
Canadian
Clean Power Coalition
Advancing Technology
for Cleaner Coal
Phase III, Final Report

Canadian Clean Power Coalition

Advancing technology for cleaner power

The Canadian Clean Power Coalition (CCPC) is an association of responsible, leading Canadian and U.S. electricity producers that believes coal, along with a diverse mix of fuels like hydro, natural gas, wind, solar and nuclear, will play an important role in meeting the energy needs of the future.

Alberta Innovates Energy and Environment Solutions

Saskatchewan Ministry of Energy and Resources

The progress and achievements of CCPC are due in large part to the continued support of Alberta Innovates and Saskatchewan Energy and Resources.

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The CCPC's mandate is to research technologies with the goal of developing and advancing commercially viable solutions that lower emissions from coal-fired power plants. The CCPC aims to find ways to generate electricity from coal that effectively and economically address environmental issues – including carbon dioxide (CO_2) emissions – and move us forward to a cleaner energy future. To-date, the CCPC and its members have spent more than $50 million furthering this objective.

Key CCPC achievements

- Provided early leadership to study carbon capture and storage (CCS) on coal plants
- Inspired industry to develop several CCS projects
- Established that significant advances and development will be required to reduce the cost of CCS before CCS will be widely adopted
- Accelerated understanding of cleaner coal technologies, and developed the most extensive collection of Canadian technical and economic information on the subject
- Sponsored the first Front-End Engineering and Design (FEED) study on integrated gasification combined cycle (IGCC) with carbon capture in Canada, and determined that low-ranked coals have a detrimental impact on IGCC costs
- Determined that there is no commercially available low-cost technology that will significantly reduce carbon dioxide (CO_2) emissions from coal plants

The case for coal

Coal is vital for electricity generation in Canada and internationally because it is a low-cost fuel with large proven reserves. In Canada alone, there are an estimated eight billion tonnes of proven reserves, one of the world's largest deposits and a natural resource advantage that should provide power one thousand years into the future. The industry also provides significant employment and an overall positive economic impact.

Air quality issues associated with coal must be addressed. Technology will provide long-term solutions to emissions issues. The CCPC is committed to finding those solutions. Organizations such as the CCPC play a role in leading the way to cleaner power generation through partnerships between government and industry.

Canada has an estimated eight billion tonnes of proven coal reserves. This resources is primarily accessed through mining, using massive, specialized equipment.

The CCPC's membership includes responsible, leading Canadian and U.S. electricity producers.

CCPC members

The CCPC's membership includes responsible, leading Canadian and U.S. electricity producers. The CCPC is always interested in expanding membership and collaborating with other entities to further our objectives.

CCPC's members represent the majority of Canada's coal-fired power generation capacity. The coalition was formed out of concern about greenhouse gas emissions, and to collectively evaluate strategies for emission reductions.

Current CCPC members are

- Basin Electric Power Cooperative
- Capital Power Corporation
- Nova Scotia Power
- SaskPower
- Sherritt International Corporation
- TransAlta Corporation

Associate member

- The Electric Power Research Institute (EPRI)

Support and additional funding

- Alberta Innovates-Energy and Environmental Solutions (formerly AERI)
- Nova Scotia Department of Natural Resources
- NRCan
- Saskatchewan Ministry of Energy & Resources

Former members

- ATCO Power
- Luscar Limited
- Ontario Power Generation
- IEA Greenhouse Gas Programme
- IEA Clean Coal Centre

Phase I

at-a-glance

Timeframe: 2001 to 2004

Goal: evaluate existing or developing technologies

Budget: $4.8 million

Key findings: substantial detail regarding existing and emerging technologies

A PHASED APPROACH

The CCPC was created in 2000 to ensure that environmental public policy decisions recognize Canada's vast coal resources as an important Canadian asset. Today, the CCPC is advancing the technologies needed to build cleaner, more efficient, more economical coal-fired power plants. Phase I, which involved study of emerging technologies to reduce emissions from coal plants, commenced in 2001. The CCPC is currently completing its third phase of study and Phase IV is scheduled to commence in fall 2011.

Overview

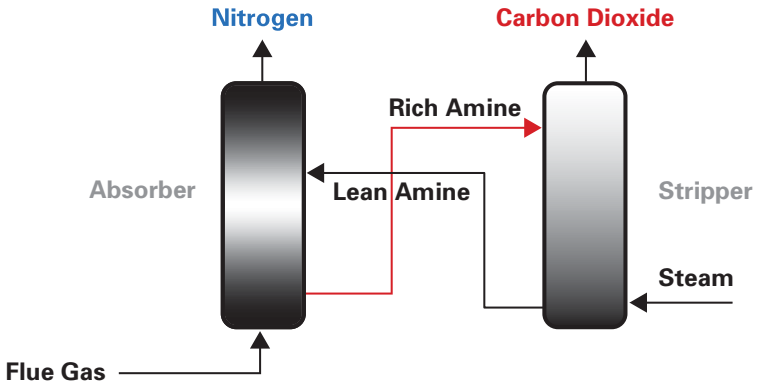
The first study work undertaken by the CCPC commenced in September 2001. The goal was to develop projects that demonstrated technology at a commercial utility scale that would allow all emissions, including CO_2 to be controlled to meet all foreseeable new regulatory requirements. The technology had to be viable for retrofitting existing plants, or for use in new coal-fired power plants. Emissions had to be reduced to a point that would allow coal-fired plants to be seen in a new light. Overall efficiency had to be maintained or improved, and costs had to remain competitive with other generation technologies.
The fundamental principle underlying the goals of the CCPC was to identify processes that would produce electricity from coal in some fashion and also provide a relatively pure stream of CO_2 that could be captured, further processed as necessary, and subsequently used or stored.

Conceptual engineering and feasibility studies, undertaken from mid-2001 to early 2004, were performed on the following:

- Technologies in development for common coal-fired plant emissions, including nitrous oxide (NOx), sulphur dioxide (SO_2), particulates and mercury
- The opportunities to capture CO_2 emissions from industrial sources and transport them to underground storage:
  - Gasification: reacting raw material, such as coal, at high temperatures with a controlled amount of oxygen and steam. CO_2 can be removed from the resulting syngas fuel
  - Oxyfuel: based on the principle that if coal burns in an environment where nitrogen is absent or minimized, the resulting CO_2 will be more concentrated and therefore easier to capture
  - Amine scrubbing: a process where CO_2, in a flue gas, is absorbed and captured
- The opportunities to store CO_2 in Canada

Implementation plans, preliminary designs and cost estimates were developed for those technologies, recognizing the diverse geographical variability of coal in Canada.

Post-combustion capture



The CCPC's Phase I budget was $4.8 million, $2.1 million of which was provided by participants. The remainder was provided by Canadian governments.

Phase I results

Developing emission reduction technologies

Research showed that technologies were either available or under development to control NOx, SO_2, particulates and mercury emissions from coal-fired power plants to levels approaching that of natural gas power generation.

Gasification

Gasification was shown to be a potentially low cost CO_2 capture technology; however, gasification requires significant development to improve availability. Gasification is a mature technology in the chemical and petrochemical industries, but is not mature for power plant applications using sub-bituminous and lignite coals as a feed stock.

Oxyfuel

Oxyfuel technology is not yet mature and many issues need to be resolved prior to full scale deployment. Any application of the technology to an existing power plant would be expensive and could involve significant operational problems. At the time of the study oxyfuel appeared to be a less cost effective way to produce power and capture CO_2.

Amine scrubbing

The study suggested that amine scrubbing technology provides the greatest opportunity for a demonstration project in that it is a mature technology in its own right, and has fewer issues to satisfy before one could develop a high degree of confidence of success. It also has the advantage of potentially being able to be applied as a retrofit to an existing facility. It can be scaled to process between 0 and 100 percent of a flue gas stream. The study showed that it may offer lower costs of electricity and CO_2 capture and the lowest risks compared to the technologies considered. In addition, it provides the opportunity to design and construct a plant in which the amine process could be de-coupled from the power generation plant, and provide the greatest operational flexibility should significant problems be encountered with the process.

CO_2 storage

The Western Canada Sedimentary Basin provides storage capacity for a vast amount of CO_2 in British Columbia, Alberta and Saskatchewan. Storage opportunities and capacities for the Ontario and Maritime regions are less understood. Transportation and storage of CO_2 is also a challenge to a demonstration project. The reports suggest that enhanced oil recovery and geological storage are the best options, and that these choices are available principally in western Canada.

Phase II at-a-glance

Timeframe: 2004 to 2007

Goal: in-depth study of top viable CCS technologies

Budget: $2.6 million

Key findings: amine scrubbing and oxyfuel processes showed improvement but capture costs were prohibitive; improvements in gasification positively impacted the cost of capture compared to Phase I

Overview

Phase I of the CCPC efforts identified promising CCS technologies and benchmarked the performance capabilities of each. Phase II was undertaken to gather more information through the detailed study of the most viable technologies. The goal was to study commercial or near-commercial technologies to better understand their design and costs.

Phase II was initiated in 2004 and was completed in 2007. Two major areas of work were undertaken:

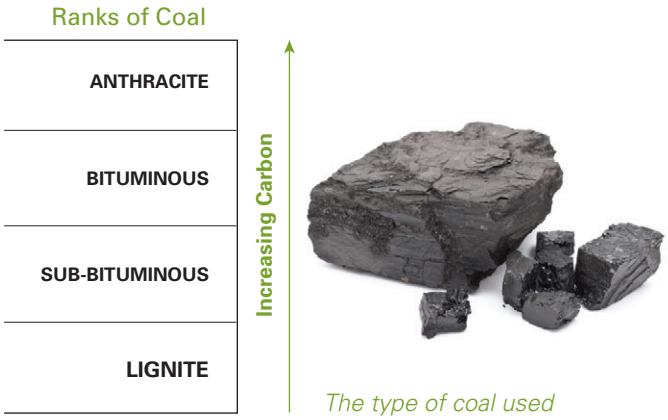
Supercritical pulverized coal (SCPC) plants with CO_2 capture

- An assessment of both amine scrubbing and oxyfuel combustion processes.

Gasification technology optimization

- Stage 1 – Assessed IGCC technologies that were suitable for low-rank coals.
- Stage 2 – Assessed feedstock blending as well as optimized electrical power and hydrogen production to improve the value of gasification. The gasification technologies selected were next generation technologies not commercially available.

The budget for Phase II was $2.6 million, $1.4 million of which was provided by participants. The remainder was provided by various Canadian governments.



The type of coal used affects the performance of any technology.

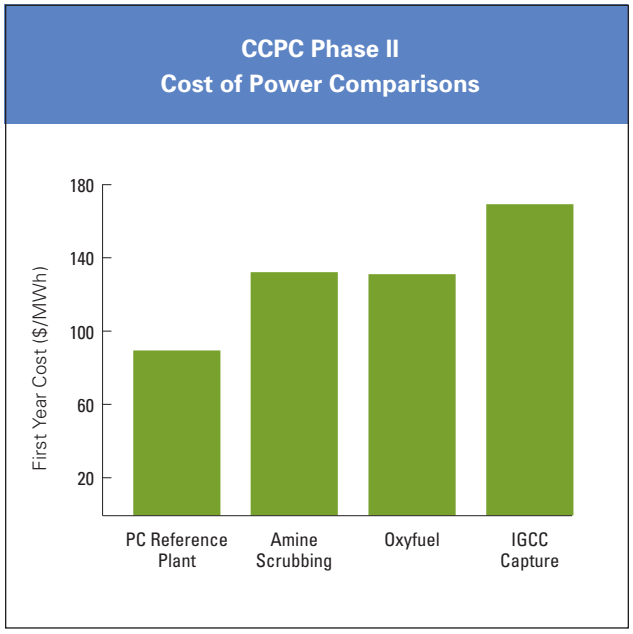
Phase II results

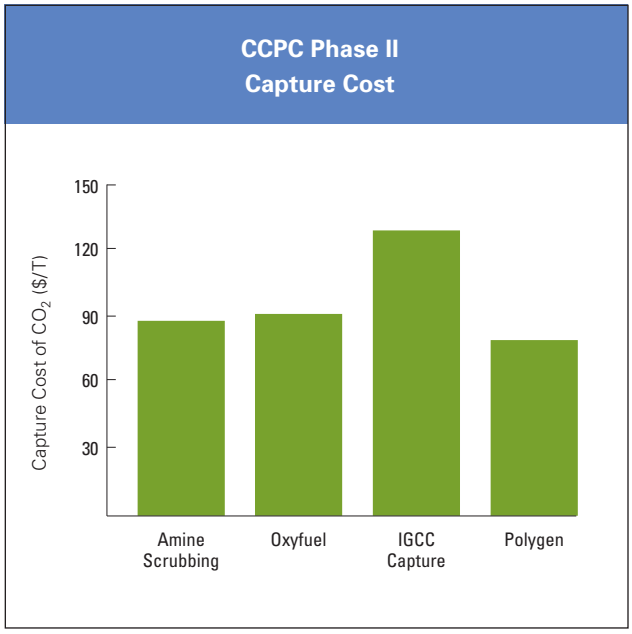
There are no commercial-scale amine scrubbing, oxyfuel or IGCC plants with CCS operating on coal; as a result, CCS technologies are fairly immature.

The technologies studied in Phase II were at different stages of development, making accurate comparisons challenging. Nevertheless, it was determined that the costs of all technologies studied are high. Additionally, the type of coal used and site specifics impact the technology choice for any given project. Therefore, detailed site-specific studies must be completed to make a final technology selection.

For these reasons, further development of a wide variety of technologies was recommended.

Phase II studies showed that further development of a wide variety of technologies is needed.





This study showed that adding CO_2 capture would increase the costs of power by more than 50 percent.

The cost of capture is expected to exceed $80 per ton.

SCPC with CO_2 capture

Further optimization of the amine scrubbing and oxyfuel processes showed significant improvement over the results from Phase I; however, capture costs were high. Mandated GHG compliance costs would need to be greater than $80 per tonne before CCS would be implemented.

Gasification

Gasification performance is dependent on coal quality, with lignite presenting the greatest challenge. Since this study, improvements in gasification processes for low-rank coals have reduced the cost of CO_2 capture.

IGCC costs were higher than the other technologies studied – this was unexpected given results from other recent studies. Since IGCC cases were for next generation technologies the cost estimates may not be comparable to other cases studied. Additionally, the economics of gasification were improved by selling hydrogen rather than just power.

Phase III at-a-glance

Timeframe: 2008 to July 2011

Goal: study new advances and technologies

Budget: $6.7 million plus $11 million for Capital Power IGCC FEED study

Key findings: to be shared fall 2011

Phase III involved the detailed study of new CCS advances and other ways to reduce the CO_2 emissions from coal plants. Five final reports containing results from phase III can be found in the appendices and on the CCPC website.

IGCC FEED

The CCPC, in partnership with Alberta Innovates (formerly AERI), Natural Resources Canada and Capital Power Corporation provided $33 million to conduct a FEED study to determine the feasibility of developing an IGCC facility with CCS at Capital Power's Genesee facility. The study detailed the design, technology, engineering and economic requirements to build a commercial-scale facility at the site. The study showed the cost to produce power from this configuration, at this location, was $9,500 per kilowatt or $266 per megawatt hour.

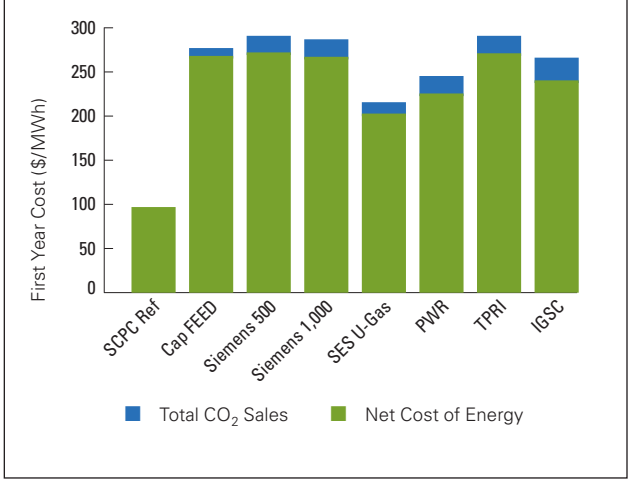
See appendices A & E for more details.

Advanced gasification studies

Feasibility studies of 10 optimized schemes to capture CO_2 from state-of-the-art sub-bituminous coal IGCC and polygen plants have been completed. The design, costs, risks and other benefits of these technologies was considered. The gasification technologies studied include:

- Three 500 megawatt (MW) Siemens gasifiers (base case)
- Two 1,000 MW Siemens gasifiers
- The SES U-Gas gasifier
- The Pratt & Whitney Rocketdyne gasifier
- China's TPRI GreenGen technology
- Jacobs Integrated Gasification Steam Cycle (IGSC)

Cost of Energy for IGCC Cases with Capture



This study showed the first year cost of energy for various IGCC cases with capture are significantly greater than a supercritical pulverized coal (SCPC) without capture.

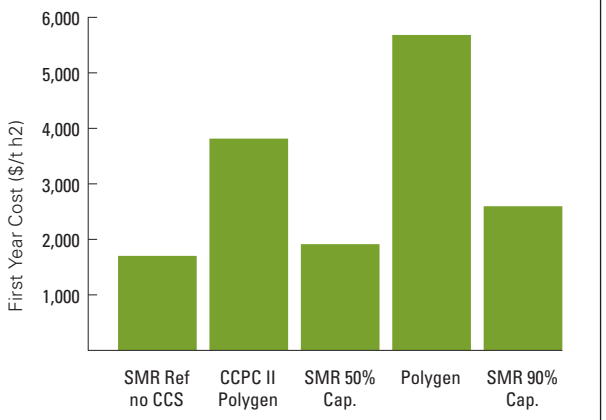
Case studies include

- Retrofit and greenfield cases
- Polygeneration cases to produce power and hydrogen for comparison to hydrogen production from a steam methane reformer with and without CO_2 capture

See appendices A & E for more details.

Carbon capture is seen as a means to reduce the emissions produced through coal combustion.

Cost of Producing Hydrogen With and Without CO_2 Capture



The cost of hydrogen production from polygen with CCS is not competitive with steam methane reformers with CCS.

CCS research

The CCPC has participated in a gasification research program carried out by CanmetENERGY. In turn, Canmet has provided bench-scale and pilot-scale experimental data and modeling results for entrained flow slagging gasification of Canadian coals.

The research included the gasification characteristics of various fuels, and bench-scale oxyfuel circulating fluidized bed combustion study employing calcium oxide to capture CO_2. A new high-pressure dry feed system, warm and hot gas clean up and coal beneficiation were studied to improve gasifier efficiency. Simulations were conducted to look for breakthroughs in process efficiency and environmental performance. Models of gasifier components have been created to support scale-up to commercial implementation, and to find process improvements.

See appendix D for more details.

Coal cleaning technology

Coal cleaning is seen as a means to reduce the emissions produced through coal combustion. A comparative study has been completed to test raw as-received coal and beneficiated coal using gasification test facilities at CanmetENERGY as part of their gasification research program. Beneficiated coal samples from several Alberta and Saskatchewan coal beds were produced at Sherritt's Clean Coal Technology Centre.

See appendix D for more details.

The CCPC was established to research commercially viable technologies that will lower coal-fired power plant emissions.

EPRI post-combustion CO_2 capture retrofit studies

The CCPC is participating in an Electric Power Research Institute project that is studying retrofitting five power plants, including one in Nova Scotia, with advanced amine CO_2 capture technology. The study will determine the thermal and economic impact of retrofitting and the technological barriers and limitations associated with each site. This project will be completed summer 2011.

Biomass use evaluation

The CCPC participated in a Nova Scotia Power research project to evaluate the potential for co-firing biomass with coal in power plant boilers to achieve cost effective CO_2 reductions. Both laboratory combustion tests and engineering studies of typical utility boiler systems have been completed.

See appendix C for more details.

IGCC roadmap

The CCPC undertook a study conducted by EPRI CoalFleet Program staff, consisting of an engineering and qualitative economic evaluation of technological advances in processes involved in gasification including:

- coal preparation and feeding – beneficiation, drying and feeding improvements
- oxygen production – ion transport membranes
- syngas processing and CO_2 capture – warm gas clean up, hydrogen (H_2) membranes, various novel CO_2 capture processes, and CO_2 purification
- the effect of increases in turbine firing temperatures – developments on gas and steam turbines

The base case for this study will be a 500 MW Siemens gasifier fired on Alberta sub-bituminous coal. An evaluation of the impact of individual and combined technologies advances on the base case were considered. An assessment of the development status of these technologies was produced.

See appendix A for more details.

Biomass co-firing

KEMA Consulting has completed a study of various technologies which can be used to complete modest and significant co-firing of biomass fuels in a coal boiler. The study reviewed the characteristics of various biomass feedstocks and also describes capital costs and configurations for six co-firing and feedstock configurations and recommends configurations for further study.

See appendix C for more details.

Coal beneficiation

Sherritt completed a study on the costs, benefits, risks and status of several dozen coal beneficiation technologies. EPRI also looked at the economic benefits of reducing specified amounts of ash and moisture for several coals.

The budget for Phase III was $6.7 million, $2.0 million of which was provided by participants. It included $2.5 million of work in kind with CanmetENERGY and the remainder was provided by various Canadian governments. Phase III also included the provision of $11 million to Capital Power's $33 million IGCC FEED study. The $11 million was provided by Alberta Innovates (formerly AERI).

See appendix B for more details.

Phase IV next steps

Timeframe: 2011 to 2013
Goal: to study oxyfuel, coal benification, biomass cofiring and new game-changing technologies
Budget: $6.1 million

The CCPC was established to research commercially viable technologies that will lower coal-fired power plant emissions. Phases I through III of the CCPC's studies have advanced the understanding of available and emerging technologies, their limitations and benefits.

The CCPC intends to launch Phase IV of its research in fall 2011.

Phase IV will involve two cleaner coal study themes

- Near-term technologies: retrofit and greenfield technologies which will be commercially available within 10 years
- New transformative technologies: designs which might be available for the new greenfield coal fleet in 2020

Near-term technologies

It is anticipated that the technologies the CCPC is classifying as near-term will have a low impact on power costs and be broadly applicable across the coal fleet. This study will offer increased confidence that these technologies will perform as expected and increase our knowledge of technologies that have not yet been extensively studied.

Near-term technologies will include

Coal beneficiation

A select few coal beneficiation technologies will be tested. Further engineering feasibility and lab scale studies may be completed depending upon the outcome of the tests.

Biomass cofiring

A detailed study of the design, costs, benefits and risks of select cofiring configurations on a limited number of feedstocks and coals may be performed for specific sites. Several biomass fuels may be examined, including torrified wood, to determine their combustion characteristics and develop models to predict performance in a boiler.

Oxyfuel

The CCPC plans to update cost estimates for building a new oxyfuel plant, possibly by engaging in costing studies being completed by EPRI on oxyfuel technologies.

New transformative technologies

New coal fleet technologies are defined as those that are designed to more economically reduce CO_2 emissions. They should be in early stages of design, have lower capture costs and have broad application potential. They should also meet CCS regulatory requirements.

New transformative technologies will include

Advanced oxyfuel

Advances in high pressure oxyfuel designs and cryogenic separation will be studied. The designs of the technology, their competitive advantages and risks, the expected costs and status of development will be reviewed.

Game-changing technologies

Ten to twenty technologies that clearly have the potential to fundamentally reduce the cost of CO_2 capture while utilizing coal will be studied. Their design, purported benefits, stage of development, barriers to development, complexity and efficiencies will be reviewed. These may include various chemical looping combustion ideas, advances in post combustion capture being studied by the U.S. Department of Energy, membranes, underground coal gasification and other technologies.

Antelope Valley Station

Boundary Dam Power Station

Project Pioneer's generating station, Keephills 3

CCPC's impact – member projects

The CCPC member companies use the research conducted by the organization to advance their own environmental performance. Examples of CCPC research at work include:

Antelope Valley

- Basin Electric worked with HTC Purenergy and Doosan Babcock to complete a $6.2 million FEED study on post combustion capture at the 450 MW Antelope Valley Station. Had the project proceeded it would have captured approximately one million tons of CO_2 per year from a portion of the plant's exhaust stream and send it to oil fields in Saskatchewan to be used in existing enhance oil recovery operations.

Boundary Dam

- SaskPower is leading the development of the world's first and largest integrated clean coal/carbon capture and storage project at the Boundary Dam Power Station in Estevan, Saskatchewan, Canada. The Boundary Dam Integrated Carbon Capture and Storage Demonstration Project will transform Unit 3 at Boundary Dam Power Station into a reliable, long-term producer of 100+ megawatts of clean base-load electricity, while enhancing provincial oil production and reducing greenhouse gas emissions by capturing one-million tonnes of carbon dioxide (CO_2) per year beginning in 2014.

Project Pioneer

- TransAlta, with partners Capital Power Corporation, Alstom and Enbridge, is developing Project Pioneer, a large-scale CCS facility at the Keephills 3 generating station west of Edmonton, Alberta. The proposed project would employ Alstom's proprietary chilled ammonia process. Once complete in 2015, Project Pioneer will capture 1 Mt/yr of CO_2. The project was pursued as a result of CCPC Phase II studies.

Mock-up of an IGCC facility at Capital Power's Genesee plant.

IGCC FEED

- Capital Power Corporation along with the Federal and Alberta governments, have funded a FEED project to determine the feasibility and cost of developing a commercial-scale coal-fuelled gasification power plant with CCS.

Nova Scotia Power

- Nova Scotia Power is developing a proposal for co-firing wood waste in both circulating fluidized bed (CFB) and pulverized coal plants. CCS Nova Scotia, whose members include Nova Scotia Power, are preparing plans to build a CCS pilot plant with the outlook of a commercial scale project by 2020.

Sherritt International

- Sherritt is studying underground coal gasification and also recently completed a coal cleaning laboratory in Fort Saskatchewan, a project that was partially funded by Alberta Innovates that will test various techniques to determine the optimal coal cleaning technology. Both beneficiated and non-beneficiated coals will then be assessed by CanmetENERGY to determine impacts on plant performance. Sherritt also developed the Dodds-Roundhill IGCC project.

CCPC's impact – collaboration

The CCPC, through its membership and ongoing research, fosters a collaborative and cooperative approach to advancing technology across Canadian industry. Along with sharing of research, CCPC represents its members on various other organizations, ensuring a comprehensive two way flow of information, and thereby allowing more efficient and effective advancements within individual organizations. Government and other funding ensure that this work continues.

Vendor access to industry

Broad access to industry can be challenging. Through the CCPC, vendors are able to present technologies and projects to the CCPC technical committee, fostering learning and allowing for industry support of new initiatives.

Research collaboration

The body of research that needs to be undertaken is vast. The CCPC serves as a central point through which studies from other organizations can be shared with industry and with each other. The CCPC currently shares research with or provides input to:

- ICO2N
- Carbon Management Canada
- CO_2 Capture Project
- Lignite Energy Council
- EPRI
- Global CCS Institute
- EPRI Oxyfuel Road Map study
- Alberta Government CCS Projects

Project collaboration

The CCPC also works with various groups to obtain funding, execute projects, or to collaborate, such as:

- EPRI
- CanmetENERGY
- Canadian Wood Pellet Association
- Climate Change and Emissions Management Corporation (CCEMC)

Industry advocacy

- CCPC was also part of an industry advisory group focusing on chemical looping combustion with the University of Western Ontario

CCPC has evolved to become the best source of information about Canadian carbon capture technology and economics.

Sharing our findings

Educating the public about cleaner coal is an important part of the CCPC's mandate. The CCPC is committed to sharing its research findings with its members and the public. Valued as a trusted information source for carbon capture costs and other information, the CCPC frequently receives queries from teachers, government, industry and members of the public.

The CCPC also undertakes structured dissemination of its study findings to interested stakeholders. Formal external communication activities have included the provision of the CCPC Internet site, fact sheets, industry reports, delivery of presentations and media releases. As a coalition, members also learn from each other and share studies and ideas.

CCPC has become a thought leader on CCS, and receives numerous questions and inquiries about the technology. Additionally, CCPC leadership presents current findings at conferences and to government. In the early days, the CCPC played a policy development role, providing industry expertise as needed. Today, CCPC has evolved to become the best source of information about Canadian carbon capture technology and economics.