CO₂ STORAGE AT THE WORLD’S FIRST INTEGRATED CCS PROJECT.

PROJECT SUMMARY REPORT

PUBLISHED 2015
For questions, comments, or more information please contact:

The Global Carbon Capture and Storage Institute
By telephone: +61 (0)3 8620 7300
By mail: Global CCS Institute, PO Box 23335
Docklands VIC 8012 Australia
http://www.globalccsinstitute.com/

The Petroleum Technology Research Centre
By telephone: +1 (306) 787-7497
By mail: PTRC, Suite 220, 6 Research Drive
Regina, Saskatchewan   S4S 7J7
http://www.ptrc.ca
The Global CCS Institute commissioned the Petroleum Technology Research Centre (PTRC) in 2013 to provide a summary report on the Aquistore project, a CO$_2$ geological storage site located near the town of Estevan in southern Saskatchewan, Canada. Aquistore will be used by owner/operator SaskPower as a dedicated geological storage option for CO$_2$ captured from the nearby Boundary Dam Power Station – the location of the world’s first commercial scale post-combustion capture of CO$_2$ from coal fired power generation. While a majority of the 1 million tonne per year of CO$_2$ captured from Boundary Dam Unit 3 is expected to be sold for enhanced oil recovery (EOR) operations at the Weyburn oilfield, Aquistore provides a facility for “buffer” storage against EOR sales fluctuations. As the first project to store CO$_2$ in a deep saline aquifer in Canada, Aquistore also serves as a monitoring and science project managed by PTRC.

The Aquistore project was initiated by PTRC in 2009 and originally intended to source CO$_2$ from an oil refinery in the city of Regina. However, when plans for CO$_2$ capture from that facility were dropped, the location of the project was switched to Boundary Dam in April 2011. The development of the project has been financially supported by government and corporate sponsors from Canada and abroad, and aided by a series of international research collaborations.

The target reservoir for storage was identified as comprising the Deadwood and overlying Winnipeg formations. These two formations were interpreted from regional characterization work to consist predominantly of sandstones with suitable properties to allow injection of CO$_2$. The upper part of the Winnipeg Formation consists of the Icebox Member, a shale which could form the primary seal (caprock) for storage. The Deadwood Formation is underlain by basement metamorphic rocks of Pre-Cambrian age that would form a lower barrier to significant flow.

The Deadwood and Winnipeg formations can also be regarded as part of a wider regional body of Cambrian and Ordovician geological age (“basal”) sandstones which hold significant storage potential across large swathes of the northern/central United States (US) and southern Canada. The Decatur project in Illinois, US by the Midwest Geological Sequestration Consortium, and the proposed Quest project by Shell in Alberta, Canada represent two examples of other storage projects targeting this basal system. A recent study by the Energy and Environmental Research Centre in North Dakota for the U.S. Department of Energy’s National Energy Technology Laboratory concluded that the system could store regional CO$_2$ emissions for at least 50 years.

Detailed investigation of the Aquistore site commenced in March 2012 with a 3D seismic survey. Following interpretation of the seismic data, an injection well was completed in September 2012 after two months of drilling, followed by completion of a second (monitoring) well in January 2013. Drilled to 3.4 km depth, these are the deepest wells ever drilled in the province of Saskatchewan. Subsequent logging, sampling and testing of the wells confirmed that the site has appropriate capacity, injectivity and containment to serve as an effective geological storage site and meet SaskPower’s operational requirements. The injection well casing is perforated at between 3,173 m and 3,356 m depth to allow injection into the Deadwood and Winnipeg formations; details of well construction are included in the main body of this report. The injection well is connected to the Boundary Dam capture unit by a 2 km length pipeline.
Subsequent to drilling, baseline monitoring surveys of the reservoir and storage site have been undertaken using a variety of techniques, including cross-well seismic and vertical seismic profiling. Examples of technologies deployed at the site are listed in the table below:

<table>
<thead>
<tr>
<th>Monitoring Technology</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Permanent seismic array</td>
<td>Installation of geophones in shallow boreholes to reduce surface interference effects and facilitate cost-effective repeat 3D seismic surveys. Also enables passive (micro) seismic monitoring</td>
</tr>
<tr>
<td>Downhole pressure and temperature</td>
<td>May provide real-time data for both wells</td>
</tr>
<tr>
<td>Downhole fluid recovery system</td>
<td>Deployed in the monitoring well to detect changes in reservoir fluid chemistry</td>
</tr>
<tr>
<td>Downhole fibre optic lines</td>
<td>Deployed in the monitoring well to enable measurement of temperature and acoustic properties – also providing an alternative to downhole geophones</td>
</tr>
<tr>
<td>Surface based technologies</td>
<td>Co-located monitoring stations enabling tiltmeters, inSAR satellite interferometry, electromagnetics, GPS and gravimeters</td>
</tr>
<tr>
<td>Shallow boreholes with piezometers</td>
<td>Baseline groundwater quality</td>
</tr>
<tr>
<td>Soil gas and atmospheric monitoring</td>
<td>Baseline conditions measured through various techniques</td>
</tr>
</tbody>
</table>

Results from the drilling and monitoring program informed the compilation of a qualitative risk assessment for Aquistore, using an expert panel under the guidance of Schlumberger Carbon Services and building on a comprehensive Features, Events and Processes database. With the considerable depth of the storage reservoir, the presence of multiple sealing layers above and the absence of significant faulting or legacy wells in the area, environmental risks associated with potential leakage were deemed to be low.

Public outreach activities commenced in February 2012 after development of a communications plan for the project. Efforts with the local community have included “kitchen table” discussions, open house and educational events. These efforts will continue as the Aquistore site is scheduled to receive the first flow of CO₂ into the injection well in 2015, following commissioning of the Boundary Dam capture facility in October 2014.
A UNIQUE CCS PROJECT, AQUISTORE IS PROVIDING BUFFER STORAGE TO A COMMERCIAL CO₂ CAPTURE PLANT AND ACTIVE OILFIELD EOR OPERATIONS

Despite the frigid temperatures, Aquistore’s first 3D seismic survey lines are laid.
## Table of Contents

### Executive Summary
- p 3

### Aquistore Overview
- Aquistore Summary and Description p 10
- Project History p 12
- Project Timeline p 14

### Project Management
- Project Management Overview p 18
- Project Management: Partner Relations p 18
- Project Management Structure p 20
- Project Partners p 21
- Research Collaborations p 25
- National Research Collaborations p 26
- International Research Collaborations p 27
- Aquistore and SaskPower p 28

### Regional and Regulatory Context
- Regional Context p 31
- Regulatory Framework p 34
- Environmental Compliance p 37

### Science and Engineering Research Committee
- Science and Engineering Research Committee (SERC) Members p 40
- SERC Formation p 43
- SERC Functions p 44
- Insight Into the Function of SERC p 46

### Site Location and Characterization
- Site Selection p 50
- Site Characterization p 52
- Regional Geology p 54
- Site Characterization Tasks and Chart p 56

### Risk Management
- Risk Management Overview p 60
- Risk Assessment Workshops p 62
- Risk Mitigation p 63
- Management and Mitigation p 65
In principal, if integrated together with fluid flow simulations and geomechanical modeling, Aquistore’s numerous MMV techniques may be capable of providing improved quantitative estimates of subsurface CO₂ distribution and pressure variations.
## Table of Contents

### Drilling Program
- Injection Well p 67
- Injection Well Design p 68
- Core Program p 72
- Observation Well p 74
- Observation Well Design p 78

### Measurement, Monitoring, and Verification
- MMV Overview p 82
- MMV Goals p 88
- Program Design p 89
- Technical Overview p 90
- Surface Monitoring Techniques p 94
- Shallow-Subsurface Monitoring Techniques p 96
- Down-hole Monitoring Techniques p 97
- Seismic Monitoring Techniques p 98

### Seismic Program
- Seismic Program Overview p 101
- 3D Seismic Program p 102
- Permanent Seismic Array p 106
- DAS Line Seismic Survey p 107

### Communications and Public Outreach Program
- Communications Steering Committee p 113
- Aquistore Stakeholders p 114
- Communications Materials p 115
- Illustrations p 116
- Communications Activities p 118

### Knowledge Sharing
- Knowledge Sharing: Conferences p 127
- Knowledge Sharing: Journals p 128
- Capacity Building p 132

### 2014 and Beyond
- p 133
AQUISTORE IS A RESULT OF THE LEARNINGS OF THE IEAGHG WEYBURN-MIDALE CO₂ STORAGE PROJECT: THE LARGEST MONITORED GEOLOGICAL CO₂ STORAGE PROJECT IN THE WORLD.

Trespassing by snowmobilers and hunters was identified as a project risk.
The Aquistore project is managed by the Petroleum Technology Research Centre.

PTRC is a stand-alone not-for-profit corporation that funds and manages research programs in enhanced oil recovery and carbon storage. Founded in 1998, PTRC employs a successful model of bringing together the interests of research and industry to create world class projects.

PTRC has leveraged its extensive experience in geological CO$_2$ storage and network of CO$_2$ capture and storage experts to create Aquistore, Canada’s first dedicated CO$_2$ storage project.
Aquistore is the only CO₂ storage demonstration project proposed for the Williston Basin.

As an independent research and monitoring project, Aquistore intends to demonstrate that storing liquid carbon dioxide (CO₂) deep underground (in a brine and sandstone water formation), is a safe, workable solution to reduce greenhouse gases (GHGs).

Managed by the Petroleum Technology Research Centre, Aquistore is built upon the learnings of the IEAGHG Weyburn-Midale CO₂ Monitoring and Storage Project, where over 22MT of CO₂ have been stored in an oil field during EOR operations. As a global leader, PTRC has over a decade of experience in CO₂ storage and monitoring work.

While reducing greenhouse gas emissions (GHGs) must include increasing energy conservation and efficiency - as well as developing renewable energies such as wind and solar power - reducing emissions from fixed-point sources of CO₂ such as refineries, coal-fired power plants, and other industries will require the development of carbon capture and storage (CCS) technologies.
Located outside of the community of Estevan in South Eastern Saskatchewan, Aquistore will serve as the storage site for the world’s first commercial post-combustion CO₂ capture, transportation, utilization, and storage project form a coal-fired electrical generating station: SaskPower’s Boundary Dam Integrated CCS Demonstration Project.

CO₂ will be captured at unit 3 of the Boundary Dam power-station (BD3), transported via underground pipeline to the Aquistore site, and injected to a depth of 3.4 km.

In collaboration with SaskPower, Aquistore will be the first integrated project globally to demonstrate deep saline CO₂ capture, transport, and storage on a commercial scale from a coal fired power plant. By bringing together industry and research, Aquistore will assist Saskatchewan in meeting its greenhouse gas reduction targets.

Aquistore will demonstrate the scientific and economic feasibility of injecting CO₂ into a deep saline formation, and provide the knowhow for other jurisdictions and companies thinking of doing the same.
Currently there are only a handful of large-scale commercial CCS demonstration projects active internationally. As the ‘first-wave’ of demonstration projects, each has had their own unique experiences both good and bad.

Aquistore has not been without its challenges.

In 2009, Aquistore was originally set up to store up to 600 tons/day of CO₂ captured from an oil refinery located within the city of Regina, Saskatchewan. The CO₂ was to be transported via pipeline and injected to a depth of 2200 m approximately 8 km outside of the city limits.

The original project goals were to:

- Demonstrate CO₂ storage in deep saline formations as a safe solution for emissions reductions.
- Develop a transportable, integrated suite of technologies.
- Create linkages and improve understanding of costs, technical and regulatory issues among industry, financial institutions, policy makers, regulators, and the public.
With a lack of CCS regulations in the province, Aquistore’s original site partner - and CO₂ source - regretfully shelved their CCS plans in 2010. This was a dire situation for the project. The project took a calculated risk and moved locations to Estevan, Saskatchewan - approximately 200 km to the south, and in the heart of the province’s coal and oil fields.

In April of 2010, SaskPower - Saskatchewan’s provincially owned energy utility - announced plans to proceed with carbon capture and storage on unit #3 of the Boundary Dam Power Station. This change in location and CO₂ supplier necessitated some scope changes. The Aquistore injection well was designed to receive up to 2000 tons/day of CO₂ as opposed to 600. While the target injection zone remained the same, due to the distance from the original site, the saline aquifer was considerably deeper at 3400 m.

Activities such as site characterization and community outreach had to begin anew and baseline monitoring surveys and numerical modelling had to be undertaken for the new location. Despite the change in scope, the original project goals remain.
<table>
<thead>
<tr>
<th>Year</th>
<th>Event</th>
</tr>
</thead>
<tbody>
<tr>
<td>2009</td>
<td>March 2009: Go Green Funding Announced</td>
</tr>
<tr>
<td></td>
<td>May 2009: SERC committee formed</td>
</tr>
<tr>
<td></td>
<td>December 2009: Management committee formed</td>
</tr>
<tr>
<td>2010</td>
<td>March 2010: SERC designs Technical Program</td>
</tr>
<tr>
<td></td>
<td>June 2010: Communications Program designed</td>
</tr>
<tr>
<td></td>
<td>November 2010: CCRL withdraws from Aquistore</td>
</tr>
<tr>
<td></td>
<td>December 2010: Site characterization completed</td>
</tr>
<tr>
<td></td>
<td>December 2010: SaskPower announces BD3 rebuild</td>
</tr>
<tr>
<td>2011</td>
<td>April 2011: Aquistore acquires land near Boundary Dam Station</td>
</tr>
<tr>
<td></td>
<td>April 2011: SaskPower announces carbon capture plans</td>
</tr>
<tr>
<td></td>
<td>April 2011:</td>
</tr>
<tr>
<td>2011</td>
<td>April 2011:</td>
</tr>
</tbody>
</table>
2012

FEBRUARY 2012: Public outreach activities begin
MARCH 2012: Baseline 3D seismic work undertaken
MARCH 2012: Permanent seismic array installed
APRIL 2012: First public open house is held
MAY 2012: Site characterization 2.0 is completed
JUNE 2012: Site construction, infrastructure installation begins
SEPTEMBER 2012: Injection well completed, evaluated
OCTOBER 2012: Baseline monitoring work undertaken
DECEMBER 2012: SaskPower announces Cenovus as EOR offtaker

2013

EARLY 2013

JANUARY 2013: Observation well completed
MARCH 2013: Aquistore wells approved for use
APRIL 2013: Cross-well seismic survey completed

LATE 2013

SUMMER 2013: Phase 2 baseline sampling continues
SEPTEMBER 2013: Electromagnetic survey completed
NOVEMBER 2013: 3D VSP survey completed

2014 - 2015

2015: CO₂ injection expected to begin
CCS projects have an inherently high capital cost, but when well managed and designed the CO₂ storage component represents only a small percentage of the overall cost of carbon capture and storage.

A drill bit used during the drilling of the Aquistore wells.
Every active CCS project is learning through demonstration and leading by example.

Inevitably every large scale project will face some challenges. Each challenge faced by a CCS project is a learning opportunity.

As one of the few active CO₂ storage projects in the world, Aquistore will provide future CCS projects with learnings and efficiencies to help them limit risk, liability, and cost.
PTRC is the manager of the Aquistore project. As such, PTRC oversees all funding, administrative, financial and managerial aspects of the project. General project management functions include:

- Overall coordination, monitoring progress of Aquistore, and addressing issues as they arise
- Selecting members of the science, engineering and research committee (SERC), and altering membership if required
- Entering into and administering subcontracting agreements
- Attending to all matters relating to the funding of Aquistore
- Coordinating and delivering all financial and status reporting to Aquistore sponsors
- Assisting in coordinating the SERC and Management Committee meetings
- Setting and approving the course, direction, and timing of Aquistore
- Approval of any material change to Aquistore
- Approval of the research program presented by SERC
- Approval of terms and changes to any budgets for Aquistore
- Approval of all reports and proposed publication of research results of Aquistore
As CCS projects may involve numerous research and industry partners, a primary project contact is essential. The project management ensures that integration of research activities is consistent with the needs of operational activities.

Communication is essential to any large scale-project. Aquistore identified robust communication within and among project participants as critical to project success. As a project with partners spread across the world and different time-zones, specific communication tools have been useful to maintaining positive and mutually beneficial partner relations.

- As-needed teleconferences with SERC. This allows PTRC to ensure alignment is maintained between the research objectives of the project and field implementation.
- Monthly Management Committee teleconferences or face-to-face meetings with project Sponsors. These regular meetings serve to update project Sponsors on progress with respect to field implementation.
- As-needed teleconferences or face-to-face meetings with CO₂ Capture and CO₂ Transportation partners to ensure integration in design of the components of the project.
- Secure-online file sharing and transfer service. Data management and transfer is essential to a CCS project such as Aquistore. With researchers and partner organizations spread across the world, an accessible and secure information and data transfer site was established to facilitate the transmission of data.
- Annual meetings. As project partners may be separated by distance, an annual in-person meeting allows for yearly updates, distribution of annual reports, presentations by and access to key project researchers, and networking opportunities. Additionally, these annual meetings allow for sponsor appreciation and the maintenance of positive relationships.
- Confidential annual reports. Project partners utilize these documents for reference, reporting, and internal communications activities.

As part of the communications portfolio, Aquistore’s Communications Manager developed and implemented a Strategic Communications Plan which provides the project with a clear set of guidelines and tools to communicate objectives of the project to key audiences to assure the project’s implementation and success.

Aquistore’s visitors also tour SaskPower’s capture facility.
As outlined in the organizational chart above, areas of expertise are identified and outlined. The presence of regulatory bodies -such as the provincial Ministries of Economy (who manages energy and resources) and Environment, provide a valuable regulatory perspective.

Aquistore is a consortium composed of both public and private institutions. Each full project partner is provided a seat on Aquistore’s Management Committee. Each organization has specific interests and areas of expertise which is valuable to the Project. Project partners have full access to Aquistore research and results and help guide the direction of the project and research program. The Management Committee will provide advice and recommendations to the PTRC including:

- The scope, course, direction and timing of the research project
- The introduction of additional sponsors
- Selection and engagement of research providers
- Budgetary matters
PTRC has brought together internationally recognized expertise and interest to Aquistore. PTRC employs a successful project model focused on combining the interests of industry with research and innovation.

Aquistore partners come from a variety of organizations in both the public and private sector. Each organization brings unique interests and perspectives. Over the lifetime of the project, Aquistore is proud to have partnered with the following organizations:

**Consumers Cooperative Refineries Ltd. (CCRL):**
The Co-op Refinery Complex is an oil refinery spread over 544 acres (2.20 km²) located in the city of Regina, Saskatchewan, Canada owned by Federated Co-operatives Limited (FCL). The refinery provides oil products to the member co-operatives of Federated Co-operatives Limited.

**Deep Earth Energy Production (DEEP):**
DEEP aims to be the first geothermal power producer in Saskatchewan. DEEP’s long term goal is to identify and develop geothermal hot spots suitable for multiple 4-5 MW power generation plants.

**Enbridge:**
Enbridge Inc. is a pipeline transport company based in Calgary, Alberta, focused on transporting and distributing crude oil, natural gas, and other liquids. Enbridge currently operates the world’s longest crude oil and liquids pipeline system, located in both Canada and USA, as well as markets and develops international energy projects. As an energy distributor, Enbridge owns and operates Canada's largest natural gas distribution company.
Go Green Saskatchewan (Saskatchewan Ministry of Environment):
The Go Green Fund is a financial commitment from the Government of Saskatchewan to assist Saskatchewan’s people, communities, non-government organizations and businesses address the province’s most important environmental issues. Go Green supports practical, cost-effective solutions delivered through innovative environmental technologies, processes and improved public understanding.

Korea National Oil Corporation (KNOC):
Founded in 1979, KNOC is the national oil and gas company of South Korea. The company operates oil and gas fields in Vietnam, Libya, Peru, Indonesia, Nigeria, Yemen, Kazakhstan, Russia, Canada and South Korea.

Natural Resources Canada (NRCan):
Natural Resources Canada (NRCan), is the ministry of the government of Canada responsible for natural resources, energy, minerals and metals, forests, earth sciences, mapping and remote sensing. NRCan works to ensure the responsible development of Canada’s natural resources, including energy, forests, minerals and metals. NRCan also uses its expertise in earth sciences to build and maintain an up-to-date knowledge base of our landmass and resources.

OYO Corporation:
The OYO Corporation was founded in 1954 as the ‘Fukada Geological Research Institute”. By promoting a harmonious relationship between humankind and nature, OYO believes in mobilizing technology to contribute to the well-being of society and corporate growth.
Research Institute of Innovative Technology for the Earth (RITE):
Established in 1990, RITE aims to contribute to the preservation of the global environment and the development of the world economy through the progress of industrial technologies. Focused on collaborative international research, RITE is a research and development organization.

SaskPower Corporation (SPC):
Established in 1929, SaskPower is Saskatchewan’s provincially owned principal energy supplier. A major employer in the province, SaskPower serves more than 490,000 customers through more than 151,000 kilometres of power lines throughout the province and covers a service territory that includes Saskatchewan’s geographic area of approximately 651,000 km².

Schlumberger Carbon Services (SCS):
Schlumberger is the world’s leading supplier of technology, integrated project management and information solutions to customers working in the oil and gas industry worldwide. Since the 1990s, Schlumberger has directed R&D efforts towards the new frontier of carbon capture and storage, investing substantially to innovate, adapt, and patent technologies specifically for use in CO₂ storage projects. SCS is involved in over 60 CCS projects around the world.

Sustainable Development Technology Canada (SDTC):
Funded by the federal government of Canada, SDTC is a not-for-profit foundation that finances and supports the development and demonstration of clean technologies which provide solutions to issues of climate change, clean air, water quality and soil, and which deliver economic, environmental and health benefits to Canadians.
In addition, Aquistore is a proud partner of:

The Plains CO₂ Reduction Partnership (PCOR):
The PCOR Partnership is led by the Energy & Environmental Research Center (EERC) at the University of North Dakota. EERC pursues an entrepreneurial, market-driven approach to research and development in order to successfully demonstrate and commercialize innovative technologies. PCOR is one of seven regional partnerships under the U.S. Department of Energy (DOE) National Energy Technology Laboratory’s (NETL’s) Regional Carbon Sequestration Partnership (RCSP) Program.

The Midwest Geological Sequestration Consortium (MGSC):
MGSC is one of seven DOE partnerships working to find a balance between growing energy needs and rising climate concerns by capturing carbon dioxide created in energy production and industrial processes and storing it safely underground in natural geological formations. MGSC is funded by the U.S. DOE through the NETL via the Regional Carbon Sequestration Partnership Program and with the Illinois Department of Commerce and Economic Opportunity.
Research collaborations are invaluable to CCS projects.

Research can contribute to the overall value of a project, and allow organizations which may not have the cash-resources to join a project to make in-kind research contributions to the project.

Developing a world-wide capacity for CCS should be a goal of all first-generation CCS demonstration projects. By building capacity and developing expertise across nations and organizations, the second generation of CCS projects can learn from the experiences and lessons of the first.

Managing research collaborations can be complicated. Any formal research projects must be complimentary to the existing research program. Independent research is beneficial, however, validity and certainty are necessary. Competing research results have the potential to stop a project.

Aquistore maintains control over all publications and research related to the project. All researchers and project partners are obligated to share any findings which they intend to publish with Aquistore. The SERC peer-reviews all publications and if necessary provides follow up.
There is significant national interest in the Aquistore project. As Canada moves to reduce its greenhouse gas emissions (GHGs), carbon capture and storage technology will contribute to meeting this goal.

As our number of research partners grows, so does the scope, expertise and depth of our research program. Aquistore is collaborating with the following organizations:

**Deep Earth Energy Production (DEEP):**
DEEP is exploring the potential for and economic and technical viability of geothermal power generation.

**Geological Survey of Canada (GSC):**
Aquistore serves as the site for which GSC will design, adapt, and test non-seismic monitoring methods that have not been systematically utilized to date for monitoring CO$_2$ storage projects, and to integrate the data from these various monitoring tools to obtain quantitative estimates of the change in subsurface fluid distributions, pressure changes and associated surface deformation.

**Natural Resources Canada (NRCan):**
NRCan is sponsoring a research project at the site to specifically study the use of non-seismic monitoring methods for Aquistore. Techniques to be investigated include: downhole and surface gravity, tracer studies, and surface deformation monitoring.

**St. Francis Xavier University:**
The partnership between St. FX and Aquistore focuses on atmospheric monitoring and soil gas sampling. A multispecies drive-around survey for has been conducted at every 10-20 m of accessible road throughout the site. A soil gas survey and soil surface efflux sampling have also be conducted.

**University of Alberta:**
The U of A has deployed an array of downhole tiltmeters at the Aquistore site in 30 m boreholes to monitor surface deformation due to deep formation CO$_2$ injection and storage. Tiltmeter array monitoring has the advantage of continuous operation and real time reporting, allowing discrete events to be correlated with tilt data. The U of A has also designed Aquistore’s unique fluid recovery system.
With a focus on collaboration and knowledge sharing, Aquistore is striving to provide the world with a cutting edge project. International partners include:

**Carbon Capture Project 3 (CCP3):**
CCP is a leading carbon capture and storage partnership of major energy companies such as BP, Chevron, Petrobras, Shell, Eni, and Suncor Energy to advance technologies that support the deployment of industrial scale CCS projects. CCP is collaborating on Aquistore’s electromagnetic monitoring work.

**Chevron:**
Chevron is one of the world’s leading energy companies. In 2012, Chevron’s average net production was 2.61 million barrels of oil-equivalent per day. Chevron also believes in investing in the development of emerging energy technologies. Aquistore and Chevron collaborated on the 2013 3D VSP survey.

**Chugai Teknos:**
Chugai has proposed to pilot a system focused on the detection of CO₂ leaks into the atmosphere using a small low power wireless module. This additional soil gas technique will be deployed at the injection well head and along the pipeline route.

**Energy & Environmental Research Centre (EERC):**
EERC’s mission is to improve global quality of life through visionary multidisciplinary research and development leading to the demonstration and commercialization of innovative energy and environmental technologies. This collaboration includes work on outreach, modelling, and core analysis.

**GeoForschungsZentrum (GFZ):**
GFZ is the national research centre for Earth Sciences in Germany. In collaboration with the Aquistore site, GFZ will explore a synthetic feasibility study based on reservoir data.

**Lawrence Berkley National Labs (LBNL):**
LBNL is a member of the national laboratory system supported by the U.S. Department of Energy through its Office of Science. Aquistore and LBNL are collaborating on a handful of projects including down-hole monitoring technologies, and Aquistore's most recent 3D VSP survey.
SaskPower is integral to the Aquistore project. As well as being a project sponsor, SaskPower is the source of Aquistore’s CO₂.

Saskatchewan has an abundance of coal. Despite being a reliable form of electrical generation, coal produces +70% of Saskatchewan’s greenhouse gas emissions. As Saskatchewan has the highest GHG emissions per capital in Canada, changes to the province’s energy profile were increasingly necessary.

In December of 2010, SaskPower announced its plans to proceed with a retrofit of Unit #3 at Boundary Dam. Unit #3 was nearing the end of its life cycle and the company was faced with the decision of continuing or with innovating. To address the environmental challenges of coal, SaskPower elected to commission the world’s largest commercial-scale carbon capture and storage demonstration project associated with a coal-fired power plant. The Boundary Dam Integrated carbon Capture and Storage Demonstration project will capture approximately one million tonnes of CO₂ each year. Unit #3 is being retrofitted with a state-of-the-art turbine and a fully-integrated carbon capture system capable of cutting CO₂ emissions by up to 90 per cent, or approximately one million tonnes a year.
A majority of the CO₂ captured at Boundary Dam will be sold to Cenovus Energy for enhanced oil recovery (EOR) in oil fields located outside of Weyburn, Saskatchewan. While SaskPower has a secure EOR offtaker, Aquistore is an integral component of this fully integrated project.

Aquistore provides a secure storage alternative to EOR. By providing buffer protection, Aquistore allows SaskPower to proactively mitigate any delays or interruptions that are encountered. By providing secure and economical buffer protection, Aquistore allows SaskPower to commission their plant earlier, test efficiencies and flow rates, and provides an alternative to venting during routine pipeline maintenance or EOR offtaker down-times.

As the integrated project moves forward Aquistore and PTRC will continue to work with SaskPower to provide monitoring, measurement, verification of the CO₂ injection.

Based on the outcome of the Boundary Dam CCS Demonstration Project, SaskPower may integrate their other coal-fired generating units with carbon capture technology, therefore requiring that storage in deep saline formations be proven as a viable option for future CO₂ storage.
SASKATCHEWAN’S RESOURCE-
HEAVY ECONOMY AND
FAMILIARITY WITH MINING,
AND OIL AND GAS OPERATIONS
HAS CONTRIBUTED TO THE EASE
WITH WHICH CCS HAS BEEN
ADOPTED BY THE PROVINCE.

A satellite imaging of Saskatchewan (centre).
“With the federal and provincial investments in carbon capture technology to date, I can think of no other jurisdiction in the world that is beating Saskatchewan’s per capita investment in advanced clean energy technology.

This project is a great example of just how serious Canada and Saskatchewan are when it comes to controlling greenhouse gas emissions.”

Premier of Saskatchewan, Brad Wall
August 29, 2013
Saskatchewan is a large geographic area with a small and sparsely distributed population.

The name Saskatchewan is derived from the Cree word *kisiskâciwanisîpiy* meaning “swift-flowing river.” A young province, Saskatchewan joined Canada on September 1, 1905. Located between Alberta to the west and Manitoba to the east, its boundaries extend from the US border along the 49th parallel to the border with the Northwest Territories along the 60th parallel.

Saskatchewan covers 6.5% of Canada, an area of 651,036 square kilometres. Of this, 591,670 square kilometres are land and 59,366 square kilometres are covered by water. The 2006 Canadian census recorded Saskatchewan’s population at 968,157, while quarterly estimates from October 2011 were 1,063,535.

The land is divided between the mostly crystalline rocks of the Precambrian shield in the northern third of the province and the sedimentary rocks of the western Canadian sedimentary basin in the south. Mineral resources include world-class deposits of uranium and potash.
Four ecozones span the province: prairie, boreal plains, boreal shield, and taiga shield. The climate is continental, characterized by large seasonal temperature ranges and low precipitation.

Saskatchewan is endowed with an abundant supply of natural resources. 25% of Saskatchewan’s economy is derived from primary industries such as Agriculture, Mining and Petroleum. The resource-heavy economy and familiarity with mining, and oil and gas operations has contributed to the relative ease with which CCS has been adopted by the province.

Estimated at 95% of all goods produced in the province directly depend on its basic resources (grains, livestock, oil and gas, potash, uranium and wood, and their refined products).

As a result of having been submerged under a prehistoric ocean, the province has an estimated 75% of the world’s potash reserves. In addition, Saskatchewan is now the largest uranium-producing region in the world, accounting for 25% of annual world uranium production in 2002.
Saskatchewan is a small but significant producer of crude oil, natural gas, and coal and electrical energy, with about 10% of Canada’s reserves for oil and 25% of its gas reserves.

Saskatchewan is the second largest oil producer in Canada after Alberta, accounting for more than 20% of the total Canadian oil production: cumulative oil production up to December 31, 2002 was 622 million cubic metres.

Saskatchewan natural gas producers account for more than 6.5 billion cubic metres annually, earning on average about $1 billion per year in the 2000-02 period, while coal producers produced 11.3 million tonnes of coal in 2002, earning $180 million.

As a country, Canada has a large coal endowment.

British Columbia, Alberta and Saskatchewan have the largest known reserves and resources in Canada that are actively mined. Canada currently holds 8.7 billion tonnes of proved resources of coal-in-place, which are the resources in known deposits that have been carefully measured and assessed.

The geological resource in Canada is far larger, however.

In addition to the proved resources, there are 190 billion tonnes of estimated resources of coal-in-place, which is the indicated and inferred tonnage with foreseeable economic interest.

The Canadian government believes that the development and implementation of new technologies such as carbon capture and storage and clean coal could, however, help sustain the use of coal for electricity generation in a carbon-constrained future.
Saskatchewan, as a consumer, has the highest per capita CO₂ emissions nearing 73 tonnes per person. While the population is small, the emissions per person are high. While solar and wind may become ideal for a province like Saskatchewan, currently the storage technology has not developed adequately to support the energy demands of a growing population. Bio-fuels and other alternative energy options are still technologies with significant development ahead of them.

Fossil fuels will remain at the core of the energy industry for many years to come. As an accessible and cost-efficient source of energy, fossil fuel combustion will continue for the near future. Indeed, upwards of 70% of Saskatchewan’s electricity is generated by combustion plants such as Boundary Dam 3.

Saskatchewan was first exposed to CCS in the early 1980’s. Shell approached Saskatchewan’s with a proposal to undertake a pilot project involving CO₂ EOR.

Carbon dioxide injection began on a small scale in 1984 and ran until 1999 before a full scale commercial carbon dioxide enhanced oil recovery project began in an adjacent reservoir in 2000 in Cenovus’ Weyburn fields. A second commercial scale carbon dioxide enhanced oil recovery project started in 2005 in Midale.

Provincial oil and gas regulators compared this proposal to normal oil field activity involving the injection of a fluid into the subsurface using standard oil field technology. Saskatchewan is familiar and comfortable with the oil and gas industry.

It was concluded that Saskatchewan could apply existing regulatory tools governing the injection of fluids into the subsurface to what was seen as another project involving subsurface injection of a solvent fluid to flush oil from a reservoir.

CCS in Saskatchewan is regulated by the provincial Ministry of Economy (Energy and Resources sector).

The starting point of a small CO₂ EOR pilot project in 1984 influenced Saskatchewan’s approach to regulation of subsurface injection of carbon dioxide ever since.
During the 30 year period that followed, the injection of CO$_2$ has remained under the province’s standard oil and gas production regulations.

Nearly 30 years of incident-free operating experience hasn’t produced any tangible evidence to indicate this approach is wrong.

Currently, oil and gas regulators in Saskatchewan are considering what, if any, additional policy and regulatory requirements may be necessary to ensure that sufficient measurement, monitoring, and verification is undertaken of the subsurface injection of carbon dioxide to demonstrate compliance with emission reduction obligations. As well, regulators are considering if additional policy and regulatory requirements are necessary for large saline aquifer storage projects.

Policies and regulations established by other jurisdictions are being reviewed to determine if any desirable revisions should be made to the policies and regulations currently applied to CCS field activity in Saskatchewan.
In regards to emissions, the Saskatchewan Ministry of Environment and Environment Canada are responsible for regulations associated with confirming that large emitters of carbon dioxide have complied with their emission reduction obligations when they have undertaken CCS.

The Ministry of Environment is currently working on the development of draft regulations that will include provisions for the issuance of offset credits for carbon dioxide that is stored in EOR projects.
Aquistore’s SERC committee is built on the expertise developed by the International Energy Agency Greenhouse Gas (IEAGHG) Weyburn-Midale CO₂ Monitoring and Storage Project.
Aquistore’s research is led by a Science and Engineering Research Committee (SERC).

This committee of globally recognized experts helps guide and execute the project’s innovative research project.

SERC members have hands-on experience in geological carbon storage-related research to develop and continually assess the project’s: site characterization, field and laboratory studies, numerical simulations, CO₂ monitoring programs, and risk assessment.
**DR. DON WHITE**

Don White is a senior research scientist with the Geological Survey of Canada. He is an applied seismologist whose research interests include seismic applications to CO₂ storage monitoring and mineral exploration.

Since 2003, Don has been the theme leader for MMV research in the IEAGHG Weyburn-Midale CO₂ Monitoring and Storage Project, where he has directed and integrated multidisciplinary research to advance development and demonstration of measurement, monitoring and verification methodologies. He serves as the Chair of the Science and Engineering Research Committee for Aquistore.

Don serves on the IEAGHG R&D Monitoring Network Steering Committee and the Society of Exploration Geophysicists CO₂ Research Committee. He is an Adjunct Professor at the Ottawa-Carleton Earth Science Centre.

---

**DR. RICK CHALATURNYK**

Rick Chalaturnyk joined the University of Alberta in 1997 and is currently a professor in the Department of Civil and Environmental Engineering. He holds a Foundation CMG Chair in Reservoir Geomechanics.

Rick has been involved in the IEAGHG Weyburn-Midale CO₂ Storage and Monitoring Research Project, and the Canadian Centre for Clean Coal, Carbon and Mineral Processing. He is a theme lead for the carbon storage theme in the Helmholtz Alberta Initiative, a member of CO₂CARE, an EU funded program looking at storage project abandonment, and is involved in several other CCS initiatives.

Rick continues to serve on the organizing committees of the IEAGHG R&D Networks in Risk Assessment, Wellbore Integrity and Monitoring and currently serves as Chair of the Canadian Standards Association Technical Committee developing a standard for the geological storage of CO₂.
DR. CHRISTOPHER HAWKES

Chris Hawkes obtained his Ph.D. (Geology) and B.Sc. (Geology-Physics) degrees from the University of New Brunswick.

He worked six years for a Calgary-based petroleum engineering and geoscience consulting firm, then joined the Department of Civil and Geological Engineering at the University of Saskatchewan in 2002, where he currently serves as an associate professor.

Chris has led geomechanical investigations for several CO₂ storage projects in western Canada, and has served as Theme Co-leader for Wellbore Integrity research in the IEAGHG Weyburn-Midale CO₂ Monitoring and Storage Project.

---

DR. JIM JOHNSON

James W. Johnson, joined Schlumberger in 2008 after 21 years at Lawrence Livermore National Laboratory. Jim holds a Ph.D. (Geosciences) from the University of Arizona. His areas of expertise include geochemical and reactive transport modeling, fluid equations of state, fluid-mineral equilibria, mineral reaction kinetics, and scientific software development. His research focuses on developing versatile simulation capabilities and applying these to address diverse subsurface problems, including hydrothermal ore deposition, nuclear waste disposal, geologic carbon sequestration, and hydrocarbon recovery.

Jim is the principal developer of SUPCRT92, a thermodynamic database and software library for calculating fluid-mineral equilibria within geologic systems, which has become a standard computational tool for geochemical investigations. At Schlumberger, Jim contributes to the development of advanced reactive transport modeling capabilities and their application to enhanced and unconventional recovery operations. He also served as Geochemistry Theme Leader for the Weyburn-Midale Project (Final Phase).
**DR. BEN ROSTRON**

Ben Rostron is a Professor in the Department of Earth & Atmospheric Sciences at the University of Alberta. He obtained a B.A.Sc. in Geological Engineering from the University of Waterloo (1986), and M.Sc. (1990) and Ph.D. (1995) in Geology from the University of Alberta. His research interests are in the area of large-scale fluid flow: petroleum hydrogeology; regional groundwater flow; hydrochemistry; numerical modelling; and geological carbon sequestration.

Ben has been involved with the IEAGHG Weyburn-Midale CO₂ Monitoring and Storage Project since 1999, including: research provider in Phase I (2000-2004); Hydrogeology Coordinator (Phase I); and Theme Leader (Geoscience) for the Final Phase of the Project (2005-2012).

Since 1999, Ben has served as an Academic Examiner of the Board of Examiners of the Association of Professional Geoscientists and Engineers of Alberta. He is a Fellow of the Geological Society of America, and Engineers Canada.

---

**DR. JAMES A. SORENSEN**

James A. Sorensen is a Senior Research Manager at the EERC, where he is a principal investigator and task manager for the Plains CO₂ Reduction (PCOR) Partnership.

Mr. Sorensen’s primary areas of interest and expertise are environmental issues associated with the oil and gas industry. Since 2003, he has focused on the sequestration of carbon dioxide in geologic media, with an emphasis on the value-added use of carbon dioxide for enhanced oil recovery.

Mr. Sorensen received his B.S. degree in Geology from UND. He is a member of the Society of Petroleum Engineers and is an author or coauthor of over 20 published papers.
In May 2009, Aquistore’s Science and Engineering Research Committee (SERC) was founded.

With particular attention paid to research and development, the SERC serves to provide a collaborative and constructive forum to investigate outstanding scientific and engineering matters arising in the project. In March 2010, this committee created Aquistore’s first technical program.

Established as a committee, each participant has voting rights and all SERC decisions are made through consultation, discussion, and ultimately - majority vote. Governed by an elected, alternating chair person, the committee members must attend meetings, functions, meet the required time commitment, and maintain confidentiality.
SERC’s primary function is to establish and maintain a research program which is consistent with the ultimate goals. Each project is voted on the basis of its own technical merits. If necessary - external expert reviewers can be selected to participate.

In addition to the SERC, there are a number of research partners and organizations which participate in the Aquistore project. Each new research collaboration is independently reviewed for merit by the SERC. In several instances, collaborative proposals between researcher organizations and existing project research have been developed.

All proposals, papers, publications, and projects related to Aquistore are peer reviewed by the SERC. Budgetary changes, RFPs, reporting obligations, and their administration are also assisted by SERC.

Additionally, SERC members are active participants in each Risk Assessment activity, ensuring all project activities are expertly reviewed and maintain overall cohesion with Aquistore’s work plan and MMV goals.
Meeting regularly, this committee is focused on maintaining objectivity, encouraging collaboration and integration, and developing an efficient and economical technical program for Aquistore.

Each SERC member brings their own area of expertise and their own informed, respected, and independent opinions.

As independent experts from a number of established academic institutions, participation in the project provides SERC members with opportunities to help grow CCS expertise through increased opportunities for graduate and post-doc students.

In addition to their technical contributions, SERC provides a valuable resource to Aquistore’s public outreach program. As independent experts, leaders in their field - they contribute extensively to the public assurance aspect of the project’s communication’s program. At each Open House hosted by the Aquistore project, these experts provide accessible information and responses to any concerns present in the local community.

A soil gas sampling port, located near the well-site.
All major CCS projects have advisory boards. With many of these technical advisory boards their function is truly advisory. Experts may offer advice and opinions, and will undertake and present research, however, ultimately the decision makers are the project managers and/or regulatory agencies.

While the primary of regulators and project funders remains, Aquistore’s SERC committee offers direct guidance to the project. Built on pre-existing relationships - the SERC functions successfully due to a mix of experience, areas of interest and leadership, and personalities.

A critical strength of the SERC is the project management experience brought by each member. While all committee members have extensive technical and research experience - a familiarity with and experience in project management has contributed directly to the success of the project’s work program.
A second critical factor is the significance of independence. Any CCS project is a large operation with many ‘moving parts’. The Aquistore SERC is built on the importance of this independence. A successful technical advisory group must be composed of independent members with no agenda excluding the success of the project and its goals.

The SERC is an organization external to PTRC. The technical review process is fundamental to the success of CCS projects. With independence and diverse areas of expertise, there is obviously a competition for attention which must be managed. Competing views without resolution could impact or impede project. However, an expert advisory group is able to critically examine all technical elements of a project.

By supporting constructively critical collaboration, independent experts can help build greater regional and international capacity for CCS.
The southern portion of the Williston Basin has been identified as an excellent geological area to permanently store CO₂.
A fundamental requirement for CO₂ storage projects is acquiring a suitable geological site.

This site must have sufficient injectivity to receive CO₂ at the rate at which it is to be supplied, sufficient capacity to store the delivered CO₂ over the lifetime of injection operations, and then must provide secure containment of the CO₂ for the long-term.
In selecting a geological site that is suitable for the injection and long-term storage of CO₂ there are three fundamental geological requirements.

- First, the reservoir formation must have the required permeability to allow sustained injection of CO₂ at rates commensurate with the CO₂ supply rates. Injectivity can be described as the ability of the injection horizon to receive fluids.

- Second, the formation must have the capacity to accommodate the large volume of CO₂ to be delivered and stored.

CO₂ storage capacity is an estimate of the amount of CO₂ that can be stored in a reservoir. Factors affecting CO₂ storage capacity include the density of the CO₂ at subsurface reservoir conditions, the amount of interconnected pore volume of the reservoir rock and the nature of the formation fluids.

- Third, the geological container must have sufficient and secure trapping ability to ensure secure long-term retention of the injected CO₂.

To be effective for geological storage, the formation that serves as the injection zone must be bounded by rocks which serve to trap the injected CO₂ and provide secure long-term retention.

Given that buoyancy forces will drive CO₂ upwards, the most critical control on containment is the flow behaviour of the overlying rock formation (i.e., the primary seal or “caprock”), as well as any features such as wellbores or faults that penetrate it.
Other considerations that must be considered in choosing a suitable storage site include:

- Accurate estimation of implementation costs.
- Minimization of risk to the environment and local inhabitants.
- Limited encumbrance of other subsurface natural resources.
- Logistical constraints in deploying monitoring technology.
- Presence of existing infrastructure.
- Land availability and regulatory considerations.
Aquistore was originally located in Regina, Saskatchewan and partnered with the CCRL’s Co-op Refinery Complex. Site characterization work was undertaken for the proposed location of Regina.

Relative permeability measurements from core samples were utilized as were core descriptions and thin section analysis. Existing 2D seismic line was purchased and a geological model was created and improved for vertical resolution. In addition, legacy well data from nearby potash mines was used in the evaluation of the Regina site. However, after two years of characterization work and program design, CCRL put their carbon capture plans on hold.

Following the withdrawal of CCRL, Aquistore relocated to Estevan and joined SaskPower. SaskPower, Saskatchewan’s regional power provider, had elected to go forward with plans to build the world’s largest integrated commercial-scale carbon capture and storage project just outside Estevan, Saskatchewan.
With a new project location, a new site characterization had to be undertaken.

Saskatchewan has a supportive regulatory environment and excellent historical geologic data. However, due to the lack of deep wells in south-eastern Saskatchewan, the characterization required significant work and expertise. Aquistore utilized preliminary geological and hydrogeological characterization, 2D seismic, 3D seismic, existing core, and historical well logs to evaluate the site prior to drilling.

A major component of site characterization work is to obtain, compile, and verify the coverage of the existing data available. The southern portion of the Williston Basin has been identified as an excellent geological area to permanently store CO₂ and the project site was identified.

The Winnipeg and Deadwood formations, constitute the deepest units within the sedimentary sequence and were chosen by the Aquistore project as the target zone for CO₂ injection.
An Aquistore image depicting the injection zone, depth, and several seals (left side).
The Deadwood and Winnipeg formations are the deepest sedimentary units in the Williston Basin, and are below all oil production and potash-bearing formations in the region. They lay on granite and metamorphic rocks similar to those of northern Saskatchewan’s Precambrian Shield.

Together the Deadwood and Winnipeg formations create a very deep saline geologic package known as a flow unit. Similar deep saline formations are found elsewhere in western Canada, throughout North America and in almost all continents on the planet. The rocks in these formations provide the best targets for geologic storage of CO$_2$ because they are highly porous and permeable, have huge volumes, and have effective barriers and geologic seals that retain the brines and CO$_2$.

The Deadwood Formation is a regionally extensive sandstone of variable grain-size that contains intervals of silty-to-shaley interbeds.

The overlying Winnipeg Formation comprises a lower sandstone called the Black Island Member and an upper shale, the Icebox Member, which would form the primary seal to the storage complex.

While these formations are defined as aquifers because they contain water, they do not contain drinkable water, or water that could be used for any agricultural purpose; this water is four to five times saltier than the ocean. These formations cover a vast area in west-central North America. In the area targeted they have no currently identified economic potential, other than as storage units for greenhouse gases.

The geological formations selected for Aquistore have, in fact, much greater capacity for storing CO$_2$ than any oil reservoir in western Canada, or likely any oil field anywhere. A key difference between the Aquistore Project and other carbon capture and storage projects is that Aquistore specifically is not associated with an oil reservoir. While much of SaskPower’s captured CO$_2$ is for EOR, Aquistore itself is a dedicated deep saline storage project.
Estevan and Surrounding Area Basin Study.
By researching papers and studies previously done by geoscientists, universities and industry it was possible to gain a broad understanding of the geology of the area and any potential issues that may arise. This understanding is crucial in interpreting seismic data and building an accurate geologic model.

Acquire Relevant Legacy Well Data.
After selecting the general area for a potential injection site, legacy well data was acquired for well bores near to the site. This data included electric logs, mud (strip) logs, well tests (production and injection), bit records, etc.

Study Relevant Core from Area/Basin.
The project was fortunate to have access to several core labs information for the Williston Basin. Aquistore utilized the Saskatchewan Core Lab and core collection recording properties from tests done. Aquistore acquired copies of legacy work done on the appropriate cores. Additionally, core data was collected from the proposed injection formation, along with the primary and secondary seals, and included permeability, porosity, rock strength, etc.

Petrophysical Analysis.
A complete petrophysical analysis was performed whereby the legacy well data was taken and corrected to core data. The logs were interpreted to derive porosity, water saturation and clay volume curves and depth matched to core data. Porosity, water saturation and core permeability were run through proprietary software that then derived optimal parameters for Coates free fluid and Timur permeability equations. An elemental analysis was performed on the wells closest to the potential injection site. This gave a good indication of how a well at the site would perform.
Cross Well Correlation.
The relevant wells around the potential injection site were cross correlated to ensure the zones of interest exist under the site. This correlation was used directly with the petrophysical analysis and in the static model.

Static Earth Model.
Geologists then combined the cross well correlation and petrophysical analysis and created 2 realizations for the 3-D geologic static earth model. The first was a Stochastic (Geostatistical) model and the second a layer cake model based on the most relevant nearby well. These models used the properties from the petrophysical analysis and core tests and distributed them across the model area. These models are the basis for Aquistore’s reservoir simulations.

Reservoir Simulation.
The reservoir engineers then took the static earth models, applied reservoir rock properties from core analysis and petrophysical analysis then performed a set of injection cases to predict injectivity, plume growth and pressure distribution. Both models were compared and contrasted.

Decision Made.
The static earth model and associated reservoir simulation results, gave sufficient confidence as to the injection site’s ability to receive and safely store CO₂. Based on these results site characterization at the site proper commenced.
Any new venture has risk. Aquistore’s leading risk management framework and mitigation plan was developed in collaboration with the experts who designed the recently released Geological Storage of Carbon Dioxide Standard CSA Z741.

Aquistore’s wells were drilled to a depth of 3396 and 3400 metres respectively.
“The purpose of risk management is to ensure that the opportunities and risks involved in an activity are effectively managed and documented in an accurate, balanced, transparent, and traceable way.”

Geological Storage of Carbon Dioxide, CSA Z741
Effective risk management should:

- Help demonstrate achievement of objectives and improve performance relative to elements of concern;
- Support strategic planning and development of robust project and change management processes;
- Help decision makers make informed choices, prioritize actions, and distinguish among alternative courses of action;
- Account for uncertainty, the nature of that uncertainty, and how it can be addressed; and
- Recognize the capability, perceptions, and intentions of external and internal stakeholders that can hinder achievement of objectives.
The identification and mitigation of risk was and remains a priority for Aquistore. As one of the few active commercial scale dedicated CO₂ storage projects, Aquistore is helping to inform the next generation of CCS projects and forthcoming regulations. Every action could be considered precedent setting and as such due care and consideration were give to every project task.

Risk Management was a critical area of focus for Aquistore.

“Risk” was evaluated by project experts in terms of the aggregated product of Severity (S) and Likelihood (L) of negative impact to defined project values.

As judged by project experts, no general areas of risk (so-called Features, Events, and Processes) were evaluated as being prohibitively high and irreducible. The highest-ranked areas of risk include elements of legal permissions, funding, operations, organization, site geology, and others.

The main purpose of Aquistore’s risk assessment was to form the basis for identifying and prioritizing actions to minimize risk during the course of the project.

The time period of interest includes the entire project: CO₂ injection, CO₂ plume activity, monitoring activity, and operator exposure to liability, extending tens of years post-injection beyond the time when the plume stabilizes.

Aspects of CO₂ capture, processing (separation- compression- dehydration), and transportation were discussed only insofar as they directly impinge upon underground storage. Despite the scope limitations, the risk workshop provided an opportunity to consider risks pertinent to the highly integrated nature of the entire CCS system.

Coordinating a large number of project partners and a diverse range of experts and stakeholders, Aquistore held two successful risk assessment workshop in August 2011 and July 2013.

The first workshop provided the foundation for the project’s risk management plan, and the second revisited to determine the project’s success in managing risk and to provide guidance on a go-forward basis.
These risk assessments focused on identifying overall project risks and developing a risk reduction plan that was fully incorporated into the project work program. Both workshops included a planning phase, a project workshop, and significant follow-up work in developing the deliverables based on input gained during the workshop.

Both workshops utilized a Features, Events, and Processes (FEPs) methodology and featured experts from a wide range of relevant fields. FEPs are described scenarios. An example includes:

“Weather and climate at the project site entail hazards and operational challenges. Human health and safety, mechanical operations, and fluid phase may be affected. Weather may affect travel to site or to offsite monitoring locations. In the long run, climate change (e.g. in flood-prone areas) could affect operations.”

The goal of the assessment work was to identify and evaluate risks to project success that are pertinent to the geologic storage of CO₂ so that risk reductions could be wisely designed and implemented.
As noted, risk was evaluated in terms of the aggregated product of severity and likelihood of negative impact to defined project values. Project values were considered those entities which are or may be at risk. Fundamental to the project, these values could include objectives, environmental standards, social goals, or health and safety standards. Project values are specific project goals developed in response to broader objectives. Aquistore’s project values are as follows:

**Health & Safety**
- No lost days due to health or safety incidents.

**Environment**
- No adverse environmental impacts.

**Schedule**
- Maintain project on schedule.

**Financial**
- Execute the project within financial budget.

**Reservoir Suitability**
- Demonstrate CO\(_2\) injection into a deep saline formation at industrial-scale rates and volumes.

**Storage Security**
- Demonstrate that CO\(_2\) is contained within the intended reservoir volume.

**Capacity Building**
- Build industry ability to implement CCS by conducting and disseminating industry leading research.

**Societal Acceptance**
- Public buy-in of project.

Preparation for the first 3D seismic survey.
Expertise was ranked individually both in areas of expertise and also levels of confidence.

Areas of expertise included areas such as: boreholes, geology details, CO₂ delivery system, legal regulatory, etc. Levels of confidence ranged from ‘person on the street’ to ‘significant years of leadership in ____ (relevant area)’. These areas and levels of expertise were then cross-referenced to weight expert answers more heavily based on the question and area of expertise.

The highest ranked areas of risk included elements of legal permissions, funding, operations, organization, site geology, and others. These higher-ranked risk areas were then evaluated and used to generate concrete scenarios for which proposed ‘treatments’ (risk reduction actions) were confirmed.

Risks were then coordinated into thematic areas and treated accordingly.

Classifying risk treatments by theme is useful because it can simplify the assignment of sets of treatments to specific individuals for execution and tracking.
For the first risk assessment workshop, the ‘top 10’ risks fell into the categories of:

- Legal-Regulatory: Permits: Environmental
- Groundwater Contamination (public perception)
- Heterogeneities
- Schedule and Planning
- Legal-Regulatory: Property Rights and Trespass
- Site Security
- Procurement Delays – Well Tubulars; Well Hardware
- Long term liability
- Short term liability
- Reservoir Pore Architecture

In the thematic risk-management structure implied, specific individuals who have pertinent technical expertise become responsible not only for executing identified risk treatments, but also more generally for a set of risk-bearing scenarios.

Examples of thematic areas of risk treatment include:

- Programmatic, partnership, contracting, and insurance areas
- Scheduling, planning, and execution
- Geologic characterization, establishing baseline conditions, monitoring
- Public engagement
- Health, safety, environment - bridging HSE practices among project partner organizations
- Well drilling and completion
- Injection operations and system integration
- Internal information and data management

Technical specialists must remain involved in the on-going mission of risk evaluation and risk management.
Aquistore is home to the two deepest wells in Saskatchewan. Representing $15M of development and installation, these wells are fully instrumented, providing downhole monitoring and CO₂ tracking.
To get 3396 metres deep Aquistore began drilling the first of its two wells in July of 2012.

Drilling to the pre-Cambrian basement took approximately two months and the well was completed in September. During the drilling of the well information was collected to verify the geology of the area as well as to confirm the potential to securely store CO₂.

The data gathered from drilling the Injection well was used to inform the drilling of the second well. The second well was slightly deeper, at 3400 m, however, due to experience and lessons learned from the first well, drilling was considerably faster. Drilling began in September 2012 and was completed in December.
Operations were preceded by a full day pre-spud safety meeting facilitated by Schlumberger Carbon Services. The triple drilling rig and crew was provided by Nabors, an Alberta based company.

Special discussions were undertaken due to the nature of the project, the attention it would garner, and the number of visitors who would be visiting the site and rig.

Under normal circumstances drilling rigs are not visited by hundreds of guests. However, as a ‘first of its kind’ project, Aquistore’s team decided that being accessible to visitors was important to the outreach and communication of the project, and subsequently safety procedures were established to support this goal. The site crew was supportive and excited to be working on and participating in a such a project. Over the course of operations, no safety or security incidents were encountered and no work time was lost to guests, injuries, or work stoppages.
Prior to drilling a 20 inch conductor pipe was set and cemented in advance of the arrival of the drilling rig. A 17 1/2 inch surface hole was drilled to approximately 621 m and 13 3/8 inch surface casing set and cemented to surface.

The drilling of the well began on July 8th, 2012 and continued through until September 18th. The well reached a total vertical depth of 3396 m. 13 perforation interval(s) were completed within the Winnipeg/Deadwood Formations between 3173-3356 metres based on reservoir quality determined from open hole logs and cores.

The 10 5/8 inch main hole was drilled to total depth of 3390 m and 7 5/8 inch casing set and cemented to surface in a two-stage cement job. 4 1/2 inch tubing was run to 3136 metres, with an injection packer set within the Icebox Member at 3142 m.
The completed rig stood over 3 stories tall.
The Injection well was specially designed to be CO$_2$ resistant. Chromium casing was used, along with a special blend of designed CO$_2$-resistant cement system. This CO$_2$ resistant cement is in place to a depth of 2600 metres. Down the well, the instrumentation consists of a CO$_2$ resistant packer and a corrosion inhibitor between the well casing and tubing. The tubing itself is 4 1/2 inch carbon steel.

The injection well is equipped with a ‘down-hole’ pressure and temperature gauges. These tubing-conveyed gauges were installed on the 4 1/2 tubing. These gauges will provide real-time data on downhole pressure (injection and/or shut in) for the well and measure internal tubing pressure (the CO$_2$ injection pressure) and the pressure between the casing and the tubing (the inhibited fluid above the packer).

Additionally a fiber optic Distributed Temperature System (DTS) and a Distributed Acoustic System (DAS) were installed on the 7 5/8 inch casing of the injection well. These systems enable monitoring of pressure, temperature and sound in multiple geologic intervals to provide evidence of containment of injected CO$_2$.

The well itself is topped by surface equipment including a 34.5 MPa wellhead.
In addition, a full suite of well logs were run.

Several runs were undertaken including:

- Induction resistivity, density. Neutron porosity, sonic (Delta T), 4-arm caliper, run to surface.
- Mini-frac
- Ultrasonic cement bond log run over surface casing
- Ultrasonic cement bond log run over injection casing
- Reservoir saturation tool - pulse neutron baseline, fluid flow profile

In addition, 30 core plugs were cut using a rotary side wall core, and a formation tester and sampler was deployed resulting in 9 pressures and 3 samples.
A specialized bit was used to acquire whole cores from the wells.
With the deepest wells in Saskatchewan, Aquistore serves at the primary data point for the south eastern region of the province.

In accordance with the project’s MMV program, three whole core barrels and 30 sidewall cores were taken in the injection well.

Of the whole core, 20 m were collected from the lowermost section of the Basal Cambrian saline system (Deadwood and Black Island Formations) including samples of the caprock and reservoir. An additional 28 m were collected, for a total length 48 m of core.

As noted, 30 side-wall cores were obtained using a rotary side wall core during the drilling of the injection well.

To aid in further characterizing the lithography a total of 20 core plugs have been sampled from the whole core. These samples will be tested thoroughly including x-ray fluorescence (XRF), x-ray diffraction (XRD), scanning electron microscopy (SEM), petrographic analysis via thin sections, gas pycnometer/porosimetry, and permeability to air and water.
Many tools and logs were run on the two wells.
Observing the drilling process at dawn.
Following the cementing and completion of the injection well, the drilling rig was lowered and ‘skidded’ 150 metres to the north.

A 16 inch conductor pipe was set and cemented prior to arrival of the drilling rig. After raising the derrick, the well was spudded and drilling of the observation well began on September 18th. A 12 1/4 inch surface hole was drilled to approximately 675 metres and 9 5/8 inch surface casing set and cemented to surface.

The injection well had reached the greatest total vertical depth of any well in Saskatchewan. As the deepest well, it was the only data point in the province for the depths and formations encountered. These ‘lessons learned’ from the drilling of the injection well helped expedite the drilling of the observation well.

No work time was lost to injuries or stoppages.
As with the injection well, casing-conveyed pressure gauges and a distributed temperature sensor (DTS) and distributed acoustic system (DAS) were installed on the 4 1/2 inch casing. These systems enable monitoring of pressure, temperature and sound in multiple geologic intervals to provide evidence of containment of injected CO₂.

A unique feature of the observation well is the fluid recovery system (FRS). This fluid recovery system was installed on the well’s casing. This system enables geochemical monitoring of fluids within the injection formation.

Drilling, site operations, and visitors tours continued through drilling until November 20th. The 8 1/2 inch main hole was drilled to total depth at approximately 3400 metres and 4 1/2 inch casing set and cemented to surface in a two-stage cement job. At a total vertical depth of 3400 metres the observation well became the new deepest well in the province of Saskatchewan.
Waiting to be utilized...
Equipping and logging the well was a delicate but successful process.
The observation well is also designed and constructed to be CO₂ resistant with CO₂ resistant cement in place to a depth of 3025 metres.

Aquistore’s observation well is heavily instrumented for CO₂ monitoring. Permanently mounted monitoring tools and gauges are installed which will help the project track and understand the movement of CO₂ in the subsurface after it has been injected. These down-hole techniques allow for time lapse logging to be conducted with no interruptions. Some of the monitoring tools being used include the fluid recovery system, pressure and temperature gauges, a fibre optic Distributed Temperature System line, and a fibre optic Distributed Acoustic System line.

The fluid recovery system will collect samples from the reservoir which helps track the CO₂ plume and provides geochemical information. The DAS line is a new technique which is being used experimentally as an alternative to a string of geophones. This DAS line has recently been activated during a VSP survey.

As with the injection well, the observation well is topped with a 34.5 MPa wellhead.
Wireline logs were also run on the observation well.

Several runs were undertaken including:

- Induction resistivity, density, neutron porosity
- Elemental spectroscopy
- Nuclear magnetic resonance
- 4-arm caliper
- Dipole sonic
- Ultrasonic cement bond log run over surface casing
- Ultrasonic cement bond log run over injection casing multiple times
- Reservoir saturation tool - pulse neutron baseline

Fibre-optic cables were used on both wells in DAS and DTS systems.
Monitoring techniques are clamped to the observation well as it is drilled.
Aquistore will provide a field-tested basis for designing effective MMV programs for other projects worldwide.

A soil gas/flux survey takes place in the autumn.
The techniques utilized and tested at Aquistore will provide the basis for best practices in monitoring for dedicated CO₂ storage projects for efficacy and economic efficiency.
The purpose of measurement, monitoring and verification (MMV) is to address health, safety, and environmental risks and assess storage performance. MMV activities support a risk management strategy that enables an assessment of storage performance and provides confidence that greenhouse gas reductions are real and permanent.

- Measurement allows the project’s avoided emissions to be determined and forms the basis for allocating storage credits.
- Monitoring refers to measurement and surveillance activities necessary to provide an assurance of the integrity of CO₂ storage.
- Verification refers to a comparison of the storage project’s predicted and measured safe performance.

Assurance monitoring techniques such as soil gas and groundwater sampling are critical to Aquistore’s MMV and communications program.
Aquistore research goals include:

- Demonstrate that CCS methods involving CO$_2$ storage in a deep saline water-bearing geological formation are a safe, workable solution for greenhouse gas emission reductions for industrial applications
- Establish, trial and demonstrate effective technologies that may be widely applicable for characterizing and monitoring carbon storage in deep saline formations
- Assist in the development of essential linkages among industries implementing or considering this technology, policy makers drafting regulations around CCS; financial situations trying to understand the economic implications of business within a carbon managed environment; and the public learning about, and living with the technology.
Aquistore’s monitoring, measurement, and verification (MMV) program will test and develop effective methods for monitoring CO₂ storage sites and ensure conformance of the storage process through continuous monitoring.

This program is seeking to minimize the risk associated with any potential leakage of CO₂ from the storage reservoir through early detection.

Located in the Williston Basin, Aquistore has ideal depth, injectivity, and the presence of a regionally expansive salt layer as an ultimate sealing unit. The geologic characteristics of the Aquistore site make it a typical yet ideal site for CO₂ storage.

As Aquistore is one of the first commercial-scale deep saline storage projects globally, many MMV techniques needed to be modified for Aquistore specifically. Due to site characteristics the learnings and technologies in Aquistore MMV program will have global applicability for other CO₂ storage programs.
Built upon the learnings of the IEAGHG Weyburn-Midale CO₂ Monitoring and Storage Project Aquistore’s MMV program has included an added focus on integrated monitoring methods such as the inclusion of non-seismic methods and constraints from reservoir flow simulations is being incorporated into the project.

The integration of data from Aquistore’s monitoring suite will provide a basis for CCS operators to select a minimum set of tools or methodologies that are specifically tailored to achieve MMV requirements set by regulators, while minimizing risk and associated MMV costs.

A significant amount of the pre-injection work is included in the geological and hydrogeological characterization of the injection site which is detailed earlier in this report.

This work formed the framework for the injection and monitoring planning and informed the establishment of parameters surrounding containment and capacity.
An InSAR reflector monitors surface deformation and minute seasonal changes.
An Aquistore ‘super-station’, fenced in to protect it from cattle and other wildlife.
Aquistore’s technical and monitoring program was designed with the following goals in mind:

- Predict what will happen over time as CO₂ is injected into the reservoir at the planned rate, accounting for uncertainties in modeling tools and input data by making predictions for a range of probable scenarios.
- Monitor what actually happens as the CO₂ is injected, specifically with respect to CO₂ plume movement, and the injectivity, capacity and containment performance of the site.
- Compare the observed results with the predictions.
- Sequentially refine the models to optimize agreement between predictions and field measurements.
- Use these refined models to predict the site’s long-term performance.
- Address the question of how well this demonstration project achieved its goals, and whether or not it has added confidence in storage as a CO₂ management option.
Experience derived from the Weyburn-Midale Project underscored the value of a strong, repeated set of baseline results. A work program was established and each task was planned with key deliverables and deadlines. The following tasks were included:

- Site Suitability
- Detailed Site Characterization
- Geophysical Monitoring
- Geochemical Sampling and Analysis
- Reservoir Surveillance Wells
- Numerical Simulations
- Risk Assessment Management Framework
- Commercialization / Economic Analysis
Aquistore is utilizing a number of surface monitoring techniques. In an effort to avoid impacting the surface and landscape, the project co-located as many of these monitoring stations as possible. A strong set of baseline samples was identified early on as a critical goal of the MMV program. Many monitoring techniques provide public assurance, especially in the area of micro-seismicity.

Techniques being used include:

- tiltmeters
- inSAR
- electromagnetics
- GPS
- gravimeters
As well as providing valuable operating information and an opportunity to field test pilot techniques, a strong MMV program with baseline measurements can be the foundation of a successful public engagement program. Begun in summer 2012, soil gas and groundwater baseline sampling have been conducted repeatedly. Acquiring baseline and subsequent monitoring surveys of groundwater and soil gas will confirm the integrity of the injection well isolation and demonstrate that domestic water supplies are not affected by CO$_2$ storage.

Shallow subsurface techniques include:

- piezometers
- groundwater sampling
- soil-gas monitoring
- multi-species atmospheric surveys
Aquistore is home to unique ‘down-hole’ monitoring techniques. Many of these tools are able to measure over the entire depth extent of the wells. The resulting information (time-lapse geophysical logging, cross-well electrical and seismic tomography, and rock-fluid property measurements) will be compared with surface and shallow subsurface monitoring techniques to characterize the subsurface distribution of CO₂.

Casing conveyed instruments include:

- fibre-optic Distributed Temperature Systems
- fibre-optic Distributed Acoustic Systems
- fluid recovery systems
- pressure and temperature gauges

Aquistore’s MMV program is an essential component of its public outreach efforts.
Aquistore has an extensive seismic program, which is discussed in the subsequent section of this report.

Seismic monitoring techniques being employed on site include:

- cross-well seismic tomography
- broadband seismographs
- permanent areal seismic array
- time-lapse 3D seismic imaging
- continuous microseismic monitoring
- vertical seismic profiles (VSP)
An Aquistore image representing the activation of the permanent seismic array.
One of the unique elements of Aquistore’s MMV program is the project’s permanent seismic array.

Traditionally, 3D seismic is the primary technology for CO₂ monitoring.

Though effective, 3D seismic can be quite expensive, Aquistore's permanent array aims to demonstrate a significantly more-cost-effective seismic acquisition method.

In March 2012, Aquistore installed a permanent seismic array. This installation will be used in conjunction and comparison with traditional 3D seismic.

This permanent array is designed to provide improved sensitivity for monitoring subsurface CO₂ relative to conventional portable surface seismic systems.
An essential element of any CO₂ injection pilot project is monitoring and verification of the injection process to establish the safety of the injection process and the long-term security of the injected CO₂.

The IEAGHG Weyburn CO₂ Monitoring and Storage Project demonstrated the feasibility of using seismic monitoring methods to track the spread of CO₂ within the subsurface when the rock and fluid properties are favourable and to quantify injection-related microseismicity.

Geophysical monitoring and related activities are intended to contribute to geological characterization of the CO₂ storage reservoir, to demonstrate the safety of the injection process, and to provide ongoing verification of the security of the injected CO₂.
The Aquistore site has one injection well and one observation well. Drilling an observation well may not be feasible for some saline aquifer storage sites, thus increasing the need for remote monitoring methods.

In addition, the depth of the Aquistore injection zone may create unique challenges for techniques like time-lapse monitoring.

Aquistore’s seismic program is one of the pillars of the project’s monitoring program. The seismic program is extensive and unique - employing constant microseismic monitoring, traditional 3D seismic, the innovative DAS line, and a permanent seismic array.
The helicopter flies in seismic equipment.
A geophone, prior to installation in the permanent seismic array.
To assist in characterizing the site, Aquistore undertook a baseline 3D seismic survey.

The project successfully obtained the necessary permits from federal and provincial regulators and acquired the baseline 3D seismic survey in March, 2012.

This completed survey provided the baseline against which subsequent monitoring surveys will be compared for seismic time-lapse imaging.

The conventional high resolution 3D seismic survey was conducted over a relatively large (5 x 6 km) region and allowed Aquistore to detail the geological characteristics of the storage container. By helping the project identify the continuity of overlying seals, local and regional geologic structures were identified.
One of the unique elements of Aquistore’s MMV program is the project’s permanent seismic array. Utilizing this exclusive permanent seismic array, Aquistore’s CO₂ monitoring, measurement and verification program is moving towards the goal of quantifying stored CO₂.

Permanent seismic arrays are composed of many permanently installed geophones. Geophones are acutely sensitive listening tools which record any injection-induced seismic activity and allow direct imaging of the CO₂ plume.

Permanent arrays have been used in a limited number of oil field operations. Primary uses include marine settings such as the Valhall field in the North Sea. In addition, geophones have been used for passive monitoring such as for earthquakes, and interestingly for nuclear explosion detection and monitoring in support of nuclear test ban treaties. Quite separate from nuclear armistices, the installation of a permanent seismic array at the Aquistore site represented the first attempt to use this technology for CO₂ tracking.

Installation of the permanent array began in March 2012. In muddy spring conditions, 630 geophones were installed at a depth of 20 metres. Over the course of six weeks, these geophones were installed on a 6 km² grid around the project area.
This permanent array was designed and installed for two central purposes.

Primarily, to ensure that recording conditions are as repeatable as possible from survey to survey for time lapse imaging. This effort ensures that changes in the seismic images are associated with CO$_2$ induced changes in the subsurface as opposed to subjective changes in the recording conditions. The same geophones are used, the same geophone locations.

Essentially – the ‘repeatability’ promised by a permanent array can help ensure more accurate CO$_2$ tracking by providing a clearer picture.

Secondly, Aquistore’s permanent array allows for continuous passive micro-seismic monitoring. The array is constantly monitoring local microseismicity to establish a baseline prior to CO$_2$ injection.

The first repeat 3D seismic survey was conducted using the permanent array. The data from this test will be compared against the baseline 3D survey acquired in March 2012. This initial monitor time-lapse survey will quantify natural variability. By occurring prior to the start of injection, this test will account for the amount of variability between surveys which is unrelated to CO$_2$ injection.

In spring 2013, Aquistore’s research team conducted additional baseline seismic work including a cross-well seismic tomography. This baseline test produces an image showing the detailed geology within the storage reservoir and the cap rock. This tomographic image will be used as a baseline for post-injection time-lapse imaging. As the monitoring program begins in earnest, the project’s research team expects to repeat these surveys annually.

The characterization of the reservoir and the survey acquired will be used over the course of the project’s monitoring program. In addition, the resulting data will be integrated with other surveillance data to fully inform the project’s MMV program. Comparisons of data can be used to model time-lapse imaging of CO$_2$ movement, allowing the project to track and trace injected CO$_2$ as it moves laterally in the reservoir.

Initial results from this survey are encouraging as they show an improvement in repeatability by a factor of at least 2 relative to comparable results from the IEAGHG Weyburn project.
A third baseline survey was undertaken in autumn 2013 in conjunction with a VSP survey of the site. By using different seismic techniques repeatedly these surveys will account for any variability and provide a clear set against which results from the permanent array can be contrasted.

The Distributed Acoustic System (DAS) line on the observation well was activated. This technique has the potential to replace the geophone string which is commonly utilized within wells. Due to the inhospitable geological environment of many deep saline storage sites, the success of a DAS line has extraordinary potential in CCS as well as in commercial applications.

By activating the permanently installed seismic array the project was able to take advantage of the schedule dynamite and vibroseis utilized during the VSP survey.

This third baseline utilized two sources - dynamite and vibroseis - and employed 3 seismic techniques - VSP, DAS, and the permanent array - simultaneously. To date, the project believes this is the only survey of this scope to have taken place in the world.
Weather and rapid temperature changes can impact drilling and installation.
Soft ground led to muddy conditions for the project.
AQuistore’s communications program is focused on public engagement and stakeholder education.

Members of the public visit Aquistore's Open House in Estevan, SK.
Communication is critical to any CCS project.

Even where CCS awareness is high, many CCS projects – successful and failed – have received negative attention. Strategic outreach and engagement is necessary for ensuring CCS projects have support.

From local farmers to political leaders to industry experts, everyone expects to be informed and everyone will have an opinion.
In June 2011 Aquistore’s Communications Steering Committee was formed.

The Aquistore Communications Steering Committee, made up of representatives from PTRC, SaskPower, Enbridge Inc., the Ministry of Environment, Schlumberger Carbon Services and CCRL, have developed a mandate to accurately and transparently engage and inform key audiences of all project components in an effort to help stakeholders better understand the potential benefits and challenges the demonstration project may pose.

This steering committee collaboratively build the project’s first communications plan. Over the fall of 2011, strategic communications plan was built collaboratively with input from the Communications Working Group. Key messages were created, and project milestones identified with accompanying communications activities.

The strategic communications plan provides the project with a clear set of communication guidelines, tools, and objectives based on the needs of key project target audiences and stakeholders.
The communications program identified 5 stakeholder groups:

**Individual Stakeholders:**
- Families, farmers, or individuals who would be impacted directly by Aquistore operations.

**Local Stakeholders:**
- The community near to the Aquistore project. The town of Estevan and the rural municipality surrounding the town. From the Mayor to the local high school – this support is necessary.

**Provincial (regional) Stakeholders:**
- For Aquistore, this involved Saskatchewan’s provincial level of government. Civil servants, provincial media, Members of the Legislative Assembly, and local members of Parliament, etc.

**National and International Stakeholders:**
- Federal governments, Environmental Non-Governmental Organizations (ENGOs), National and International media and journals, Canadian federal government agencies and agents.

**Internal Stakeholders:**
- From project partners to the employees within PTRC. Buy-in, knowledge, and loyalty from internal stakeholders are significant yet often overlooked.
Aquistore’s communications program makes use of traditional and ‘new’ materials and mediums. Some materials and mediums utilized include:

**Online and Social Media Presence**
Aquistore’s project website was launched to coincide with the project’s official ground-breaking event (July 2012). The website was designed to be aesthetically ‘green’, friendly, and accessible to potential sponsors as well as members of the public.

Social media was used occasionally, although not frequently. Aquistore’s Twitter page provides an opportunity for direct and ‘unfiltered’ engagements with individuals, organizations and stakeholder groups.

Social media can be intrinsically valuable in highlighting the novelty of a project – effectively amplifying the ‘cool factor’. While not experienced during Aquistore operations, social media are invaluable in any unexpected or crisis situation as accessibility and transparency are often integral to crisis management and communication.

Fact sheets were designed and tailor-written for each new event and expected audience.
Project Literature
The project produced a number of ‘fact-sheets’ for public events detailing key facts about CCS and the project. Individually written and designed for target audiences these fact-sheets ranged in content from the project schedule to the MMV program and permanent seismic array. A number of pull up banners (April 2012), posters, and hands on display materials (December 2011) were individually developed to be used in a number of settings such as conferences and/or Open Houses.

Additionally, a consortium package was produced to provide information to prospective partners on the Aquistore project, as well as several technique specific brochures.

Hands-on Learning
In public forums, a key goal of CCS communicators is to express complicated and/or technical ideas in a simple and accessible way. During public events hands-on activities and materials can be of great assistance. Aquistore utilized core samples of various flow zones and sealing units to explain the concepts of permeability and porosity to great effect.
This Aquistore image is a to-scale representation of the injection depth and surface details.
An image can be a more effective way to convey an idea and all of its complexities. While clear language is critical, images can be innately helpful when dealing with a non-technical audience.

The technical nature of CCS can be confusing and intimidating to members of the public. While people may not know what a geophone is, or what a vibroseis truck does, the image can convey action much more clearly than a paragraph of technical language.

In public outreach activities, Aquistore utilized illustrations to great effect.
Aquistore’s communications activities began in earnest in 2012. With the majority of site construction and drilling taking place over that summer, outreach and engagement was begun well in advance.

External engagement efforts included:

Kitchen Table Discussions
In February 2012, in advance of any site activity or major announcements, Aquistore’s project team held a series of ‘kitchen table discussions’ with local land owners/users who had the potential to be affected by site operations.

The team visited each household and met with local stakeholders to discuss concerns and answer questions. These meetings and the positive relationships built proved invaluable.

Local Outreach
In March 2012 project team presented to local authorities in the community of Estevan. Project experts met with the mayor and city council as well as the reeve (rural representative) to discuss Aquistore and answer any outstanding questions.

In advance of CO$_2$ injection, Aquistore’s project and communications team is returning to Estevan to revisit local champions and stakeholders.

Open House
In April 2012, the project hosted its first open house. Staffed by project members and researchers, this open house was a large-scale effort to engage with the local community. Heavily advertised, over 75 interested citizens and local dignitaries attended this event and learned about the project.

With CO$_2$ injection expected in 2014/2015, a second Open House is scheduled to present baseline results to the community and to answer any remaining questions in advance of injection.
Ground-breaking Event
Aquistore held a formal ‘ground-breaking event’ which coincided with the project’s annual meeting in July.

The ground-breaking ceremony which featured a project tour focused on the integrated aspect of Aquistore including a visit to SaskPower’s Boundary Dam, hands-on presentations focused on site geology, and seismic and monitoring techniques, as well as a tour of the drilling rig. In addition to project partners, local authorities and regional media affiliates were invited to celebrate and profile Aquistore’s launch.

Tours
Over 300 individuals have visited the Aquistore site. Many CCS projects are remotely located or heavily restricted. As a transparent and accessible project, visitors are welcome. In addition to building relationships and goodwill, these tours serve as a broader CCS education tool.
Farm Tours
Aquistore has individual stakeholders with unique needs. Near to the project site are a number of farmers, who were engaged with at the Kitchen Table Discussions prior to site construction. As a follow up, site tours and a second engagement session was offered to local land owners in October 2012. Project Managers toured local families, answered questions, provided updated information.

Education
The PTRC is exploring collaborative opportunities with Regina Public Schools’ Board of Education. Campus Regina Public is a school within Regina offering students the opportunity to gain industry experience in a variety of fields while earning high school credits.

In collaboration with the school board, PTRC is supervising and consulting on the curriculum for an oil and gas/CCS program in the hopes of educating tomorrow’s work force and expanding broader public knowledge of CCS.

Internal Engagement efforts included:

Communications Working Group
To parallel the Management Committee, monthly teleconferences are held with Communications professionals from partner organizations.

These meetings serve to update and provide a forum for discussion of communications related issues. Monthly updates are sent out to all members.

Annual Meeting
Begun in July 2012, Aquistore holds a day of technical presentations and updates for project partners and interested parties. Aquistore experts and leads are available to present and answer questions. A second annual meeting was held in July 2013.
Tours
Following the Annual Meeting, project partners and stakeholders were taken on a day tour of Aquistore and the Boundary Dam site. PTRC staff members were invited to participate.

The PTRC corporate board is also invited to witness project progress and learn about operations.

Lunch and Learn
To engage and encourage staff interest, PTRC holds biannual Lunch and Learn conferences. Held internally, they are an opportunity for staff to learn about company projects such as Aquistore and to ask questions. Accessing internal expertise and opening dialogue within organizations is often overlooked.
Due to weather conditions, most visits occur during the summer months.
With safety and access protocols in place, the rig crew were excited with the numerous visitors.
A visiting geologist examines well cuttings.
Aquistore is committed to providing prospective CCS projects and staff with project learnings and efficiencies.

Aquistore’s experience and knowledge are helping the next generation of CCS projects limit their risk, liability, and cost.
Committed to profiling the project and actively seeking new partners, Aquistore has been a presence at a variety of industry conferences over the life of the project. Members of the Aquistore team have represented the project and its research through booths, posters, and presentations at numerous conferences. A representative sample includes:

- 11th, 12th Annual Conference on Carbon Capture Utilization and Sequestration (CCUS Conference, Pittsburgh, PA)
- Green House Gas Technology Conference (GHGT-11, Kyoto, Japan)
- Pacific North West Economic Region Annual Summit (PNWR, Saskatoon, Saskatchewan)
- 2012, 2013 MGSC Annual Meeting and Workshop (Champaign, Illinois)
- 2012, 2013 PCOR Partnership Annual General Meeting
- Conference of the Research Chair on CO₂ Geological Storage (Quebec City, Quebec)
- ULTimate CO₂ (Paris, France)
- Bi-lateral Clean Energy Dialogue on CCS (Regina, Saskatchewan)
- ZERO Conference (Norway, Oslo).
In addition to attending conferences, Aquistore has hosted a number of industry conferences.

In September 2012, Aquistore facilitated the 2012 Bilateral Clean Energy Dialogue on CCS. This annual conference hosted by Natural Resources Canada and the United States Department of Energy allows for frank discussion between industry experts and policy makers.

Following the one day conference, a tour of Aquistore and Boundary Dam was held.

In May 2013, PTRC hosted the International Energy Agency’s Greenhouse Gas Executive Committee Meeting in Regina, Saskatchewan.

Aquistore facilitated a tours and a one day symposium on the Global State of CCS.

Additionally in May 2013, Aquistore hosted an afternoon session at SaskPower’s first Consortium Symposium. Coinciding with the launch of SaskPower’s international CCS consortium Aquistore presented on project research and the importance of geological storage.
Members of the Clean Energy Dialogue tour the project site.
Summer students pose after a hot summer tour of the rig and site.
Industry Journals
Aquistore has been featured in a number of industry publications.

With a focus on knowledge sharing, the project has continued to reach out to the international community. Aquistore has kept the world updated on results and accomplishments through articles featured in publications including: the IEAGHG Newsletter, the CCSA newsletter, the Carbon Capture Journal, GHG News, EPMCWorld, the Exchange Monitor, and Power Engineering Magazine.

Media and Attention
Committed to local engagement and increasing public awareness of CCS, Aquistore has been featured in a number of local publications including, the Regina LeaderPost, the Saskatoon Star Phoenix, the Estevan Mercury, Pipeline News, Canada Newswire, Estevan Lifestyles Magazine, Regina Business Magazine, Discover Estevan, CTV News, CBC News, and Global News.

As one of a handful of active and accessible CCS projects internationally, Aquistore has attracted a great deal of attention from across Canada and the world.
Many CCS projects are remotely located or have significant restrictions on site access. Due to the close working relationship between PTRC and SaskPower, Aquistore facilitated numerous tours of both sites for project guests and partners.

In the summer of 2012 the project hosted over 250 visitors for site tours including local land owners, project sponsors, regional dignitaries and stakeholders, provincial and federal government members, members of foreign governments, corporate boards, and international researchers.

In August 2012, Aquistore hosted a delegation of geologists and project staff from the South African National Energy Development Institute (SANEDI) for a two week development workshop. Aquistore is committed to supporting other jurisdictions exploring geologic storage.

For the future, project leaders are in discussions to host capacity building workshops and professional development conferences for CCS professionals to share knowledge, build networks, and learn from this first generation of CCS projects.
Sunset at the Aquistore site.
THE IEA REPORTED:

“IT IS EXPECTED THAT AT LEAST 20 FULLY INTEGRATED CCS PROJECTS IN DIFFERENT REGIONS AND GEOLOGICAL MEDIA ARE REQUIRED BY 2010 TO ADEQUATELY DEMONSTRATE THE FEASIBILITY OF THIS TECHNOLOGY FOR BROAD DEPLOYMENT BY 2020”

WITH A FOCUS ON COMMERCIALIZATION AQUISTORE WILL BE ONE OF THESE DEMONSTRATION PROJECTS.
Climate change is of increasing concern internationally. Carbon Capture and Storage is an integral part of energy security and our energy future in the coming years. This first generation of CCS projects, of which Aquistore is one, are necessary to build international confidence in a critical technology. Aquistore is not just a research project; The project is providing the research and policy know-how to local and global jurisdictions, and companies.

In partnership with SaskPower’s Boundary Dam Integrated Carbon Capture and Storage Demonstration Project, Aquistore will see an extension of the research project in 2013 and will demonstrate the feasibility of commercial scale CO₂ storage capacity.

Injection is targeted to begin in late 2014/early 2015. This collaboration is expected to be the world’s first commercial-scale, fully integrated carbon capture and storage project from a coal-fired power plant.

The monitoring program is projected to continue until 2017. Aquistore, its SERC team, and research partners will continue to conduct a comprehensive measurement, monitoring and verification program prior to, during injection, and throughout the life of the Aquistore project.
As monitoring work continues, MMV results are integrated with the Risk Assessment work. CO₂ quantification is an ultimate goal of CCS projects, and Aquistore will work towards this. The integrated monitoring results will also inform directions for future development in the area of risk assessment as it relates to CO₂ storage and monitoring.

Aquistore’s communications program will continue to focus on promoting the project and geologic storage, sharing knowledge, and expanding public awareness of CCS at a local, national, and international level. As MMV results are interpreted, the project intends to host a second open house in Estevan to release baseline results to the local community, and liaise with civic and provincial stakeholders. As Aquistore is a unique project, the evolution of this communications plan throughout the life of an active, industrial-scale CCS project and the learnings contained within is invaluable to the CCS community internationally.

Aquistore will demonstrate both the scientific and economic feasibility of injecting CO₂ into a deep saline geological formation, and provide the knowhow for other jurisdictions and companies thinking of doing the same.