pacific Gas Market Growth).

***Objectives***

Like the energy markets themselves, generation costs in each Partner country vary greatly, primarily based on the availability of resources and technologies. While the costs of LETs

have been estimated in many different situations, there is value in drawing this information together and determining where a specific technology is in the development and diffusion pathways and estimating/translating relative cost potential in specific Partner country energy markets. This study is intended to draw on and complement, rather than replicate, the suite of ongoing effort on this issue and will be focused on addressing the major gaps in the knowledge base.

The project's objective is to determine the current level of maturity of a broad portfolio of Low Emission Technologies and to derive their relative cost profiles over time within Australia. The study will also identify the cost-effectiveness of these technologies in the context of the comparative environmental attributes—assessing the impact on energy costs of meeting clean development and climate objectives in an integrated way (e.g., what are the additional costs of reducing greenhouse gas emissions if local air quality issues demand a change in generation technologies).

The relatively high cost of LETs is but one barrier to their deployment. An additional objective of the project is to identify and explore the enabling infrastructure or systems (e.g., intellectual property issues, enabling legislation/regulation, and integration of LETs into the electricity grid system) required to deploy these technologies within the Partnership region. These institutional and system barriers may occur at different stages through the commercialization pathway of a technology. As such it is essential to determine at what stages these factors impact on the deployment of specific LETs. This will provide for a better understanding of how and when to address impediments.

***Status (as at March 2009)***

Complete

*Study* Completed late 2008 – dissemination strategy being finalised.

***Project Location***

N/A

***Project Contacts***

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## CFE-06-13: CO2 Enhanced Coal Bed Methane (ECBM) Project

***Project Description***

The project draws on combined expertise and technology of Japan and Australia in seeking to validate and test the characteristics which underpin viable CO2 sequestration. It will address key issues of safety, longevity, interaction of gases with coal, identify quantitative and predictive rates of injection and uptake of CO2 in coal seams. The project intends to replicate results from Japanese field trials in Australia to assist in promoting the effective use of ECBM technology to countries such as China.

The project will assist in promoting the effective use of such technologies in APP countries and in the wider region. The work includes environmental monitoring, and essentially, the assessment of coal seams if viable as long term and safe option for sequestration.

The completed work will enable results to be applied to other coal sites and to other countries, through tools that allow interactions between CO2 and coals to be characterised and to develop reservoir models that will use this data to predict the fate of stored CO2.

The project consists of three stages:

- Stage 1 will create a Consortium of Australian, Japanese and Chinese interests to raise further funding and undertake preliminary technology verification and laboratory based research;
- Stage 2 will consist of an ECBM field trial in Australia where ECBM technologies will be developed; and
- Stage 3 will consist of an ECBM field trial in China.

***Participation***

Lead partner: Australia and Japan

Participating partners/organisations: China and Korea

***Objectives***

The project aims to provide a pathway to the adoption of a zero emissions technology from fossil fuels through ECBM. The project aims to develop techniques to maximize CO2 injection and methane recovery rates and to overcome the permeability loss that is associated with CO2 absorption. In doing so, the project aims to promote international best practice in a manner that improves economic and environmental performance of member countries.

***Status (as at March 2009)***

Not Complete

A possible Australian ECBM trial site has been identified and schematics showing the layout for the drilling program were prepared. Field sites and technical design options were discussed with a potential Australian trial partner in February 2009. Discussions were also held with a Chinese Partner to arrange a field site visit. The proponent contributed to developing the project business case for the Australian trial partner. Ongoing detailed negotiations have been held with JCoal to review a draft agreement on their participation in the project and a contract with an Australian trial partner to host a field site was negotiated in February 2009.

***Project Location***

Australia and China

***Project Contacts***

**Project Manager:**

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## CFE-07-15: Project Title: Coal gasification performance assessments for low emissions IGCC systems

***Project Description***

This project builds on existing relationships between some of the leading coal gasification research groups within the AP6 partnership. CSIRO has established collaborative research links with TPRI in China and a proposal for a joint gasification research program was developed during 2006/07 for the Chinese Ministry of Science and Technology.

By integrating the technology development capabilities of the Chinese partners and the coal performance expertise available through the Australian partners, it will be possible to ensure that the research aspects of the program are well aligned with technology development and implementation pathways in the partner countries. This will allow effective integration of the important fundamental aspects of the coal gasification systems with the development of the key 'enabling' technology modules that will be required to continue the development of current generation IGCC systems towards the low, and ultimately near zero, emissions power plant configurations required in the future and will provide a clear technology development pathway for the research and technology development activities being conducted in the proposed partnerships.

To enhance the collaborative aspects of this work, the project has been integrated into the cLET program on gas cleaning, syngas processing and $CO_2/H_2$ separation in gasification systems.

This project addresses the following application and technology development pathways for coal gasification based technologies:

- IGCC-based power generation systems to improve the thermal efficiency and environmental performance of coal based power generation. This is the first generation of IGCC technology and will form the platform for further development and implementation of low, and near zero, emission power technologies as the cost and scale of coal-derived syngas cleaning processing and hydrogen/CO2 separation systems are improved.
- Coal gasification as a core technology for CO2 capture and the principal pathway to hydrogen energy systems based on coal.

It is the purpose of these collaborative activities to increase the understanding of coal gasification processes in entrained flow gasification systems, and to understand the impacts of coal type and quality on gasification performance and downstream syngas processing technologies. It is proposed that a mathematical modelling activity will be conducted between the participant organisations to develop suitable interpretive models that will enable the coal gasification performance data to be applied to practical gasification systems. This activity builds on the first pilot scale gasification campaign conducted by CSIRO and Co-operative Research Centre for Coal in Sustainable Development (CCSD) using the Siemens pilot scale (5MWth) facility in Germany during 2007.

The initial areas identified for collaboration are:

- Understanding of the gasification reaction and slag formation and flow characteristics of important Chinese and Australian coals, and their impact on gasifier design and operation.
- Methods for the assessment of gasification performance of coals.

- Development of mathematical modelling frameworks capable of incorporating the important coal performance data available from laboratory and pilot scale measurements.
- Coal quality and gasification performance impacts on syngas cleaning, processing and separation processes.

It is expected that this program will complement TPRI's pilot and larger-scale gasification technology development program as well as CSIRO's gasification and syngas research programs.

Milestones achieved: The cLET project milestones associated with this project for the current period are:

- 12/2007 – Define project scope, facilities, resources and planning schedule – The project schedule and scope was modified as a result of developments between CSIRO and TPRI. This milestone was advanced via a meeting between TPRI and CSIRO staff in December 2007. This meeting established the broad intent of the collaboration and led to the development of a draft term and scoping document that formed the basis of further negotiations. A more detailed technical meeting was conducted on 23-25 March 2008 where the project scope and important scheduling issues associated with the likely relocation of the TPRI pilot (36 tonne/day) was discussed. Pending finalisation of a suitable project agreement, the laboratory component of the program can now be progressed using Chinese coals which have already been tested in the pilot plant. Coal samples and associated pilot results and modelling data developed by TPRI will be made available to the project and CSIRO will share laboratory data on coal reactivity
- 30/11/2008 – Agreement with TPRI – this has been delayed as a result of the need to modify the program to include only laboratory and modeling aspects of the original program. (The original program sought to include pilot scale tests but theses are not possible in the timeframe and scope of the current project). A meeting between CSIRO and TPRI in December 2008 has confirmed an agreed scope of activity and the appropriate agreement documents are being drafted.
- 30/1/2009 - Laboratory test work begins in Australia – This has been deferred to May 2009 as a result of the need to revise the scope of the program. Efforts are being made to identify appropriate samples with TPRI so that they can be shipped to Australia as soon as possible. This is being progressed in parallel with the development of a revised project agreement between TPRI and CSIRO.

The laboratory work has been specified on the basis of some similar laboratory and pilot scale test work recently conducted through the CCSD program for a suite of Australian coals.

- 31/05/09: Laboratory scale gasification data provided to TPRI for modelling program - Integration and correlation of laboratory and pilot scale gasification data for TPRI test coals has been deferred until the samples have been identified by TPRI and received in Australia. Current efforts aim to begin the test work in Australia from May 2009. Preliminary laboratory work on some reference Australian coals has been conducted and linkages with pilot scale test data for the same coals (obtained through the CCSD program) are being investigated. This has provided a framework for the program that will be conducted with the Chinese coals and test data. [Including information on project milestones and progress]

***Participation***

Lead partner country & organisation: Australia, CSIRO

Participating partner country & organisation: Peoples Republic of China: Thermal Power Research Institute (TPRI)

***Objectives***

The work proposed here, builds on an existing relationship between the project partners to conduct a comparative evaluation of the gasification performance of Chinese and Australian coals using techniques and facilities developed in Australia as well as larger scale facilities available through TPRI in China. The project will produce key data on coal gasification and slag flow behaviour for a range of coal types likely to be considered for future gasification and IGCC applications in China and internationally.

***Status (As at March 2009)***

Not complete

***Project Location***

Australia (laboratory program) and China (existing pilot scale test data, sampling and modelling analysis)

***Project Contacts***

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# Appendix B: Thematic Areas

## Theme 1 Carbon Dioxide ($CO_2$) Capture and Storage

This theme covers the development, demonstration and commercial application of geological storage of $CO_2$ captured from natural gas operations, chemical plants, and low or zero emission power plants. As such, there will be synergies with the work that is being done to develop technologies to enable the capture of $CO_2$ under the coal gasification theme and the advanced combustion theme.

The initial focus of the Task Force under this theme will be to take measures, including capacity building, joint research, general exchanges and information sharing, to improve the development of $CO_2$ capture and storage technologies in the Partner countries. This work will flow through to the trial storage projects in Partner countries, which in turn could be linked to pilot or demonstration trials of low emission technologies. The ultimate objective under this theme is to support the development and reduce the costs of relevant technologies that are needed to make low emission technology a viable option for addressing future greenhouse gas emissions.

All members of the Partnership are also members of the Carbon Sequestration Leadership Forum (CSLF), which has a similar $CO_2$ storage agenda. Activities developed under the Partnership will be designed to complement and draw on and apply the wider expertise that is available through the CSLF.

## Theme 2 Post-Combustion Capture, Oxy-Fuel Combustion and Other Advanced Technologies

This theme covers the development and commercial deployment of advanced combustion technologies, which enable the capture of $CO_2$ through oxy-fuel combustion or post-combustion capture of $CO_2$ from gas or coal power generation.

The Task Force will focus on the following technologies for new power stations—noting that the Power Generation and Transmission Task Force will focus on technologies to improve the thermal efficiency and environmental performance of existing power stations:

- Advanced coal cleaning technologies, such as ultra clean coal or Hyper coal, that allow direct firing of coal in gas turbines as part of a combined-cycle power station. These technologies can achieve significant reductions in greenhouse gas and local environmental emissions, eliminate power station ash and provide an alternative to heavy fuel oils suspended in water.

- Supercritical and ultra-supercritical power stations and high-performance gas turbines.

- A range of advanced fluidized-bed combustion technologies that reduce local emissions and support the more efficient combustion of lower grade fuels.

To make an effective contribution to the development and deployment of technologies under this theme, the Task Force will support a range of projects that reflect the stage of development of each technology.

For instance, many of these technologies (e.g., supercritical pulverized coal systems) are commercially available. In these cases, the role of the Task Force and the projects that it

supports will be one of considering and addressing barriers to the further commercial deployment of these technologies in member countries.

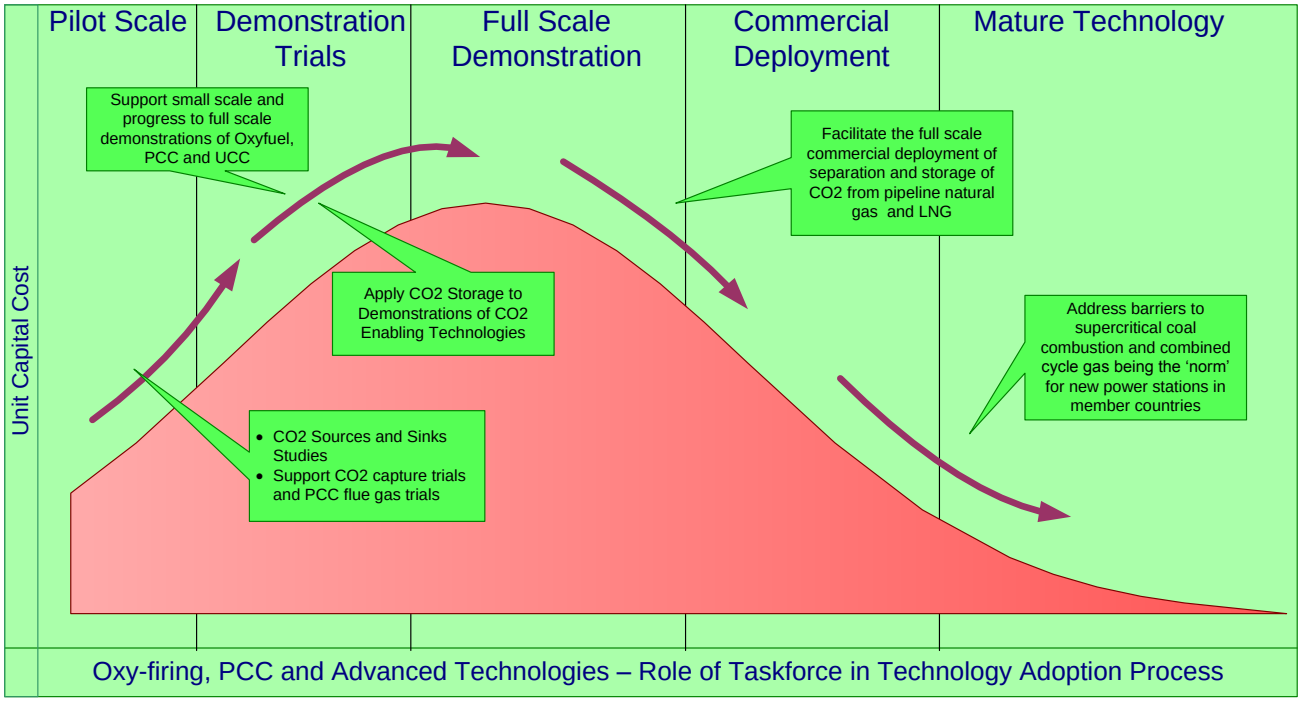
Other technologies are being further refined or need to be progressed to the demonstration stage (e.g., ultra clean coal, oxy-fuel combustion and post-combustion capture). The Task Force can add value by facilitating pilot trials and/or the commercial demonstration of these technologies.

In cases where demonstration projects are likely to proceed without further assistance (e.g., ultra-supercritical plants), the Task Force can add value by acting as an information clearinghouse, and focus its attention on the further development and deployment of high-priority technologies. In common with other technologies, this work may require coordinating the results of research programs, developing financial incentives, and building the skills and capacities needed to deploy these technologies.

The Task Force will consider establishing working groups to bring together experts and industry operators in these technology areas to provide guidance and to develop and implement programs and activities covering these technologies.

**Figure 2** illustrates the technologies covered in these theme and their stages of development/diffusion.

**Figure 2 Stages of Development/Diffusion—Oxy-Fuel Combustion, PCC, and Advanced Technologies**




## Theme 3 Coal Gasification

The Task Force will seek to enhance the further development and commercialization of coal gasification technologies and the potential contribution that these technologies can make to greenhouse gas emission abatement. There are three broad aspects of coal gasification that the Task Force will consider, namely:

1. Coal gasification-based chemical and liquid fuel plants.

2. IGCC-based power stations to improve the thermal efficiency and environmental performance of converting coal to electric power.

3. Coal gasification as an enabling technology for $CO_2$ capture and as one pathway to the hydrogen energy economy.

4. Facilitate trials of gasification with alternative fuels like pet coke, residues from petroleum refineries.

Demand for coal gasification technologies for the chemical industry is strong and expanding, for example in China, the United States and Japan, where gasified coal is used for fertilizer production. This application also has great potential in India. Demand is contributing to the further development and standardization of gasifier designs, which in turn should improve the economies of scale for the design and production of gasifiers. These benefits should in time flow through to gasifiers used in IGCC power stations.

The application of coal gasification to power generation through IGCC technologies has been under development for the past two to three decades. Within Partner countries, the United States and Japan have been actively developing and commercializing IGCC technology. IGCC power stations have been demonstrated on a commercial basis. Semi-commercial and commercial IGCC coal power stations are operating in Japan and the United States and orders have been placed in the United States for major new IGGC power plants. In Australia, a project involving production of hydrogen from coal to produce IGCC fuel is in the planning stage. However, diffusion and transfer to other markets, including other Partner countries, are still limited. This reflects the relatively high capital and operating costs and technological risks of IGCC—which in turn is a reflection that this technology is in an early stage of deployment.

The application of $CO_2$ separation and capture to coal gasification has become a major R&D focus over the last decade. The demonstration of coal gasification power plants with integrated $CO_2$ separation and capture is being progressed in Partner countries through FutureGen in the United States, extensions to the EAGLE project in Japan, GreenGen in China and ZeroGen in Australia.

The Task Force will develop a coal and oil gasification strategy and work program that will focus on:

- Adapting coal gasification chemical and liquid fuel plants to produce surplus electricity and/or to capture and store the $CO_2$ streams that these plants produce. This work could be progressed through possible pilot/demonstration storage projects.

- Facilitating the commercial deployment of IGCC technology, including by addressing research gaps; facilitating demonstration projects in Partner countries; adapting incentive schemes, such as international carbon financing to support investments in IGGC plants; and by addressing new skill sets needed to operate these plants effectively.

- Facilitating the development of proposed $CO_2$ capture and storage associated with IGCC plants (e.g. FutureGen and GreenGen), using these projects to target research priorities across member countries, progressing capacity building, conducting joint research, facilitating information exchange, and developing appropriate incentive mechanisms.

- Facilitating research, trials and development of gasification technology with alternative fuels like pet coke, residues or gas for commercial deployment and associated $CO_2$ capture and storage. Project proposal to be developed by USA, Australia and India.

This strategic approach is outlined in Figure 3, while Figure 4 illustrates the stages of development/diffusion.

**Figure 3 Coal Gasification— Strategic Directions**

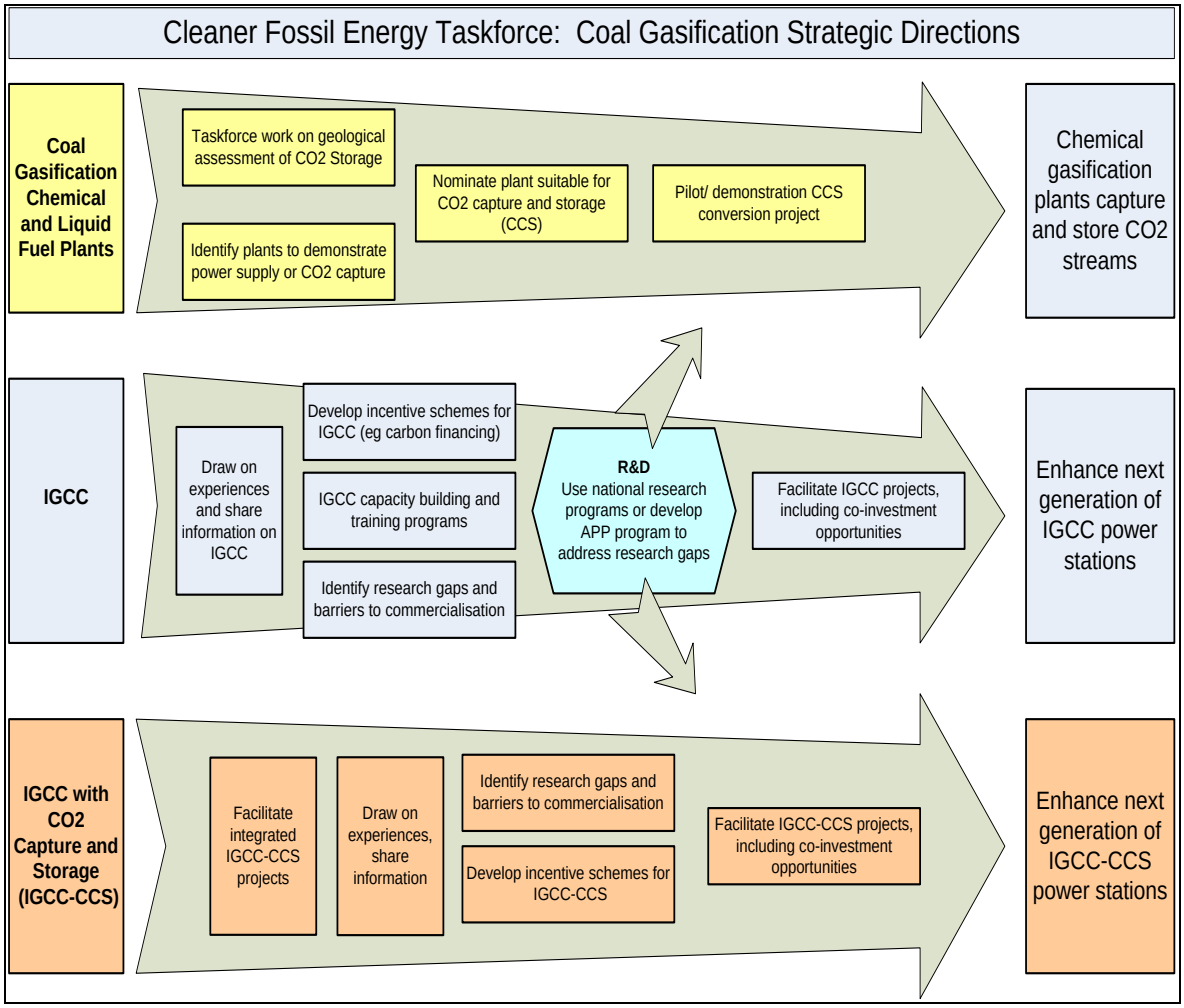
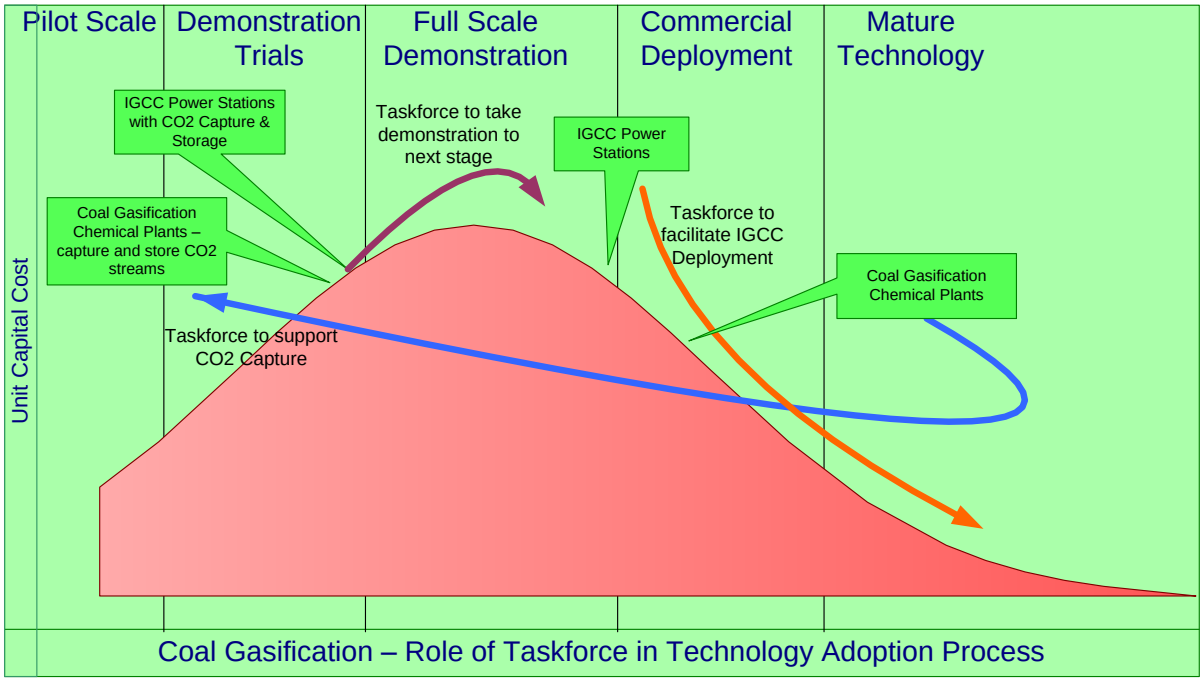



**Figure 4 Coal Gasification - Stages of Development and Diffusion**



## Theme 4 Energy Market Access for Gas

Gas is becoming increasingly important in the global energy mix. Natural gas is the least carbon intensive of the fossil fuels and its greater use can help offset some of the growth in greenhouse emissions from expanding energy use. As well as greenhouse benefits, greater penetration of natural gas into Partner countries will help to improve air quality, and enhance fuel diversity and energy security.

Presently, the natural gas share of electricity generation in member countries varies from 0.3% (China) to 24% (Japan). There is a similar range in the use of natural gas as a heating/cooling and cooking fuel. Increasing the share of gas in all uses will help Partner countries in the transition from their current high emission fossil fuel technologies to the new low emission technologies that will emerge over the next few decades.

The focus of this theme will be on facilitating increased uptake of gas in Partners' economies by implementing best practice in market design, increasing the supply of pipeline gas and natural gas sourced from coal seams, and increased trade of liquefied natural gas (LNG) within Partner countries to meet growing energy demand. This will also meet the environmental objective of reducing greenhouse gas emissions, the social objective of access to reasonably priced energy for all citizens, and the geopolitical objective of supply security.

The Task Force will seek to:

- Identify actual potential cross-border impediments, such as regulatory and market impediments, and promotion of good practice regulatory models to ensure a consistent Partnership framework for natural gas.

- Encourage uptake of $CO_2$ capture and storage in the oil and gas industries of the Partner countries to support other Partnership initiatives.

- Develop an understanding of coal seam gas opportunities in the Asia-Pacific region, and other ways of growing the use of gas as an exportable fuel, e.g. compressed natural gas (CNG) or the use of gas as a feedstock for low-$CO_2$ liquid petroleum products, e.g., gas to liquids (GTL).

## Theme 5 Gas Handling Infrastructure Improvements

The use of natural gas in all member economies is strongly dependent on pipeline distribution systems, ships, large-scale storage and re-gasification processes and high system pressures and/or low system temperatures. Gas losses along the oil and gas value chain occur as a result of normal operations, maintenance, outdated technology, management shortcomings and system disruptions. Although natural gas is a clean source of energy, fugitive emissions during production, processing, storage and transportation account for 15% of total global atmospheric methane emissions. Their reduction will not only help the climate change effort by lowering emissions, but also increase the amount of gas available for sale, enhance supply security and increase revenues. Because the emissions are predominantly methane (with some, usually minor, mix of $CO_2$) the greenhouse effects are extremely significant.

Even small incremental reductions in gas wastage and loss can be expected to have a very large benefit on the overall greenhouse emissions of Partner countries. Current methane emissions in the Partner countries probably amount to at least 23 billion cubic meters of $CH_4$, or 90 million metric tons of carbon equivalent.

Emissions can be reduced in a cost-effective way in countries with significant gas infrastructure already in place by retrofitting upgraded technologies and equipment, and by improving operations and management practices. In countries with rapidly developing new gas infrastructure, learning, technology and prudent practices can be applied in such a way that an early engineering and management focus on minimizing gas losses can be successfully built in.

The global average efficiency of gas-fired power plants increased from 35% in 1992 to 42% in 2003, but regional variations are large. The Partnership represents an opportunity to raise the regional efficiency of gas-fired power generation by collaborating on the development of improved combined-cycle technology and by sharing knowledge and information on operations and management practices.

The Task Force will seek to:

- Quantify the current methane losses from Partner countries' gas infrastructure.
- Quantify the overall greenhouse effect and the value loss to member economies.
- Develop a recognition that leak prevention and mitigation should be a core business activity and policy focus, through a case study approach.
- Encourage access to, and application of, capital towards leakage reduction technologies and projects.
- Research ways to make investments in leak reduction viable in areas where gas prices are artificially low.
- Develop ways and means for Partner countries to share information on best practices for leakage reduction from infrastructure, and to facilitate the application of emission reduction technologies and practices.
- Engage the oil and gas industry to improve awareness of emission reduction opportunities.

All members of the Partnership are also members to the Methane to Markets Partnership, which has very similar goals to those described under Theme 5. Activities under the Partnership will be designed in coordination with the Methane to Markets Partnership, so that both Partnerships can complement each other and draw on and apply their combined expertise.

# Appendix C: Country Sector Reviews of Partner Countries

## Australia

### *Government Clean Fossil Energy Policy*

The policy framework for clean fossil energy in Australia is reflected in the Energy White Paper, *Securing Australia's Energy Future*. Priority is given to the development of technological solutions that address environmental, greenhouse and energy policy objectives. This framework recognizes Australia's global responsibilities as a major supplier of coal and LNG, Australia's reliance on technology developed offshore and the contribution that Australia can make domestically and internationally to the development of low emissions technologies. Australia actively supports practical bilateral and international cooperation on greenhouse.

Government-industry partnerships, such as the COAL21 Partnership, the LNG Action-Agenda and Cooperative Research Centres, have developed strategies and technology roadmaps for developing carbon capture and storage, a national clean coal strategy, industry development strategies for LNG and national low emissions technology R, D&D strategies and programs. A cooperative government-industry approach is built into technology development and deployment programs, such as the AUD$500 million Low Emissions Technology Demonstration Fund, the Greenhouse Challenge Plus, the Greenhouse Gas Abatement Programme and Generator Efficiency Standards. Australian coal producers have also established the AUD$300 million COAL21 Fund to support the demonstration of low emissions technology in Australia.

### *Research and Development Activities*

The IEA Clean Coal Centre has reported favorably on the comprehensiveness, coordination and information sharing of clean coal technology R&D in Australia. Much of this research is being progressed through the Commonwealth Scientific and Industrial Research Organization (CSIRO) and its Energy Transformed Flagship Initiative, and through Cooperative Research Centres covering the utilization of black and brown coal and $CO_2$ capture and storage (CCS). Australia has undertaken, for example, world leading research into mapping $CO_2$ storage potential, the gasification performance of different coals, gas separation, brown coal gasification, advance coal cleaning and supporting research for technologies that enable $CO_2$ capture.

### *Industry Demonstration Activities*

Projects demonstrating low emissions technology currently under consideration in Australia include:

- Pilot trials of $CO_2$ storage.
- The Callide-A oxy-fired combustion projects.
- Post-combustion capture pilot and demonstration projects.
- Ultra clean coal demonstration power station.
- Stanwell ZeroGen coal gasification with carbon capture and storage (CCS).
- Brown coal gasification and coal gas to liquids with CCS.

- Brown coal drying including integrating drying gasification combined cycle.

- Large-scale $CO_2$ storage, such as from the proposed Gorgon LNG project and proposed Monash coal gas-to-liquids projects.

## Canada

***Government Clean Fossil Energy Policy***

As a major fossil fuel producer, Canada is committed to cleaning the production, processing and use of fossil fuels. It will achieve this through a combination of regulation, and the research, development and deployment of clean energy technologies. The federal government's *Turning the Corne*r plan for climate change action signaled its intention to introduce a suite of industrial greenhouse gas (GHG) regulations, which would facilitate the cleaning of all fossil fuel sectors, such as oilsands operations and coal-fired electricity generation.

Action is taking place at both federal and provincial levels. Federal Budget 2009 introduced a Clean Energy Fund, which will contribute to cleaner fossil fuels through development and demonstration of technologies, such as carbon capture and storage. It re-iterated Canada's aggressive commitment to reduce GHG emissions by 20% from 2006 levels and to have 90% of its electricity come from non-GHG emitting sources by 2020. Provinces have also introduced measures to encourage cleaner fossil fuels, including British Columbia's carbon tax; Ontario's commitment to phase out coal-fired electricity and double its renewable energy output by 2025; and Alberta's long-term strategy to reduce the environmental footprint of oilsands development.

The federal and provincial governments recognize the important role that carbon capture and storage (CCS) will play in meeting commitments to mitigate GHG emissions, recognizing that CCS is one of the only technologies currently available for making major GHG emission reductions at large final emitters (e.g. coal fired-electricity, oil sands), which contribute a significant portion of Canada's overall industrial emissions.

Advancing the commercial deployment of CCS has been identified as a priority for advancing clean energy technologies, including the funding of CCS under federal and provincial R&D programs and for large demonstration projects. Since 2008, over $3 billion in federal and provincial government funding has been committed for advancing upwards of seven large-scale CCS demonstration projects. This amount includes $125 million, which the federal government had allocated in 2007 for small field trials and engineering design studies. It is expected that the approved projects will begin in 2009. It also includes additional funding for large scale CCS demonstration projects under the federal $1 billion Clean Energy Fund announced in the 2009 Budget.

***Major R&D Activities***

***Coal and Power***

- Clean coal R&D activities at CanmetENERGY-Ottawa (NRCan) are guided by Canada's *Clean Coal Technology Roadmap*, developed by NRCan with support from Industry Canada and industries. Working with industry and academic partners, projects include:
  - Advanced power cycles including working to develop models to characterize the operation of SOFCs in various configurations and modes of operation;
  - Advanced fuel cells: development of models to characterize the operation of solid oxide fuel cells in various configurations and modes of operation;

- Gasification of western Canadian coals for power generation and hydrogen production using upgraded pilot-scale gasifier plant.
- Gasification mapping of low-rank coals, coal and petcoke blends, water-oil emulsion and refinery resids;
- Fine particulate emissions from stationary combustion sources;
- Computational fluid dynamics modeling of clean coal systems and sub-systems;
- Advanced coal burner concept development to improve efficiency and minimize NOx emissions;
- Plasma ignition system for clean coal power generation;
- High efficiency retrofit strategies for power generation;
- Advanced fuel utilization strategies for power generation;
- Plasma Corona Radical Shower for developing robust and economically-optimized industrial solutions for controlling $SO_2$, $NO_x$, and Hg emissions during coal combustion.

- Clean coal research at Canadian universities:
  - Dalhousie University: clean energy from coal and biomass;
  - Carleton University: closed gas turbine cycle project; advanced Brayton-cycle-based zero emission power plants burning fossil fuels;
  - McMaster University: development of integrated electrostatic air pollution control system for small-scale combustion passed power generators
  - University of Saskatchewan: mathematical modeling of a circulating fluidized bed (CFB) lignite combustor; novel biochar and coal char sorbents for the removal of mercury from coal combustion flue gas;
  - University of Alberta: fluid coke as a sorbent for mercury; mercury emission control from coal-fired power plants.

***Carbon Capture and Storage R&D***

- CCS R&D activities at CanmetENERGY-Ottawa (NRCan) are guided by Canada's *$CO_2$ Capture and Storage Roadmap*, developed by NRCan with support from Industry Canada and industries. Working with industry and academic partners, projects include:
  - Third-generation oxy-fuel systems to explore the possibilities of minimizing or eliminating the flue gas recycled from oxy-fuel systems;
  - Development of integrated thermo-chemical processes for the production of hydrogen and oxygen from advanced high-temperature energy conversion systems with $CO_2$ capture;
  - Post-combustion $CO_2$ capture;
  - Oxygen-fired circulating fluidized bed combustion;
  - Advanced simulations of oxy-fuel systems and coal gasifiers for CO2 capture;
  - High pressure oxygen firing (HPrOx) power cycles for fossil fuels to improve efficiency of power generation systems with capture;
  - Post-combustion capture strategies using ammonia-based and hybrid ammonia/MEA;
  - Development of $CO_2$ capture via looping cycles using calcium-based sorbents in a large testing facility;
  - Sorbent development and evaluation for enhanced $CO_2$ capture using high-temperature sorbent looping process;
  - Advanced hot-gas clean up with enhanced $H_2$ production and $CO_2$ capture from gasification syngas.

- The International Energy Agency GHG Weyburn-Midale $CO_2$ Monitoring and Storage Project – an international consortium of over 30 different government, industry, and research partners from around the world, is carrying out the final phase of the world's largest CCS measuring, monitoring, and verification research program at the site of the EnCana-Apache commercial $CO_2$-EOR operations (see below).
- Storage Atlas of Canada – NRCan-led consortium will develop an inventory of the potential and capacity for $CO_2$ storage in geological formations across Canada.
- Institute for Sustainable Energy, Environment and Economy (ISEEE) (University of Calgary) is conducting research into regulatory, economic and technological barriers to CCS.
- International Test Centre for $CO_2$ Capture (University of Regina) – research consortium investigating improvements of the chemical absorption process (using a variety of solvents) as well as developing new technology and carrying out technology screening studies.
- International Performance Assessment Centre for Geological Storage of $CO_2$ (IPAC-$CO_2$) (University of Regina) – newly announced initiative that will evaluate CCS performance and risk issues, assess and advise on proposed CCS projects around the world and share findings with other research organizations.
- Consortium led by Dalhousie University will perform a geological storage assessment of onshore and offshore storage potential in Nova Scotia.
- Québec established a Research Chair at the Institut national de la recherche scientifique (INRS) to evaluate the geological storage potential in the province and to initiate a pilot project to inject $CO_2$ in 3-4 years, possibly in the Lower St-Lawrence area.

***Oil and Gas***

The oil and gas research, development and demonstration (RD&D) programs of NRCan are aimed at fulfilling federal responsibilities by providing the science and technology needed for regulations, codes and standards, and for protecting the environment. The total NRCan expenditure on oil and gas related RD&D in FY 2005-06 was $34.8 million.

NRCan's RD&D programs are organized into two major portfolios. The first of these is the bitumen, oil and gas portfolio. The objective of this portfolio is to provide science and technology for the continued, secure supply of affordable and cleaner fuels, with little or no adverse environmental impacts in terms of GHG and criteria air contaminant emissions, water quality and quantity and land contaminants and footprint. Activities under this area fall in two sub-components: oil sands environmental (air, land and water issues) and clean air/groundwater issues in the conventional upstream oil and gas industry.

- *Upstream Petroleum Air Issues Research Initiative (UPAIRI)*- To provide effective air emissions R&D in support of clean energy production in the upstream oil and gas sector. As a result of the quality of Canada's petroleum air issues research, the leader of this Program Michael Layer remains as the Canadian co-Chair of the international Methane-to-Markets (M2M) Partnership Oil and Gas Technical Committee, along with co-Chairs from Russia and Mexico. The UPAIRI work funded through the Program of Energy Research and Development, has long comprised Canada's contribution to the M2M Partnership and the APP CFE charter links all UOG Air Issues activity under the CFE, to be undertaken by the M2M Oil and Gas Committee.
- *Petroleum Conversion for Cleaner Air* - Find new or improved, cleaner and more efficient solutions to reducing environmental emissions by developing and disseminating

new knowledge and new technologies on petroleum conversion. Another major component of this program is the use of technical and industry knowledge to provide decision makers with timely, accurate and non-partisan information on which to base their decisions.

- *Mitigating the Impact of Bitumen Production from Oil Sands* - The objective of this program is to provide the knowledge necessary to reduce the impact of oil sands development on water, air, and land through a combination of understanding of the fundamentals, through to the application of this knowledge to pilot and field demonstrations of relevant technologies, and onto providing policy makers with the best information possible.
- *Gas Hydrates as a Canadian Energy Alternative* - Conduct R&D to ensure the safe, efficient, and environmentally sustainable exploitation of natural gas hydrate resources in Canada. In 2002, a five-nation international research consortium (consisting of Canada, Japan, Germany, USA, and India) conducted large- and small-scale production experiments to evaluate the efficiency of pressure reduction vs. heat stimulation techniques for initiating in situ dissociation of gas. These experiments, along with of state-of-the-art well logging and extensive post-field laboratory studies, provided critical scientific and technical data supporting the design and engineering of a subsequent Canada-Japan extended production testing program conducted at Mallik during the winters of 2007 and 2008.

***Industry-Led Carbon Capture and Storage Demonstration Activities***

***British Columbia***

- Spectra Energy - Fort Nelson (northeast BC) – evaluation of the geological, technical and economic feasibility of $CO_2$ capture at the Fort Nelson gas processing plant, and storage of up to 1.2 Mt annually of sour $CO_2$ gas in deep underground saline reservoirs.

***Alberta***

In July 2008, Alberta committed $2 billion to support three to five large-scale CCS projects in the province, which are expected to reduce $CO_2$ emissions by up to five megatonnes annually by 2015. Funding decisions for the projects are expected to be announced by March 31, 2009. The following industry-led projects are currently at various stages of realization, ranging from fully operational to initial designs:

- Shell Canada Quest Project - $CO_2$ capture from the Scotford Upgrader near Fort Saskatchewan and injection into deep pre-Cambrium saline formation.
- EPCOR Genesse project - front-end engineering design study to examine the engineering, operational and costing details for a 270-MW IGCC power plant, which will capture more than 1.25 Mt of $CO_2$ annually.
- TransAlta Clean Coal and CCS Demonstration Project – evaluating post-combustion $CO_2$ capture technology, using Alstom's proprietary Chilled Ammonia Process, at one of TransAlta's coal-fired plants west of Edmonton
- Apache Zama Acid Gas EOR Project (northwest Alberta) – evaluation of the impact of acid gas injection on EOR, assessing the integrity of the caprock and monitoring and verifying the storage integrity of the injected gases.
- Enhance Energy – several $CO_2$-EOR projects under development, including joint venture with Fairborne Energy Ltd. for the Clive project.

- Integrated $CO_2$ Network ($ICO_2N$) – an alliance of 15 of large Alberta emitters, which has been working for more than 2 years carryout various studies on a proposed system for the capture, transport, distribution and storage of $CO_2$.
- Heartland project in Redwater area (HARP) – evaluation of the potential for the Redwater Leduc Reef complex to store up to 1000 Mt of $CO_2$, followed by demonstration.
- Wabamun Area Saline Aquifer Project (WASP) – study by UoC to assess issues related to the potential to permanently store up to 1000 Mt of $CO_2$ from coal-fired power plants in the Wabamum area.
- Alberta Saline Aquifer Project (ASAP) – an initiative of 26 participating energy industry groups to identify three saline formations for large-scale storage of $CO_2$.
- Pembina Cardium – evaluation of the feasibility of $CO_2$ -EOR in the Pembina Cardium oilfield in central Alberta – the largest conventional oilfield in Canada. A pilot $CO_2$ injection was successful in 2005.

***Saskatchewan***

- EnCana Weyburn (since 2000) and Apache Midale (since 2005) commercial $CO_2$-EOR operations, injecting over 2.8 Mt of $CO_2$ annually to recover incremental oil
- SaskPower Boundary Dam Integrated CCS Project – project to rebuild existing 100-MW lignite-fired unit, using post-combustion capture technology, and to store 1 Mt $CO_2$ annually by 2015 (through $CO_2$ -EOR or direct storage into deep saline aquifers). The federal government has contributed $240 million to this project whose total costs are estimated at $1.4 billion.
- Aquistore Project – industry consortium, led by the Petroleum Technology Research Centre (PTRC) in Regina, to demonstrate the feasibility of storing 500 t/d of $CO_2$ in deep saline aquifers.
- Trans-Canada Energy - Belle Plaine Integrated Polygeneration Facility – gasification of petroleum coke to generate 300 MW of electricity and several other energy by-products, incl. hydrogen, steam and $CO_2$, for use at nearby industrial facilities or for EOR in nearby oilfields.
- Saskatchewan - Montana Project – Capture of $CO_2$ at one of SaskPower lignite-fired plants and transport to Montana for EOR or deep aquifer disposal.

## India

***Government Clean Fossil Energy Policy***

The share of fossil energy will remain more than 90 % of primary commercial energy sources in India. While coal constitutes about 50 % of the energy mix, oil and gas account for about 45%. The future projections given in the Vision 2020 document shows almost the same ratio of coal and oil & gas in the energy mix. Out of the total quantum of oil & gas, the share of gas will further go up with corresponding reduction in oil. Coal shall remain India's most important energy source till 2030 and possibly beyond until substantial gas replaces power generation.

Government policy is to pursue technologies that will maximize energy efficiency, demand side management and energy conservation to ensure energy security and reliability. The emphasis is reduced consumption of fossil fuels through substitution with improved fuels and efficient technologies while CDM projects to ensure minimum GHG emissions.

***Research & Development Activities***

The National Mission for long term energy security and environment concern emphasize research and development of clean coal combustion technologies, new coal extraction methodology/technology, in-situ coal gasification, IGCC technology, coal to liquid (CTL) gas to liquid (GTL), carbon capture & storage (CCS), hydrogen technology and gas hydrates, etc.

***Industry Demonstration Activities***

Preliminary development activities in coal cleaning, combustion control & efficiency improvement, IGCC technology has been initiated by the Power & Coal sector. Hydrocarbon sector to take up various clean energy options through GTL/CTL, SOx/NOx emission reduction, gas hydrates and hydrogen technology development.

## Japan

***Government Clean Fossil Energy Policy***

Since the position of Clean Fossil Energy, especially coal, in the energy resources policy is to be determined on the basis of its relative advantages and the relative disadvantages as compared with other energy sources, it would be important to preserve and intensify such advantages and to make efforts to overcome such disadvantages.

Although coal has the advantage of superior supply stability at present, reducing its higher emission quantity of $CO_2$ per unit calorific value is the largest task faced; however, coal has remained one of the alternatives in the pursuit of a well-balanced energy supply structure to cope with various issues.

In the future, with advances in the development of innovative, environmentally friendly coal utilization technology (clean coal technology (CCT)), such as high-efficiency energy conversion technologies through coal gasification, $CO_2$ Capture and Storage (CCS) technologies, and other technologies anticipated towards 2030, coal is expected to become a promising alternative as a $CO_2$-free energy source in the pursuit of a well-balanced energy supply structure.

***Research and Development Activity***

Implementation of research and development of integrated coal gasification fuel cells combined-cycle (IGFC), for example, the EAGLE project is progressing to establish its technologies with coal feed 150t/day pilot plant.

Implementation of research and development of coal flush partial hydro-pyrolysis technology, for example; ECOPRO project using a 20t/day pilot plant has been started to establish the process technologies for commercialization.

Implementation of research and development of $CO_2$ Capture and Storage (CCS) technologies (Aquifer/coal bed sequestration), for example, a $CO_2$ injection demonstration experiment, which is the injection rate of 40 t-$CO_2$/day, is processing in NAGAOKA project.

***Industry Demonstration Activities***

- Implementation of demonstration test of integrated coal gasification combined-cycle (IGCC), for example, the demonstration plant of IGCC with an air-brown type that is capacity of 250MW will progress to operation stage in 2007.

- Implementation of demonstration test of Callide-A Oxy-fuel Demonstration project.

- The contents of Clean Coal Day-related business.

## Korea

### *Government Clean Fossil Energy Policy*

The 2nd Fundamental Energy Plan (2003) is the basis of the governmental policy on fossil energy in Korea. The main direction of the policy on the fossil energy sector is to establish the market-oriented environment. To encourage energy industries to operate cleaner, the Plan also includes government-driven research and development activities for more efficient and cleaner uses of fossil energy. The future portfolio of power generation is forecasted in the 2nd Power Supply and Demand Plan. New power plants are built according to the Plan. New and Renewable Energy Deployment Enhancement Plan and the Fundamental Plan on the Rational Use of Energy are the detailed plans for energy R&D. We also have a Master Plan on the Hydrogen Economy, which spans 2005 to 2040.

### *Research and Development Activities*

Most of fossil energy R&D in Korea is sponsored by the Ministry of Commerce, Industry and Energy (MOCIE). Korea Energy Management Corporation (KEMCO) manages energy R&D programs including New and Renewable Energy R&D Program and Cleaner Energy Use R&D Program. By Korean law, energy obtained from coal gasification is regarded as New Energy. Under those two programs, IGCC, ultrasupercritical PC boilers, poly-generation, coal bed methane, hydrogen production and coal cleaning researches are in progress.

The Ministry of Science and Technology (MOST) also carries out $CO_2$-related research through Carbon Dioxide Reduction and Sequestration Centre (CDRS). Oxy-fuel combustion and post-combustion $CO_2$ capture technologies are being developed through CDRS.

### *Industry Demonstration Activities*

CFE Projects being demonstrated by Korean industries include:

- Ultrasupercritical PC boilers.

- 300 MW class IGCC plant (planning stage).

## The United States

### *General U.S. Government Cleaner Fossil Energy Technology Policy*

U.S. goals for clean fossil energy are articulated through federal and state legislation, such as the Energy Policy Act of 2005; through government agencies, such as the Department of Energy and Environmental Protection Agency; and through other organizations, such as the National Academy of Sciences. A number of drivers are currently shaping fossil energy policy, including:

- Environmental protection—Acquisition, transport, and use of fossil energy must be accomplished in a manner that minimizes impacts on the environment.

- Efficiency—Higher efficiency reduces the energy needed required for a given output, yielding lower emissions (including $CO_2$), conserving domestic resources, and reducing energy imports.

- Economic development—Development and utilization of domestic fossil energy resources helps sustaining economic growth by creating jobs and reducing energy imports.

- Reliable and predictable energy supply—The supply of energy, in its various forms, should be reliable and predictable to support economic growth and minimize price fluctuations.

- National and energy security—Energy systems need to be resistant to natural disasters and deliberate attacks, and energy trade should not result in negative geopolitical situations.

***Major R&D Activities***

*Coal and Power*

- *FutureGen*—A US$1-billion industry/government partnership to build a coal gasification-based, nearly emission-free, integrated electricity and hydrogen production plant with carbon capture and storage.

- *Clean Coal Power Initiative*—A government/industry partnership to conduct full-scale demonstrations of new technologies to cut pollutants from coal-fired generation by nearly 70% by 2018.

- *Gasification*—By 2010, complete R&D to develop advanced power systems capable of 45-50% electrical efficiency at a capital cost of $1000/kW or less.

- *Innovations for Existing Plants*—Develop technologies ready for demonstration by 2007 that can reduce emissions of mercury by 50-70% at 50-75% of today's cost; NOx to less than 0.15 pounds per million BTUs at 50-75% of selective catalytic reduction cost; and particulate matter by 99.99%. By 2010, develop technologies to reduce mercury by 90%, increase by product utilization by 66%, and reduce water use in power plant cooling systems.

- *Advanced Combustion*—By 2010, develop "hybrid" coal power systems integrating gasification with advanced combustion to achieve thermal efficiencies above 50% at a capital cost of $1000/kW or less; by 2015, develop an advanced "hybrid" as a candidate core technology for the Vision 21 power plant.

- *Fuel Cells* –R&D includes developing (1) solid-state fuel cell modules at less than $400/kW, (2) tubular solid oxide fuel cells, (3) molten carbonate fuel cells, (4) phosphoric acid fuel cells, and (5) fuel cell/turbine hybrids.

- *Turbines*—By 2010, develop turbine technology that efficiently uses coal-derived gases, including hydrogen, to produce electricity in FutureGen plants.

*Oil and Gas*

- *National Methane Hydrates R&D Program*—Produce the knowledge and products necessary for commercial production of methane hydrates by 2015.

- *Deep Trek & Other Drilling R&D*—Develop technologies to help operators safely drill and complete deep wells (>15,000 feet) faster, cheaper, and cleaner.

- *Enhanced Oil/Natural Gas Recovery Using $CO_2$ Injection*—DOE's program focuses on evaluating candidate locations for future $CO_2$ injection to facilitate enhanced oil recovery, utilizing $CO_2$ from industrial sources, as well as geologic sources.

- *Petroleum Fuels*—Facilitate economically efficient transition of the U.S. oil and gas processing and fuels delivery system to ultra-clean processing/fuels.

- *Domestic Oil & Gas Conservation*—(1) micro-hole systems, (2) marginal & stripper well revitalization, (3) environmental protection, (4) diagnostics, imaging & fundamental R&D, (5) transmission, distribution & storage, (6) field projects, technical assistance & technology transfer, (7) LNG, and (8) natural gas regulation.

- *Oil Shale/Tar Sands/Other Unconventional Sources*—Examine the potential of these resources for liquid fuels, including (1) strategic value, (2) public benefits, (3) possible ramifications of failure to develop these resources, and, (4) related public policy issues.

*Carbon Capture and Storage*

To address potential climate change concerns and facilitate continued utilization of domestic fossil energy resources, the United States is pursuing demonstration of safe, cost-effective $CO_2$ capture, storage, and mitigation technologies at commercial-scale by 2012, leading to substantial deployment and market penetration beyond. Through the Carbon Sequestration Leadership Forum and seven regional government/industry partnerships, the United States is leveraging national and international initiatives to advance the understanding of carbon capture and storage and to accelerate technology development and deployment.

*Industry-Led Technology Demonstration Activities*

A number of industry-led activities complement and reinforce public efforts aimed at achieving U.S. cleaner fossil energy goals. These initiatives convey the private sector's commitment to sustained use of fossil energy in an efficient, secure, and environmental responsible manner.

- Solid State Energy Conversion Alliance seeks to accelerate development of solid oxide fuel cells and get them to the market as quickly as possible as an affordable power generation option. The Alliance comprises (1) Industry teams, which design the fuel cells, handling most hardware and market penetration issues; (2) Core Technology Program teams of universities, national laboratories, and companies, which look into research problems affecting the industry teams; and (3) the U.S. government, which facilitates interaction between the first two groups and manages the program.

- DeepStar is a joint industry project focused on technologies to increase deepwater hydrocarbon production and reserves. Nine multi-national oil companies lead the effort, with support from dozens of product and service companies.

- Recognizing the importance of global climate change in future energy scenarios, and acknowledging the significant role that coal and other hydrocarbon fuels will continue to play, a number of leading U.S. utilities, oil companies, and technology vendors are pursuing IGCC technology and carbon capture and storage. For example, American Electric Power, Duke/Cinergy, TXU Energy, and NRG Energy have all publicly committed to investments in IGCC technology. BP and GE Energy have also announced plans to collaborate on building ten to 15 hydrogen-fuelled power plants capable of separating and storing $CO_2$ underground.

- CoalFleet for Tomorrow® (CoalFleet) emphasizes deployment and has not only analyzed and shared lessons learnt but has analyzed the financial barriers to deployment and suggested incentives for various types of firms. CoalFleet has also developed design guidelines and economics for IGCC and will publish USC design guides in 2006 while improving these with each version (in 2006 CoalFleet worked on version 4 of the IGCC design guides). CoalFleet will have IGCC plus CCS guidelines in 2006 and USC plus CCS in 2007. CoalFleet has international collaboration and support from over 300 GW worth of coal generators, coal companies, oil and rail and most major suppliers of IGCC worldwide (GE, Shell, Siemens, Conoco Philips, Rocketdyne), and several combustion suppliers (Alstom, B&W). CoalFleet is proposing to build on this collaboration for two of the Partnership's CFE initiatives.

# Appendix D: Glossary

**Summary of Key Technologies Identified in the Sector Review**

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| Integrated Gasification Combined Cycle (IGCC) | In the IGCC process, coal is not combusted, 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. If carbon capture is required, the syngas is reacted with steam prior to combustion to produce hydrogen and $CO_2$. These gases are then separated. The hydrogen is burned as a clean emission free fuel in the gas turbine and the $CO_2$ is compressed for geological storage. |
| Oxy-Fuel Combustion | In oxy-fuel combustion, the coal is burned in oxygen rather than air and the flue gas is recycled through the system. This eliminates nitrogen and increases $CO_2$ concentrations in the resulting flue gas to facilitate capture. |
| Post-Combustion Capture | In post-combustion capture, conventional coal or gas power plants (including the possibility of retrofit to existing ones) are fitted with solvent absorption technology to selectively absorb $CO_2$ in the flue gas. The loaded solvent is then heated and passes through a stripping column, where steam is used to regenerate the solvent and remove the $CO_2$ for capture. |
| Ultrasupercritical Pulverized Fuel | Most of the new clean coal technologies under development have 10–20 per cent lower greenhouse gas emissions than conventional pulverized fuel (pf) coal-fired power plants. New clean coal technologies include supercritical and ultra supercritical steam, fluidized bed combustion and a range of coal gasification systems. These technologies significantly increase thermal efficiency. This means less coal is required to produce a given amount of energy. Advanced modern plants use specially developed alloys, which enable the use of supercritical and ultra supercritical steam to achieve efficiencies of 45 per cent and above. As the technology advances, efficiencies of 55 per cent and above should be achievable in the near future. |

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| Coal Cleaning and Equipment | Also known as *coal cleaning*, *coal preparation* and *coal beneficiation*. As-mined coal is of variable quality and contains impurities. Coal beneficiation is the process by which these impurities are removed to produce a cleaner product. Coal washing increases the heating value and the quality of the coal, by lowering the level of sulfur and mineral constituents. Coal washing can reduce the ash content of coal by over 50% and reduce sulfur dioxide ($SO_2$) emissions.<br><br>The removal of ash reduces the amount of coal that is transported so that reduction in energy needed to transport coal, especially over large distances, will outweigh the additional energy used in washing coal.<br><br>The major greenhouse benefit is in terms of providing coals that support optimum design parameters of power stations. Processes have also been developed, for example—ultra clean coal in Australia and Hyper coal in Japan—which remove almost all the impurities in coal. This product can be burned directly in gas turbines to achieve major improvements in thermal efficiencies. |
| Poly Generation | Gasification systems, such as coal gasification, use the syngas for power generation and to produce chemicals or liquid fuels. The additional revenue streams from poly generation can help offset the additional costs of coal gasification power. |
| Reformation of Fossil Fuel | There are several technology options for the production of hydrogen that use renewable energy in the reformation of fossil fuels, including methane from natural gas. The reformation of fossil fuels may become a more efficient process for generating and storing power from renewable energy. |
| Hydrogen Production | Gasification technologies will support the production of hydrogen that can be burned directly into advanced gas turbines or used in hydrogen fuel cells, which can be used in either stationery or transport applications. |
| Enhanced Coal Bed Methane | Enhanced Coal Bed Methane (ECBM) recovery is seen as a potential opportunity for sequestering $CO_2$ in unmineable coal seams and obtaining improved production of coal bed methane as a valuable by-product. |

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| Coal Mine Methane | At active underground mines, methane must be removed from underground operations for safety reasons. This is done with large-scale ventilation systems that move massive quantities of air through the mines. These ventilation systems keep mines safe but also release large amounts of methane at very low concentrations, often termed Ventilation Air Methane (VAM). At some active mines and abandoned mines, methane is also produced from degasification systems (also commonly referred to as gas drainage systems) that employ vertical and/or horizontal wells to recover methane. There are a variety of uses for drained CMM including natural gas pipeline injection, electric power production, co-firing in boilers, district heating, mine heating, coal drying, vehicle fuel, and manufacturing/industrial uses, such as feedstock for carbon black, methanol, and dimethyl ether production. For VAM, technological development has progressed to the point where low cost solutions are now commercially available. |