

PROJECT PIONEER

FINAL REPORT ON PROJECT PIONEER

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Capital Power
Corporation



ENBRIDGE

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IMPORTANT NOTE REGARDING PROJECT PIONEER – APRIL 2012

On April 26, 2012, TransAlta, along with partners Capital Power and Enbridge, announced the decision not to proceed with the carbon capture and storage (CCS) project called *Project Pioneer*.

The Pioneer partners concluded that the technology works and that capital costs were in line with expectations. However, the market for CO₂ sales and the value of emissions reductions in Alberta and Canada are not sufficient, at this time, to allow the project to proceed.

While it is disappointing to be unable to achieve the result hoped for, it is important to remember that the purpose of Project Pioneer was to ‘prove out’ the technical and economic feasibility of CCS before going down the major capital investment path. That purpose was achieved: the two years of hard work by the Project Pioneer team was a major success.

The Pioneer partners come out of this with a much deeper understanding of CCS in an Alberta setting. And of course, it is the intention to share this understanding with the federal and provincial governments and the global scientific community so others can benefit from what was learned.

This decision isn’t a reflection on the long-term viability of CCS or the future of coal-fired generation. Coal is a critical fuel for power generation in Alberta and world-wide, and TransAlta believes it will continue to be a vital part of the global fuel mix.

TransAlta, Project Lead, Project Pioneer

ABSTRACT

The safe storage of CO₂ can be a vital part of the solution to the challenge of global climate change. Project Pioneer (also referred to as Pioneer or Project) was a joint effort by TransAlta Corporation, Capital Power L.P., Enbridge Inc., the Governments of Alberta and Canada, and the Global CCS Institute to demonstrate the commercial-scale viability of carbon capture and storage (CCS) technology retrofitted onto a modern coal-fired power plant.

The Project was to be one of the largest and most advanced CCS projects in the world, and had the leadership and partnership expertise to make the Project – and Canada – a global leader in CCS. After completion of a feasibility study and despite substantial government and industry investment, the Project was not economically feasible due to insufficient CO₂ sales markets and emissions pricing in Alberta and Canada. The project was cancelled in April 2012 and will continue to serve as a prototype and information source for the commercial-scale application and integration of CCS technology.

fig. 1.0

KEEPPHILLS 3 PLANT



1.0

INTRODUCTION TO THE PROJECT

Project Pioneer would have been one of the first carbon capture and storage (CCS) projects to utilize an integrated approach for CCS, and was expected to serve as a prototype for the long-term, commercial-scale application and integration of CCS technologies to achieve reductions in greenhouse gas emissions. The partners in Project Pioneer were TransAlta Corporation (TransAlta), Capital Power L.P. (CPLP), Enbridge Inc. (Enbridge), the Alberta provincial and Canadian federal governments, and the Global CCS Institute as a Knowledge Sharing Partner.

Project Pioneer was being proposed to capture 1 million tonnes of carbon dioxide (CO₂) annually from a coal fired power plant and to transport the CO₂ by pipeline to a sequestration site or to be utilized for enhanced oil recovery (EOR) in a depleted oil/gas field.

The key components of Project Pioneer were:

- Carbon capture facility (CCF)
- Pipeline from the CCF to the sequestration site
- Pipeline from the CCF to the EOR site
- Saline formation sequestration site

The CCF would have treated approximately one third of the flue gas from Keephills 3 and would have captured approximately 1 million tonnes of CO₂ annually. The CO₂ would have been compressed and transported by pipeline to a sequestration site to be injected approximately 2 km underground into a saline formation known as the Nisku Formation. A pipeline was going to have been built also to transport the CO₂ to the primary EOR target, the Pembina oilfield, where the CO₂ would have been injected and used for EOR. The Pembina oilfield is approximately 80 km southwest of the Keephills 3 facility.

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2.0

EXECUTIVE SUMMARY

Project Purpose

The purpose of Project Pioneer was to explore the feasibility of, and subsequently to construct and operate one of the first industrial scale demonstration projects of carbon capture and storage (CCS) technology retrofitted onto a modern coal-fired power plant. As the name indicates, this was a pioneering effort, and, although a decision not to proceed was made in late April 2012, Project Pioneer will continue to serve as a prototype and information source for the commercial-scale application and integration of CCS technology.

Project Pioneer was guided by the following strategic drivers:

- Demonstrating a viable technology option for near-zero emissions from coal-fired electricity;
- Developing an understanding of the economic viability of CCS;
- Implementing a solution to present day greenhouse gas (GHG) emissions and for the existing coal fleet; and
- Addressing environmental policy uncertainty and related capital decision making challenges.

Pioneer Partners

Pioneer was developed under the leadership of TransAlta Corporation (TransAlta), with strategic industry partners Capital Power L.P. (Capital Power) and Enbridge Inc. (Enbridge). Financial support was provided by the Governments of Alberta and Canada, and from the Global CCS Institute of Australia. Pioneer was a unique collaboration with varying tiers of involvement; from strategic industry partners, to government funding partners, to service providers and a customer intending to purchase carbon dioxide (CO₂) under long-term commercial arrangements.

Project Description

Project Pioneer was to capture one million tonnes of CO₂ annually from the Keephills 3 coal-fired power plant, located in Alberta, Canada. The captured CO₂ was to be transported by pipeline as a dense-phase fluid to a regional oilfield for use in enhanced oil recovery (EOR) and also to a local sequestration site for deep geological storage.

Project Pioneer was designed to retrofit CCS on an operating power plant, as opposed to incorporating it into the design and construction of a new power plant. Modifications to the power plant were not expected to be extensive and it was hoped that this retrofit approach would become applicable to any coal-fired power plant, thereby providing a practical way to significantly reduce CO₂ emissions from the existing coal fleet.

The Carbon Capture Facility (CCF) would have diverted approximately one-third of the flue gas emitted by Keephills 3 and treated it to remove CO₂ before release to the atmosphere. The CO₂ design annual capture quantity was a nominal 1 million tonnes but the CCF was in fact designed for an instantaneous capacity of 1.17 million tonnes per year (134 tonnes per hour) to take into account the Keephills 3 and CCF availability factors. 90% of the CO₂ present in the flue gas was to be removed.

The technology chosen for the CCF was amine scrubbing, which is a widely practiced chemical process. Project Pioneer was to demonstrate the applicability of amine absorption to coal-fired power plants, which would have been a new application for the process at this scale. Specifically, the KM CDR Process[®] of Mitsubishi Heavy Industries was selected.

The Pioneer pipeline system would have transported CO₂ from the Keephills site CCF to the EOR oilfield (74 km) and the sequestration site (8 km). In order to provide maximum operational flexibility each pipeline leg was designed to be able to accept 100% of the instantaneous CCF CO₂ output. Both legs were designed to the same technical specifications. It was expected that during the commissioning period and occasionally during possible process upsets, all of the CCF volume would be sent to sequestration to avoid shipping off-specification CO₂ to the EOR customer. It was desired that most of the CO₂ be destined for EOR because of the positive economic impact of CO₂ sales on Project economics.

The EOR site was the Pembina oilfield, located 70 to 80 km southwest of Keephills 3. The Pembina oilfield was selected due to its proximity to Keephills and also because oil companies operating the field were interested in CO₂ EOR but lacked a large volume CO₂ supply. In addition, the pipeline would not be required to cross any major river, thus minimizing construction complexity and environmental disturbance. Project Pioneer did not to include EOR operations in its scope but engaged in negotiating a long-term CO₂ supply and purchase agreement with one of the operating companies in the Pembina oilfield.

The sequestration site was designed to permit the instantaneous injection of CO₂ at a rate of 1.17 million tons per year (134 tonnes per hour) into the 1,800 meter deep Nisku geological formation. It was expected that most of the captured CO₂ would be directed to EOR. Therefore, the planning basis was the sequestration, by intermittent injection, of up to 1 million tonnes of CO₂ over 10 years, with most of the injection occurring in the first several years. The sequestration scope included the associated measurement, monitoring and verification (MMV) plan to quantify injection volumes, confirm geological containment, and detect any potential leaks to ensure utmost safety.

Lessons Learned During Initial Phase

Work undertaken by the Pioneer team during the Initial Phase was intended to inform a Limited Notice to Proceed investment decision by the Pioneer industry partners. This work included Front End Engineering and Design (FEED) studies for the CCF, pipelines and sequestration facility, drilling and testing of one injection well, commercial development activities, regulatory and permitting activities, and economic and risk analysis.

Following the conclusion of the Initial Phase studies, the industry partners determined that although technology, engineering designs, operational processes, and capital costs were in-line with expectations, markets for CO₂ sales and the price of emissions reductions were insufficient to allow the Project to proceed. The Project will continue to serve as a prototype and information source for the commercial-scale application and integration of CCS technology. Pioneer resulted in a much deeper understanding of CCS that is being shared, so others can benefit from these learnings. The following are lessons learned in each area of the Project.

The *policy framework* will need to provide more support for the development of markets for CO₂ sales and more certainty about the value of GHG emissions reduction credits in order for commercial CCS projects to have sufficient assurances about future revenues.

The *cost of CCS*, although in-line with expectations, was found to be relatively high. Approximately three-quarters of costs were associated with carbon capture and decisions about the CCF were the main drivers of costs and financial risk for the Project.

Government funding remains necessary for early demonstration CCS Projects. However, the public funding mechanisms used to support Pioneer were found to be challenging owing to their complexity.

Market demand for CO₂ continues to be uncertain. The size of this market is highly dependent on rapidly changing oil and gas technologies. *The market price of CO₂* is also uncertain and there remains limited visibility and certainty about the present and future value of *CO₂ emissions credits*.

Amine scrubbing technology was determined to be the technology most mature and closest to commercialization from a technical standpoint. Project Pioneer concluded that it was technically and operationally feasible to retrofit amine scrubbing technology on a coal-fired power plant. Design was optimized by considering the CCF as a standalone CO₂ production unit and not as a power plant compliance unit, and by adopting reliability practices from the chemical industry rather than from the power industry. Production of steam and power by a standalone cogeneration unit simplified the interface with the host power plant and reduced overall cost. Deep and early involvement of the power plant owners made for a win-win situation.

The *pipeline system* was a relatively straightforward matter due to the fact that standards, specifications and indeed operating pipelines exist for CO₂ transportation.

The design of the *sequestration facilities* and of the MMV program was informed at the early stage by preliminary studies but hampered by a paucity of well control information. In order to validate the conclusions of the preliminary studies it was found to be imperative to drill an evaluation well and to secure as much information as possible from it. The MMV program must be designed rigorously, starting from a full risk assessment, and include a complete baseline characterization and suite of monitoring and mitigation measures.

The *regulatory consultation, application and permitting process* was determined to have performed more or less as anticipated. Certain regulatory gaps did exist relative to CCS but government was making efforts to fill them albeit in a timeframe that was challenging for Pioneer.

Project complexity made *risk management* an extremely challenging task. Complexity arose from the large number and wide diversity of partners and stakeholders and the newness of CCS in general.

Stakeholder engagement went above what is required by regulation. It nurtured existing relationships while developing new connections with stakeholders. Coordinated outreach strategies are required to communicate evolving technical information in a consistent and timely fashion as projects develop.

Knowledge sharing was integral to the Project. A dedicated knowledge sharing specialist ensured that networks and relations were developed with other organizations and projects. The development of a knowledge transfer network was a valuable accomplishment of Pioneer, as it provided the Project team with information and learnings from other Projects and thus avoided costs and sped up the Pioneer learning curve.

When the *Project partnership* includes members from different industries, expectations for risk tolerance and financial returns need to be aligned. Transparency and a willingness to share information with partners and with public sector funders were necessary to allow the Project to advance smoothly. Project leadership needed to be flexible, adaptive and innovative because there are few precedents and little industry and company experience with commercial CCS projects. Project Pioneer evolved constantly and several elements underwent significant changes in order to respond to emerging challenges.

3.0

MOTIVATION FOR PROJECT PIONEER

The global requirements for energy are provided by a diverse portfolio of fuels. Coal is the world's most abundant fossil fuel and the single-largest input into electricity generation, fueling approximately 40% of the world's electricity. Coal's abundance, broad geographic distribution and comparatively low and stable cost means that it delivers affordable electricity to billions of people worldwide.

In the western provinces of Alberta and Saskatchewan, coal is an economically-important energy resource. In particular, Alberta holds 33.5 gigatonnes or 70% of Canada's coal reserves. In fact, while Alberta has become widely known for its oil sands, Alberta's coal contains more than twice the energy of all the province's other non-renewable energy resources including oil sands, conventional oil, and natural gas. More than half of Alberta's electricity generation is fired by coal. At the current rate of extraction, Alberta's coal reserves would supply the province with electricity for the next 1,000 years. Coal is a low-cost fuel that plays a major role in keeping power prices at reasonable levels and in preventing power shortages and reliability problems. Thus, coal is a critical resource for Alberta's and Canada's long-term prosperity.

In order to ensure energy security and affordability, it is important to maintain diversification of the fuel mix and to keep coal as a major pillar of energy supply. However, coal is also responsible for most of the world's CO₂ emissions. Therefore, a valuable global opportunity exists to identify, develop and implement technologies to significantly reduce CO₂ emissions from coal-fired power plants.

The motivation for Pioneer was built on the foundation of the related imperatives of:

- Combating climate change by reducing GHG emissions into the atmosphere; and
- Ensuring a sustainable supply of clean, affordable energy and, particularly, ensuring a future for Alberta's coal reserves as a low-cost, environmentally responsible form of power generation.

In the western Canadian context, these global trends are particularly significant for electricity generation, as coal is both the dominant fuel source and a major contributor to GHG emissions.

4.0

GENERAL DESCRIPTION OF PIONEER

Project Pioneer was designed to retrofit CCS to an operating power plant, as opposed to incorporating it into the design and construction of a new power plant. TransAlta viewed that retrofitting power plants for CCS was of much greater importance and applicability than CCS for new units, given that the majority of GHG emissions from the power sector over the next 20 years will be from existing facilities.

The following sections provide an overview of Project key components.

Carbon Capture Facility and Keephills 3

Project Pioneer was designed to be installed on the modern operating Keephills 3 power plant operated by TransAlta and co-owned by TransAlta and Capital Power. Keephills 3 is Canada's most technologically advanced coal-fired power plant and was commissioned in 2011.

Keephills 3 has a capacity to generate 495/447 gross/net MW and consumes 1.8 million tonnes of coal each year from the Highvale Mine.

Keephills 3 utilizes supercritical boiler technology, which is more energy efficient than typical pulverized coal units. The technology relies on higher than typical boiler temperatures and pressures as well as a high-efficiency steam turbine. The higher efficiency means that less coal is needed to produce the same amount of power. Therefore, CO₂ emissions per unit of power produced are lower than from a conventional coal plant.

In addition, Keephills 3 features advanced air emissions controls resulting in NO_x, SO₂, and mercury emissions lower than typical plants. Technologies incorporated into Keephills 3 include the most recent advances in low NO_x combustion; hydrated lime slurry to control SO₂; a pulse jet fabric filter dust collection system to control particulates; and activated carbon storage and injection system to control mercury emissions.

The Carbon Capture Facility (CCF) was designed to be an addition to the operating Keephills 3 facility, complementing the air emissions control system by removing CO₂ from the gases released to the atmosphere. The chosen design was to also remove the remainder of the SO_x and some of the particulate matter not removed by the Keephills 3 emissions control system.

The CCF was intended to divert approximately one third of the flue gas emitted by Keephills 3 and treat it to remove CO₂ before it is released to the atmosphere. This approach would enable capturing a nominal 1 million tonnes of CO₂ annually without having an excessive impact on the power generation process. The reason to limit the CCF to only one third of the flue gas was to manage risks and costs within acceptable limits. The CCF would thus be of a sufficient size for a technology demonstration at a meaningful industrial scale, while controlling the budget and risk to a level acceptable to the industry partners.

The CCF was, in fact, designed to an instantaneous capacity of 1.17 million tonnes per year (134 tonnes per hour) to take into account the Keephills 3 average availability of 90% and a minimum CCF availability of 95%. The chosen technology removes 90% of the CO₂ present in the flue gas.

Amine Scrubbing Process

The process finally selected by Pioneer for the CCF was amine scrubbing, which is a widely-practiced chemical process also known as amine gas treating, gas sweetening and acid gas removal. It is a process commonly employed in oil refineries, but also in natural gas processing plants in Alberta and other natural gas producing regions. One of the goals of Project Pioneer was to demonstrate the applicability of amine absorption to coal-fired power plants, which would be a relatively new application for the process.

Amine scrubbing refers to a number of commercial technologies that use various alkanolamines to remove acidic components such as hydrogen sulfide (H_2S) and CO_2 from gas streams. The underlying principle is the exothermic, reversible reaction between a weak acid such as CO_2 and a weak base such as an alkanolamine. The flue gas to be treated is contacted by the aqueous alkanolamines solution in an absorbing column or vessel where a soluble salt is formed from the reaction between the CO_2 and the alkanolamines. The flue gas, now depleted of CO_2 , is then released to the atmosphere. The solution, 'enriched' with the CO_2 , is sent to a stripping column or vessel where, by the addition of heat, the salt formation reaction is reversed and the CO_2 and the alkanolamines are regenerated. The "lean" alkanolamines solution is recycled to the absorbing unit while the CO_2 is made ready for transportation by dehydrating and compressing it.

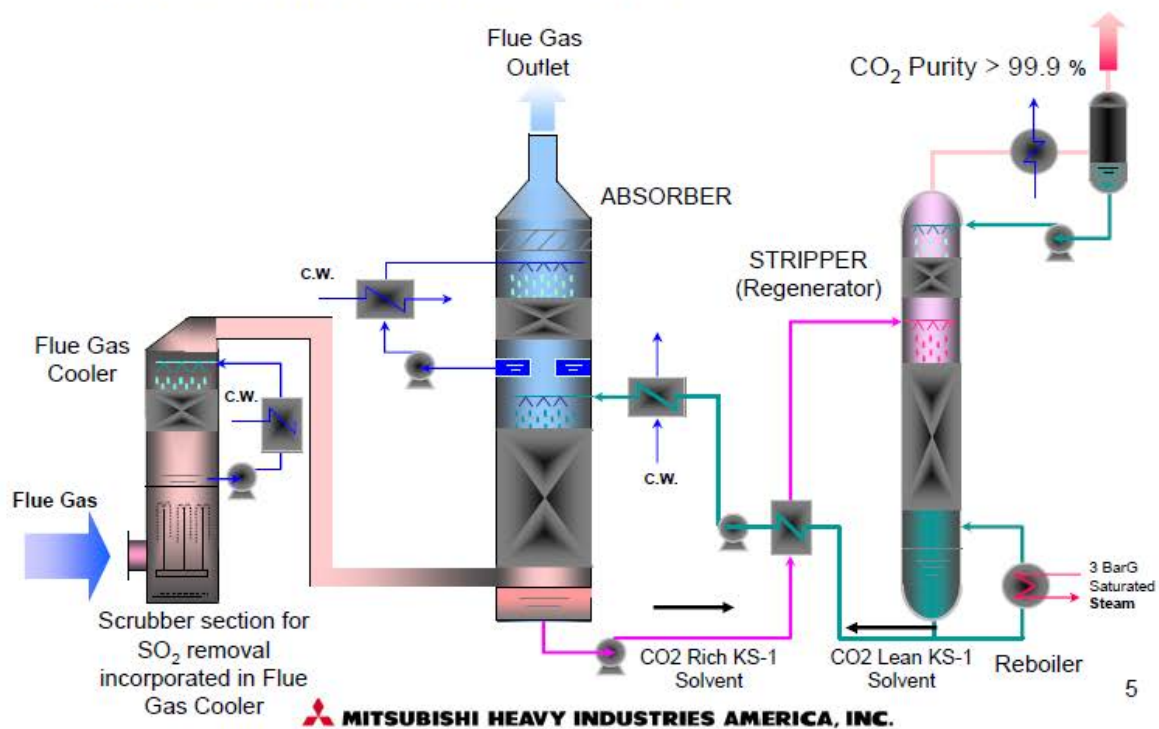
The following figure shows the process flow diagram for amine capture.

fig. 3.0

AMINE SCRUBBING PROCESS

Basic Process Flow Diagram

Post-Combustion CO₂ capture process
Using MHI proprietary KS-1™ solvent



5

Pipeline Transportation

The Pioneer design included the transportation of the captured, dehydrated and compressed CO₂ 800 meters from the Keephills 3 plant site to the CO₂ metering station at the head of the pipeline legs to the EOR oilfield and the sequestration site. In order to provide maximum operational flexibility, each pipeline leg was designed to be able to accept 100% of the instantaneous CCF CO₂ output.

The pipeline diameter selected was NPS 10 (nominal pipe size of 10 inches or 273.1 mm outside diameter). The pipeline was designed to accept 99.5% pure dense-phase CO₂ compressed to 14 MPa. A metering station was to be constructed at the oilfield receiving terminal where product custody would have been transferred to the oil producer. CO₂ is an acid gas that will react with water to form carbonic acid which will cause corrosion challenges. Thus, it is crucial that CO₂ accepted for pipeline transportation meet stringent quality specification, particularly for contamination by water. Proper dehydration of the CO₂ stream is important in order to avoid the critical dew point temperature that may be encountered due to line shut-in or exposed pipe in contact with ambient temperature conditions. The Pioneer CO₂ specification for water content was maximum 50 ppmv (parts per million by volume).

While CO₂ is non-toxic, at high enough concentrations it can be an asphyxiant and a major CO₂ release could potentially have serious consequences. The design of the CO₂ pipelines must reflect the potential risks involved, particularly block-valve spacing.

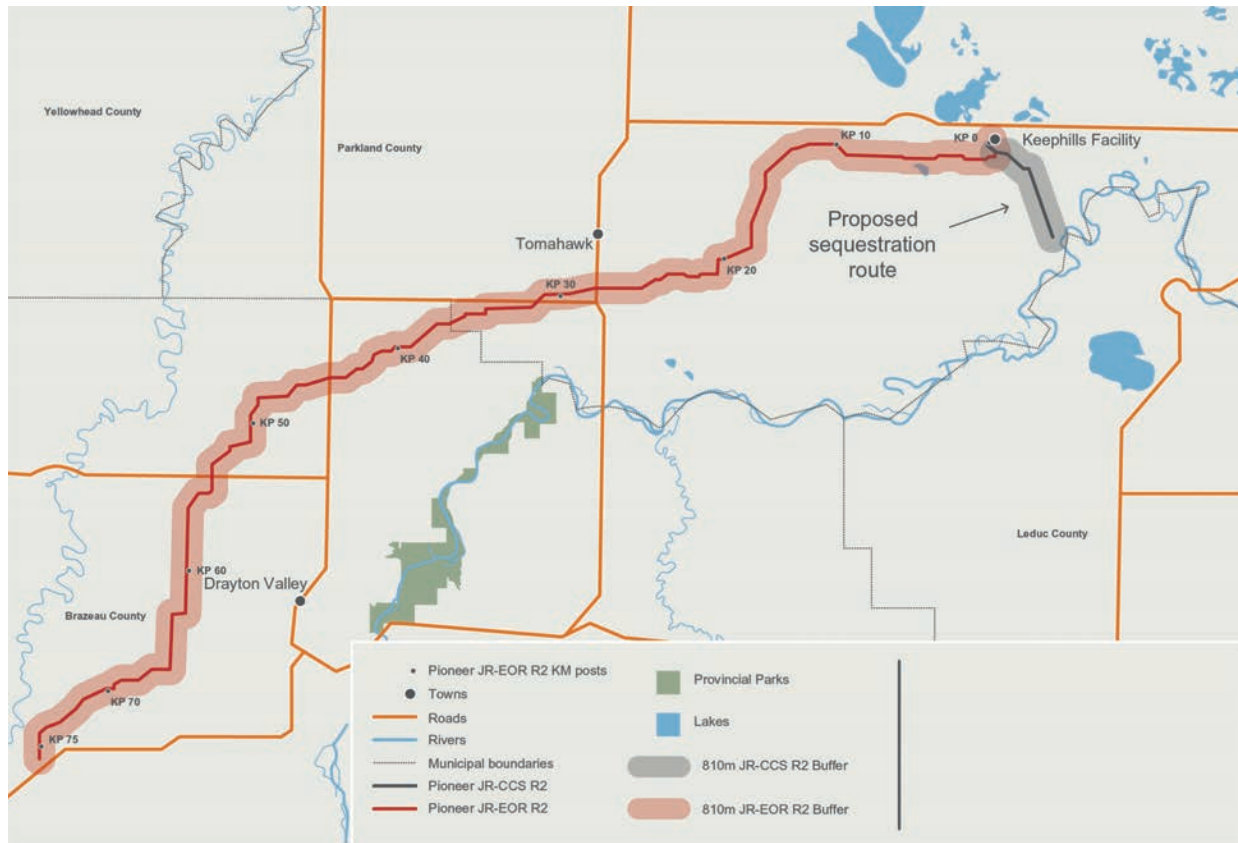
Several pipeline routing alternatives for the EOR pipeline were considered based on environmental, social, economic, and geotechnical analysis. Although shorter routes were technically feasible, the selected route utilized existing right-of-way (ROW) for about one quarter of its length, and was determined to be more acceptable to landowners and local communities. The selected pipeline route was 74 km long and crossed minor waterways and three highways. The largest urban area close to the pipeline route was the Town of Drayton Valley located 5.6 km east of the pipeline.

The pipeline to the sequestration site was designed to the same technical characteristics as the EOR pipeline because it was also designed to be capable of handling the same CO₂ volumetric rate, which is 100% of the CCF output. As with the EOR pipeline, the sequestration pipeline would have originated from the Keephills CO₂ metering station.

The sequestration pipeline was to be approximately 6 to 8 km long and was to terminate at a metering station located at the sequestration site, which was to be located to the southeast of the Keephills site. The routing utilized existing ROW for 80% of its length.

The two pipeline routes are shown in Figure 4.

fig. 4.0
PIPELINE ROUTES



Sequestration Site

In CCS, CO₂ is captured and then utilized in one of two ways: for EOR or for sequestration. The dominant CO₂ approach in the medium to long term is expected to be sequestration, which is the injection of CO₂ into characterized and appropriate geological formations deep below the surface. EOR is only applicable where suitable oil reservoirs are present, and only for the limited time required to recover additional oil from the reservoir. Sequestration, on the other hand, is possible anywhere appropriate deep saline formations exist, which are geological formations far more prevalent and extensive than oil reservoirs.

The basics of geologic storage are known and it is practiced in specific and limited industrial situations, such as for acid gas disposition. The deployment of sequestration to mitigate climate change will however, require large scale implementation, the scale of which will be one or two orders of magnitude larger than existing industrial practice. Furthermore, it will mean that potential future sequestration locations might be closer to population centres than the few projects currently in operation.

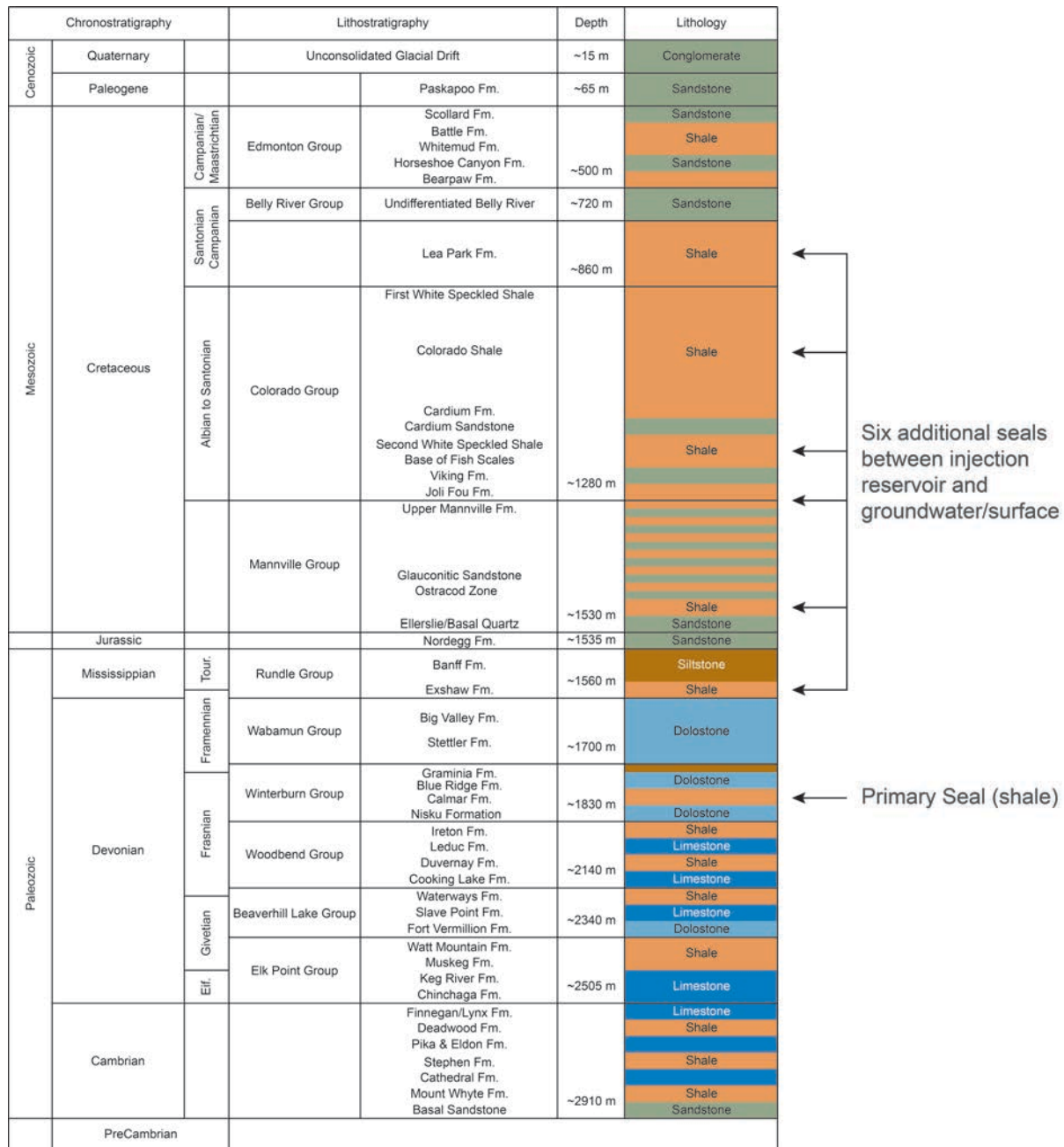
Project Pioneer was to be one of the world's largest CCS implementations, serving to prove the technology, precisely quantifying its costs and demonstrating its safety and viability. The sequestration site was designed to permit the instantaneous injection of CO₂ at a rate of 1.17 million tons per year (134 tonnes per hour) into the 1,800 m deep Nisku geological formation. In other words, the sequestration infrastructure and storage complex was to be able to accept the full output of the CCF. However, it was expected that most of the captured CO₂ would be directed to EOR. Therefore, the planning basis was the sequestration by intermittent injection of up to 1 million tonnes of CO₂ over 10 years, with most of the injection occurring in the first several years. Although injection was to be intermittent, the system was designed to always be available, subject to a reasonable ramp-up time.

Pioneer Storage Complex

Several past studies, including the Alberta Saline Aquifer Project (ASAP) and the Wabamun Area Storage Project (WASP), had identified the 1,800 meter deep Nisku Formation in the Wabamun Lake area as a prospective reservoir for large-scale geologic sequestration of CO₂ in a saline formation. The Nisku formation is an intermittently porous and tight dolomitized carbonate formation. It does not have major hydrocarbon production in the area and is the deepest stratigraphic unit with relatively extensive reservoir quality. The Winterburn storage complex, as defined by the Project, includes the Ireton, Nisku, Calmar, Blue Ridge, Graminia, Wabamun, and Exshaw formations. Underlying the Nisku formation is the Ireton formation, which is a regional shale that forms the bottom seal of the Winterburn storage complex. The interbedded shales and carbonates of the Calmar, Blue Ridge, and Graminia formations form the upper portion of the Winterburn Group and were expected to act as a primary seal for CO₂ injection into the Nisku Formation. The Exshaw formation overlies the Wabamun Group and is a regional sealing shale able to serve as a secondary seal above the primary seal. Figure 5 provides an overview of the stratigraphic column in the Wabamun Lake area.

fig. 5.0

STRATIGRAPHIC COLUMN IN THE WABAMUN LAKE AREA



NB: This stratigraphic column is idealized for the Wabamun Lake Area and the stratigraphy and depths are based on several sources including the HOME CPOG BRIGHTBANK 10-5-52-2 well. A number of generalizations have been made and the column is not to scale.

Geological Assessment Program

A full CO₂ Storage Evaluation Program was undertaken and used to develop the scope of sequestration activities during the course of the 10-year injection period and a second 10-year closure period. The purpose of the Storage Evaluation Program was to evaluate the validity of potential geologic sequestration of CO₂ in the Winterburn Storage Complex. Despite the completion of several other studies indicating that the Nisku formation in the Wabamun Lake area was likely suitable for large-scale geologic sequestration of CO₂, sufficient information to support regulatory approvals for a CO₂ storage scheme and a well-founded investment decision did not yet exist. The Program provided the necessary information to support both internal and regulatory decisions regarding the Project Pioneer CO₂ sequestration scheme.

The Program involved evaluating the ability of the Winterburn storage complex in an area near the Keephills facility to provide sufficient injectivity, capacity, and containment to inject over a 10-year period and permanently store up to 1 million tonnes of CO₂. The Program included the drilling and testing of one evaluation well, associated seismic acquisition, evaluating the integrity of existing wells in the Project area, and baseline environmental measurements. Water injection testing was completed in the evaluation well, but no CO₂ injection tests were undertaken. A baseline three-dimensional (3D) seismic survey was planned but not initiated by the time of Project cancellation.

The evaluation well resulted in the acquisition of a large volume of high quality geological information:

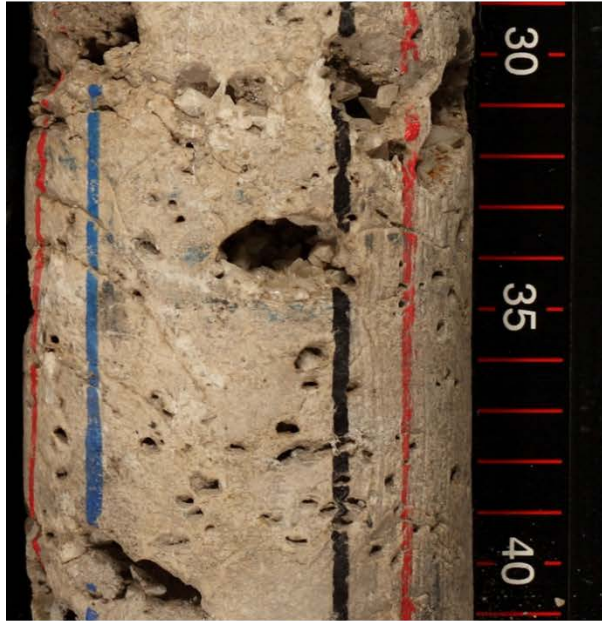
- 45 m of caprock and reservoir core;
- Reservoir fluid samples;
- State of the art wireline logs; and
- Injection test.

Photographs of core from the Nisku and Calmar formations are shown in Figure 6. The Nisku formation appears porous and vugular while the overlying Calmar seal is tight. Data was used to update the numerical geological model and support the development of a reservoir model to analyze CO₂ injection and plume development scenarios.

fig. 6.0

PHOTOS OF CORES FROM THE EVALUATION WELL

Nisku Formation



Calmar Formation



The overall conclusion of the evaluation well program was the confirmation of very good storage formation and good caprock at the selected location. The evaluation well was determined to be capable of accepting the total Project Pioneer instantaneous injection rate of 1.17 million tonnes of CO₂ per year.

5.0

COMMERCIAL ARRANGEMENTS

Project Pioneer was a unique collaboration between TransAlta, Capital Power and Enbridge, the Governments of Canada and Alberta, the Global CCS Institute, key suppliers of goods and services and an EOR customer aimed at building and operating a fully-integrated CCS project in the power sector.

Strategic Industry Partners

TransAlta, Capital Power and Enbridge were the strategic industry partners. They provided the overall direction for the Project, brought their respective expertise and, as equal owners, financial investment.

Partner selection was done by TransAlta. As a basic tenet of the consortium approach taken by Pioneer, all strategic industry partners had to participate as equity partners with an equal share across all elements of the project – capture, transportation and storage.

The main partner selection criteria were an underlying strategic interest in CCS, skillsets complementary to the Project, balance sheet strength (as no project financing was used) and risk management ability. Risk sharing between partners of the various Project risks that aligned with the government funding requirements was key. Strong relationships based on previous experience with Capital Power and Enbridge, as well as similar risk/return profiles, made them ideal candidates as industry partners.

Project Pioneer brought together industry partners who had been leaders in power generation, energy delivery and environmental issues for years. TransAlta was the project leader, and brought extensive experience in power generation, construction and innovation to the Project. The company provided technical, commercial and project management to Pioneer. Capital Power was the generation partner and brought best-in-class power technology. Capital Power shares a long history with TransAlta and is the joint venture partner with TransAlta in Keephills 3. Enbridge was the transportation partner, bringing its pipeline expertise as a North American leader in energy delivery.

Funding Partners

Governments of Alberta and Canada

Both the Alberta and Canadian governments were key funding partners in Pioneer. Government funding was integral to the Project, as substantial funds were required to produce a business case acceptable to the industry partners. Funding was granted by government in order to advance CCS technology and to promote knowledge sharing. The Project was awarded approximately \$779 million in funding commitments from the Governments of Canada and Alberta. This included \$27 million through the federal EcoENERGY Technology Initiative (ETI) and \$315.8 million from the Clean Energy Fund (CEF), both of which are administered by Natural Resources Canada (NRCan), and \$436 million from the Province of Alberta. Provincially, the majority of funding was committed by Alberta Energy through the CCS Fund in the amount of \$431 million, with an additional \$5 million contribution from Alberta Environment's EcoTrust Grant to support FEED and development work.

The structure and nature of government funding drove many business decisions and added an additional layer of complexity to the Project that required strategic management of timelines and goals. Continuing funding requirements were many and included the meeting of Project milestones as well as specified operating targets, principally reduction of at least 10 million tonnes of CO₂ after ten years of operation. Project economic returns to industry partners were capped through mechanisms in both the CEF and CCS funding agreements. Importantly, these agreements also required the repayment of funding if the Project did not meet certain minimum performance thresholds. At the time of project cancellation, only a small fraction of the Project budget had been spent by industry and governments to fund the Initial Phase studies.

Global Carbon Capture and Storage Institute

The Global CCS Institute (GCCSI) acts as an industry/government partnership and provided \$5 million AUD to promote knowledge sharing during the Initial Phase of the Project, and thus served as the knowledge sharing partner. The GCCSI accelerates the adoption of CCS, a key solution in mitigating climate change and providing energy security. The Institute facilitated conversations between Project Pioneer and other CCS projects and subject matter experts. The organization's commitment was used to support Project Pioneer and specifically the activities during the Initial Phase FEED and development work.

Technology and Service Suppliers

Many suppliers brought exceptional expertise and enthusiasm to the unique challenges presented by the nature of a project without precedent in Alberta. They included:

- *Mitsubishi Heavy Industries America*. Turnkey supplier of the 1 million tonnes per year CCF using its proprietary amines-based capture technology.
- *Enbridge*. In addition to being a strategic industry partner, Enbridge provided pipeline design and engineering and would have provided permitting, procurement, construction, commissioning and operation of the complete pipeline system.
- *Schlumberger Carbon Services*. Responsible for the design, permitting, procurement, construction, commissioning of all wells and for the performance of the sequestration field. Essentially, Schlumberger was responsible for all downhole work terminating at each well valve. This included all MMV activities required by the regulator.
- *Golder Associates*. Provided consulting services related to environmental matters, particularly in relation to the acquisition of permits.
- *Alberta Innovates – Technology Futures*. Provided advice and support to the design of the MMV Program.
- *Stantec Consulting*. Acted as Owner's Engineer, providing oversight and advice relative to the CCF.
- *Communica Public Affairs*. Developed and coordinated public consultation programs in concert with the industry partners' internal experts.
- *Ipsos Reid*. Provided public opinion polling services.
- Individual expert consultants.

6.0

SALE OF CO₂ TO EOR

Pioneer would not have had stake (planning, permitting, ownership or operation) in any aspect of the EOR field, nor would EOR customers have ownership or operational responsibilities for the CCF, the pipelines or the sequestration field.

The EOR element added a key revenue stream to the Project by virtue of selling the CO₂ product to the EOR customer and the generation of emission reduction instruments for CO₂ sequestered at the EOR site. Pioneer was to derive benefit from all emissions reduction instruments generated which meant that the value of these instruments would remain constant for Pioneer whether carbon was sequestered on-site or whether CO₂ was sequestered through its use in EOR.

The Project expected sales of up to 1 million tonnes/year of CO₂ beginning in late 2015 to the EOR customer, generating revenues expected to be in the range of \$300 million over a 10 year operating period.

Avoided Emissions Value

The economics of the Project were developed within an expectation of a carbon cap and trade system for Canada which would have allowed the creation of immediate value from emission reductions achieved by CCS prototype projects. That value stream would have been monetized as either emission reduction instruments or as avoided compliance costs. In either situation, this anticipated value stream was estimated to be in the range of \$300 million over the course of the Project. Regulatory uncertainty over the valuing of emissions reductions associated with CCS complicated the Project.

An arrangement, likely in the form of government regulation that would enable the monetization of avoided emissions instruments created by Pioneer was required for the Project to proceed. This proved to be most challenging as public policy decisions require careful deliberation by government and the timeline for decision making did not align well with other timelines for the Project mandated within the funding agreements.

K3 Interface

A degree of complexity surrounded the interface of Pioneer with Keephills 3, in some measure due the differing ownership of the two facilities. Pioneer had adopted a “no-harm, no benefit” approach regarding the Keephills 3 facility. Of particular note was the question of the long term effect of using steam from Keephills 3 for Pioneer’s capture process and any liability associated with potential damage to Keephills 3. Given the range of expected future natural gas prices, the use of cogeneration for the production of steam at Pioneer was a cost-neutral option. As such, the decision to use internal cogeneration for Pioneer rather than using Keephills 3 as a steam source was made and greatly simplified this interface issue.

7.0

REGULATORY AND PERMITTING

The regulatory consultation, application and permitting process for the Project was progressing as anticipated at the point of Project cancellation. The scope of the environmental assessment was defined in large part by NRCan's determination that the Project was subject to a screening level assessment and the Province's decision not to request the completion of an Environmental Impact Assessment. Provincial regulatory permitting requirements were also as expected, though there was some uncertainty surrounding Alberta Utilities Commission application requirements given CCF design modifications which resulted in no energy penalty for Keephills 3 and no grid connection for the power generating unit. The general impression from the provincial and federal regulators was that the permitting schedule was achievable.

8.0

STAKEHOLDER CONSULTATION AND ENGAGEMENT STRATEGY

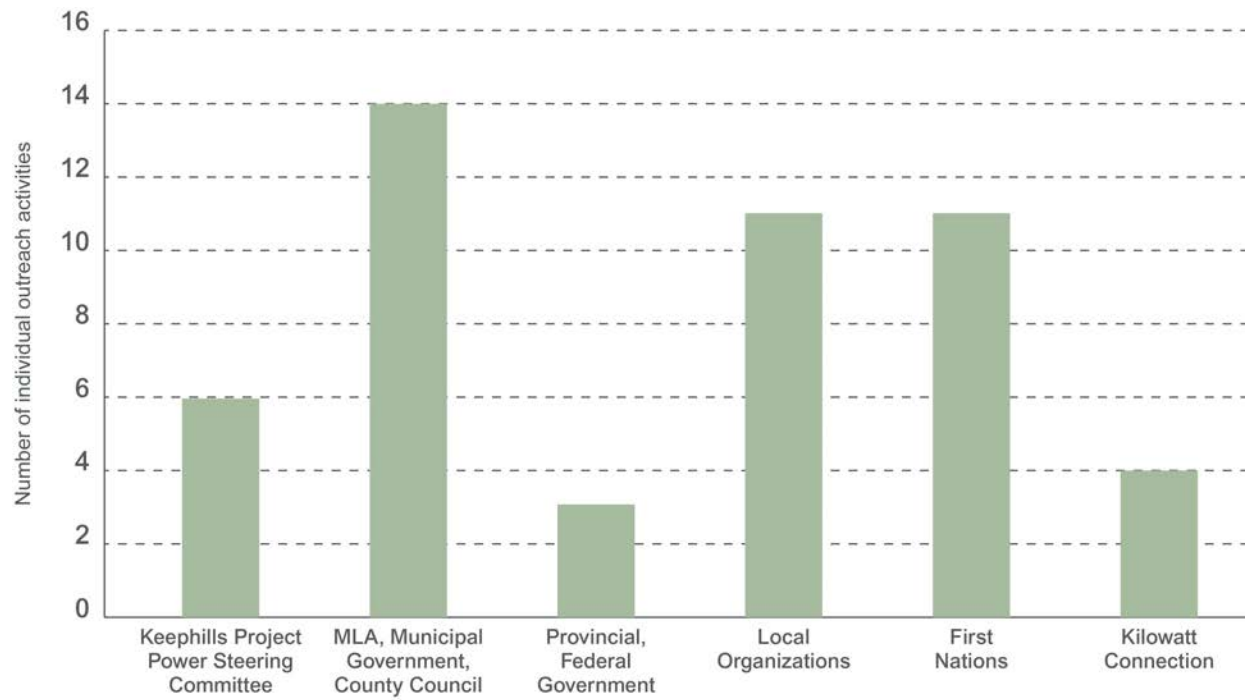
Carbon Capture and Storage is an emerging technology and, as such, its characteristics, benefits and impact are not widely known. It was concluded that the implementation of CCS in Alberta would lead to questions and concerns from the public, First Nations, neighbouring communities, as well as many other stakeholder groups.

It is widely recognized that a comprehensive and sincere consultation and engagement process is required for success for any development project and particularly when novel technology is involved. The Pioneer consultation and engagement process was critically important. It often was the mechanism through which stakeholders first heard and learned about CCS. It was also an important building block toward achieving success and obtaining the 'social licence' to proceed with the Project.

Extensive efforts were made to involve all stakeholders. Figure 7 provides a recap of the consultation activities.

fig. 7.0

CONSULTATION AND ENGAGEMENT ACTIVITIES BY STAKEHOLDER GROUP



9.0

KNOWLEDGE SHARING

Knowledge generated by the Project was of global interest, particularly with respect to technical findings, the identification and management of risks in such projects, the development and acceleration of regulatory frameworks for CCS, and the understanding of the economics associated with large commercial-scale CCS projects. Those involved in the Project recognized that global knowledge transference amongst CCS projects would help in addressing common challenges and allow for successes to be repeated.

Knowledge sharing had mutual value for the Project, as it was bidirectional: Project partners learned through incoming knowledge from other sources, as well as being able to share outgoing knowledge with others, including other CCS projects and academics. The Project's leadership felt quite strongly that there was a direct link between what and how much the Project shared, and what and how much knowledge was received, in return.

Knowledge transfer was facilitated by the openness of participants involved in CCS in general and in Pioneer in particular, driven by the consortium philosophy and expectations from the partners that knowledge and experience generated by such emerging and prototype projects would accelerate the development of CCS as well as potentially drive down costs of such projects. Significant collaboration occurred and continues to occur amongst Canadian projects and organizations, as well as global collaborations.

Other projects which developed similar roles were Longannet Power Plant in Fife, UK, led by Scottish Power, as well as the Alberta Carbon Trunk Line being planned by Canada's Enhance Energy, and the Shell Quest project in northern Alberta.

Project Pioneer's Knowledge Transfer Specialist worked to build knowledge and relationships with CCS proponents both globally and locally, including with the GCCSI in Australia and with Alberta Energy and Natural Resources Canada. The role was an important part of establishing connections and facilitating some key relationships for the Project, as well as acting as a designated point of contact for information exchanges.

10.0

RISK ANALYSIS

CCS projects could be considered a special type of oil and gas capital projects. On the one hand, the standard approach used for risk management of oil and gas capital projects is applicable to CCS projects. On the other hand, the uniqueness of CCS projects as well as the characteristics of a particular project should influence the design of the Risk Management System (RMS).

The uniqueness of CCS projects is reflected in the following points:

- CCS integrates several subprojects that are different in nature: carbon capture, transportation, and sequestration. The complexity of interfaces between the subprojects and between the engineering, procurement and construction work packages creates multiple additional risks.
- The technologies used in CCS cannot yet be considered fully proven despite the existence of several working CCS pilots and projects. One of the reasons for this situation is that there is no standard configuration for CCS projects. A variety of technologies are available to be used for carbon capture, transportation and sequestration. The level of maturity of some of them is low, especially in the area of carbon capture and sequestration. This creates the possibility of the existence of unknown risks.
- The commercial model for CO₂ marketing is not mature. The absence of supply gives rise to the lack of demand and vice versa. This vicious cycle has yet to be broken. Focused and coordinated efforts are required from industry and governments to resolve this stalemate.

- The economic viability of CCS projects is heavily dependent on realizing a financial benefit from the emissions reductions created. A broad regulatory framework does not exist to create emissions reduction instruments (credits) from CCS nor does a liquid carbon market to provide a mechanism to monetize them.

The challenges facing CCS projects were drivers behind programs by the Governments of Canada and Alberta to support several CCS projects and to provide funding for their development. Project Pioneer was one of them. In addition to the general CCS challenges, the following characteristics of Project Pioneer added to Project complexity:

- The Project included participation and contributions from TransAlta, Capital Power, Enbridge, the Federal and Alberta Governments and the Global CCS Institute. The large number of partners made stakeholder management one of the sources of risks.
- The Federal and Alberta Governments wore two hats as related to the Project: funding partners and regulators. In the former capacity, governments worked to accelerate project development albeit introducing an added layer of complexity with the funding rules. In the latter role, however, governments became a potential source of delays and complications regarding the permitting process and the promulgation of CCS regulations.
- The CCF was to be retrofitted to the existing Keephills 3 coal-fired power plant. This type of brownfield construction approach generally entails many risks related to physical interfaces with existing facilities and restrictions imposed by power plant operations.

-
- Even when only one type of storage (geological formation vs. oil reservoir) is contemplated, a CCS project needs to be considered complicated. The scope of Project Pioneer, however, included both types of storage. This increased the overall complexity of the Project and gave rise to several commercial risks relating to sales of CO₂ for EOR purposes.
 - Part of the Pioneer scope was to prove the economic feasibility of CCS through selling CO₂ to an EOR customer. Despite the fact that there are a large number of Alberta oil reservoirs that are a good fit for miscible or immiscible CO₂ flooding, the emergence of new technologies for oil recovery such as horizontal drilling and multi stage hydraulic fracturing made CO₂-based EOR a less attractive investment opportunity for the potential EOR customer at the time. This became a major obstacle for Project Pioneer to overcome.
 - While regulation of GHG emissions exists in Alberta under the Specified Gas Emitters Regulation, the value ascribed to emissions reductions is a maximum of \$15/tonne. This value proved to be too low for Pioneer and it was not clear how additional value could be realised, creating a major source of uncertainty for the Project.
 - Four major subprojects were to be integrated to form Project Pioneer: the CCF, the pipeline from the CCF to sequestration facilities, the pipeline from the CCF to the EOR site, and the sequestration facilities. Project development and execution would have required robust coordination and interface management between the several supply, engineering and construction companies involved in the subprojects. This requirement for coordination inevitably generates corresponding risks.
 - The project spans four industries, namely power, chemical, pipeline and oil and gas. All these industries conceptually treat risk analysis the same way but there are differences in methodology, process, criteria and priority. Trying to accommodate this into one set of risk guidelines and a master risk register was a challenge. In addition, corporate risk analysis is confidential, hence complete openness and clarity was not possible in all cases.

Both general CCS challenges and features specific to Project Pioneer were taken into account when shaping the Project RMS.

11.0

PROJECT ECONOMICS

A comprehensive Discounted Cash Flow (DCF) model was developed to understand the economics of the Project. Various estimates of capital and operating costs as well as of revenues were key inputs into the model. A modest 10% after-tax unlevered return was targeted.

Assumptions for plant commissioning, start-up and ramp up to 1 million tonnes of CO₂ per year were built into the model. Accounting was made for planned and forced outages to the Keephills 3 facility as well as for the Pioneer facilities. Scenarios were also created to model various performance levels of the CCF. Conservatively, no residual or terminal value was ascribed to the Project in the economic analysis, as the base assumption was that that reclamation costs would be equivalent to the scrap value of the assets if decommissioning occurred.

The period of operations was set at 10 years, from 2016 to 2025, which was determined largely by the availability of government operating funding for this timeframe. Assumptions were made for this period regarding revenues derived from the sale of CO₂ for EOR, realization of value for avoided emissions instruments and the receipt of government operating funding. Costs for operating the CCF, pipelines and sequestration facility as well as costs for items such as general and administrative costs (G&A) and taxes were estimated. In addition, costs were included beyond the 10 years of operations to account for the subsequent sequestration facility 10-year post-closure period from 2026 to 2035.

The availability of government funding and their complex requirements were important factors in the economics. Examples of the complexity in government contracts include stacking and matching tests, profitability tests, annual funding limits and the need to reach milestones necessary for the disbursement of funds.

The Project was anticipated to be in service by December 31, 2015. This would have allowed the Project a full ten years of operating funding, given the termination of the operating component of provincial CCS funding in 2025.

A positive Net Present Value of \$7.3 million indicated that the Project was expected to achieve an unlevered after tax return slightly above 10%. Given that the government funding had no expectation of a return of or on its capital, this 10% return is effectively that of the industry partners.

Capital and Operating Costs

Total capital costs were estimated to be \$668.9 million, including construction of the CCF, the sequestration and EOR pipelines, the sequestration facilities, interest, owners' costs, contingency, and escalation (Table 1). The majority of these costs were for construction of the CCF, at \$478.5 million (which included \$6 million for debottlenecking post initiation of commercial operations). Capital cost for the pipeline system, at \$80.6 million, was the second greatest contributor. Owners' costs were estimated at \$77.9 million, mainly comprised of the Initial Phase work (FEED and engineering studies, the evaluation well and development costs) as well as Execution Phase costs outside the scope of the CCF, pipeline or sequestration contractors. Capital costs for sequestration and interest were the least, at \$23.0 million and \$9.0 million, respectively.

Total operating costs were estimated at \$586.6 million. While gas commodity and transport costs comprised the largest single portion of these expenses, they were exceeded by total operations and maintenance (O&M) costs, at \$239.5 million (Table 1). The maintenance portion of the CCF O&M cost estimate was based on a typical chemical industry based percentage of the CCF replacement asset value, with other O&M costs, such as chemicals, consumables and staffing costs specifically determined. Of the particular sources of

O&M costs, CO₂ capture costs were substantially greater than those estimated for the pipeline system, sequestration facilities, post-operation, and cogeneration. The final interface design for Keephills 3 reduced costs for the Project, as cogeneration was a more cost-effective alternative given low natural gas prices. Post-operating O&M were associated with MMV costs expected to be incurred after the termination of CO₂ injection.

table 1.0

BREAKDOWN OF ESTIMATED CAPITAL AND OPERATING COSTS FOR 10 YEARS

Capital Costs	Total (million \$)
CCF	\$478.5
Pipeline	\$80.6
Sequestration	\$23.0
Owners Costs	\$77.9
Interest During Construction	\$9.0
Total Capital Costs	\$669.0
Operating Costs (10 years operating and 10 years post-closure)	Total (million \$)
Gas Commodity and Transport Cost	\$239.5
CCF O&M	\$190.9
EOR and Sequestration Pipelines O&M	\$39.3
Sequestration Facilities and Post-operating O&M	\$33.8
Administration, Insurance, Property Taxes, etc.	\$48.6
Income Taxes	\$34.5
Total Operating Costs	\$586.6

Cost of CO₂ Abatement

Based on the Project estimate, the gross cost of abatement for the Project is calculated to be approximately \$125 per tonne CO₂. This is derived from total capital and operating costs of \$1.255 billion divided by the capture rate of 1 million tonnes per year for 10 years. Economies of scale and experience curve effects are not factored into this assessment. While the Project was to be of substantial scale, it was less than full commercial implementation. The relative newness of the technology used in the CCF resulted in a number of process allowances, the optimization of which could lead to cost reductions in future projects.

All items in Table 1 are included in this estimate of the gross cost of abatement, while CO₂ sales revenues and the value of emissions reduction instruments are excluded. CO₂ sales revenues and the value of emissions reduction instruments are still uncertain and a wide range exists for their estimate. The net cost of abatement would be \$65 per tonne CO₂ if one assumes:

- a CO₂ sales price of \$30 per tonne;
- a value of \$30 per tonne for the emissions reduction instruments; and
- that all of the captured CO₂ is sold for EOR purposes.

12.0

CONCLUSION

Project cancellation was a tough decision for the industry partners to make. Disappointment was felt as the final short term result was not the outcome that was hoped for. However, upon thoughtful analysis, the Project was a clear success. The Project team is proud of its many accomplishments. Pioneer leaves a legacy of valuable knowledge to the global community and will guide the way to future policy developments and industry investments that will eventually transform CCS from a prospective solution to an everyday reality.

The decision to terminate the Project was not a reflection on the long-term viability of CCS or the future of coal-fired generation. It was dictated by specific Project circumstances such as the preference for new technologies using horizontal wells over CO₂ EOR in the regional oilfield, uncertainties about the current and future value of emissions credits and strict government funding deadlines that did not allow more time for alternative market strategies to be investigated and brought to fruition.

Coal is a critical fuel for power generation in western Canada and world-wide that should continue to be a vital part of the global fuel mix that will provide affordable and environmentally responsible energy for the future. The safe storage of CO₂ can be a vital part of the solution to the challenge of global climate change. Methods and technologies for CO₂ storage are advancing rapidly, as are the legal frameworks to regulate them. Pioneer contributed to this advancement. Three of the four CCS projects in Alberta are going ahead and others are moving forward in Canada and globally. It is clear that CCS can play a critical role in helping Alberta and Canada meet climate change goals and responsibilities. CCS represents a safe, practical solution that is Canada's single largest CO₂ mitigation option. It offers the opportunity to maintain the low-cost power supply that sustains the economy and supports a high quality of life.

The Pioneer partners gained from the Project a much deeper understanding of CCS in an Alberta setting. This understanding has and will continue to be shared with the global scientific community, and with industry and governments worldwide, so others can benefit from Project learnings. Knowledge sharing and the collaboration network fostered by Pioneer will reduce costs and accelerate other CCS projects in Canada and internationally as these project teams benefit from the lessons learned by Pioneer.

13.0

APPENDIX

Pioneer Industry Partners



TransAlta Corporation is Canada's largest publicly traded generator of electric and renewable power. With approximately \$3 billion in annual revenue, more than \$9 billion in assets, and power plants in Canada, the United States and Australia, TransAlta has transformed over the last century to become an experienced and respected power generator and wholesale marketer of electricity. Today, TransAlta is Canada's largest coal-fired generator with over 3,000 MW of coal-fired generation. It also owns and operates large coal mining facilities in central Alberta. The company has been a leader in addressing greenhouse gas emissions from the power sector.



Capital Power L.P. is a growth-oriented North American independent power producer that develops, acquires, and operates power generation from a diverse range of energy sources. Capital Power owns more than 3,300 MW of power generation at 16 facilities across North America and has an additional 487 MW of wind generation under construction or development.



Enbridge Inc. is a leader in the safe and reliable delivery of energy in North America and is proud to be recognized as one of the Global 100 Most Sustainable Corporations in the World. Enbridge transports energy, operating the world's longest, most sophisticated crude oil and liquids transportation system.



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