# APPENDIX: THE AQUISTORE RESEARCH PROJECT

**IN ORDER** to assure that the risk of $CO_2$ storage in deep geological formations is low and to assure the public that it is a safe and acceptable practice, governments and industry invested in the IEAGHG Weyburn-Midale $CO_2$ Monitoring and Storage Project from 2000–2012[61]. The logical next step beyond that project was to conduct similar research to build upon its acquired knowledge with the focus on $CO_2$ storage in a deep saline aquifer. Aquistore is such a project. The Petroleum Technology Research Centre (PTRC) manages the Aquistore research, development and demonstration project that is studying injection and storage of $CO_2$ in a deep saline aquifer near the Boundary Dam Power Station from 2010–2017.

**AQUISTORE** is funded by industry and government agencies from Saskatchewan, Canada and the USA as part of a portfolio of national and international commercial-scale CCS demonstration projects aimed at supporting the development of appropriate public policy and regulation, and especially gaining social acceptance of CCS as a means of reducing greenhouse gas emissions associated with industrial activities such as power generation.

In late 2010, SaskPower proposed Aquistore select its injection and monitoring site at a location near its Boundary Dam Power Station, now called the SaskPower Carbon Storage and Research Centre. Taking a long-term view, beyond the end of the Aquistore research project, the location will be used by SaskPower—the site owner and operator—as a dedicated $CO_2$ geological storage site for BD3. The SaskPower Carbon Storage and Research Centre site has capacity to store some of the $CO_2$ from SaskPower's operations for many decades, possibly centuries (pending results of the Aquistore monitoring project). However, in the absence of a carbon price or a carbon tax that incentivizes $CO_2$ disposal into a deep saline aquifer, it is expected that most of the carbon dioxide captured by SaskPower at Boundary Dam will be sold to nearby oil producers for $CO_2$-enhanced oil recovery in order to support the business investment case for the capital cost of retrofitting the power station units to generate clean coal power with PCC. Nevertheless, the $CO_2$ injection well provides some buffer storage capacity to SaskPower in the event that any oil producer that purchased captured $CO_2$ is unable to take some or all of the purchased $CO_2$, particularly if wellbore injectivity at the storage site improves as has been predicted[62].

Aquistore's technical and monitoring program development and progress has oversight from a Scientific and Engineering Research Committee (SERC) that includes geoscience and engineering experts from across North America, both from the preceding IEA GHG Weyburn-Midale $CO_2$ Monitoring and Storage Project and from the US Department of Energy's Regional Carbon Sequestration Partnerships.

## The technical and monitoring program was established to achieve the following goals that were set by the Project's funders and key stakeholders:

- Predict the movement of the $CO_2$ plume over time, including various probable scenarios.
- Monitor the performance of the storage reservoir in terms of injectivity, capacity and containment.
- Compare field data with predictions to assist in developing and refining predictive models used to forecast probable long-term performance of the storage reservoir.
- Determine whether (or not) the project has served to enhance social understanding and acceptance of $CO_2$ geological storage as an option to reduce anthropogenic GHG emissions.

## The technical program involves the following tasks:

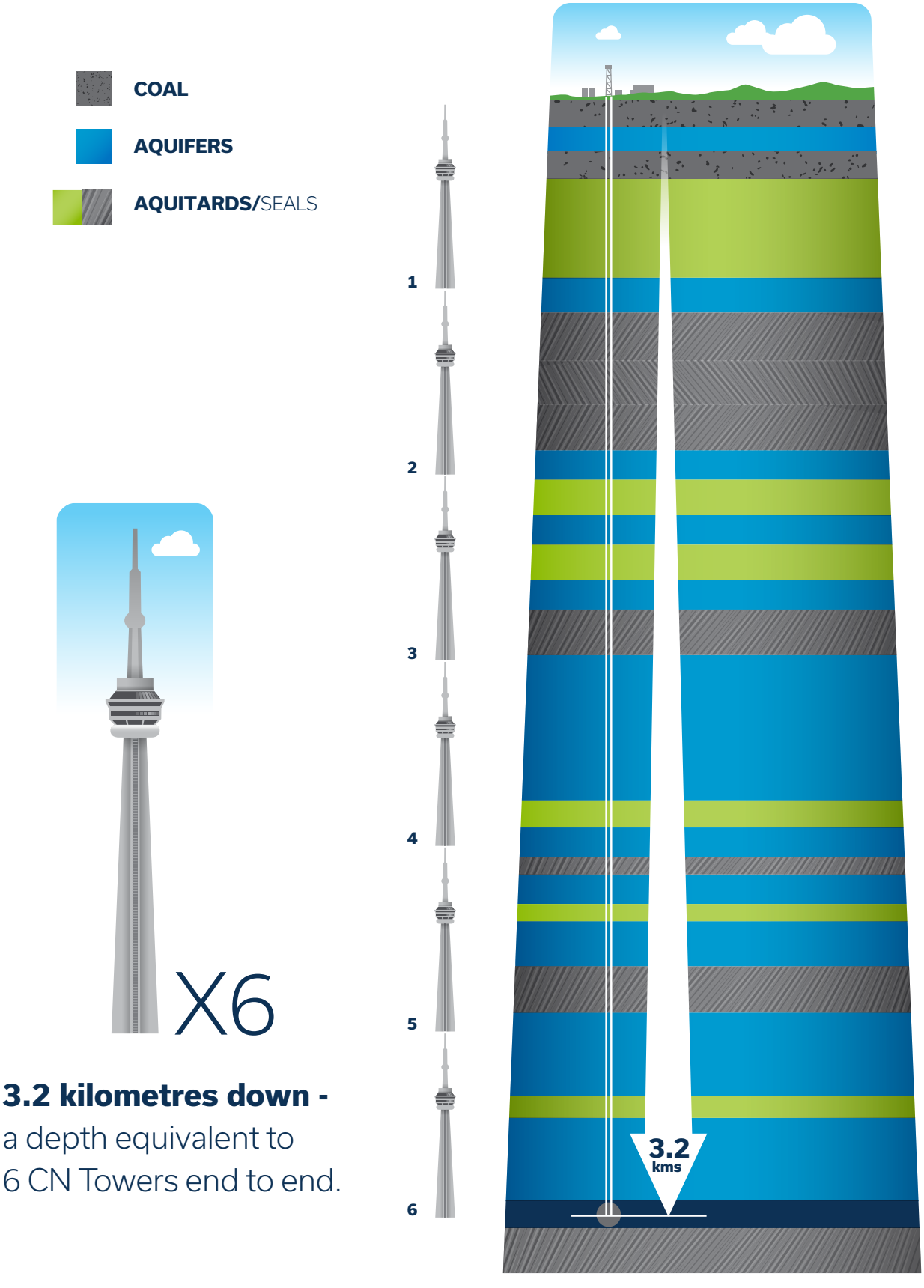
1. Site Suitability
2. Detailed Site Characterization*
3. Geophysical Monitoring*
4. Geochemical Sampling and Analysis*
5. Reservoir Surveillance Wells*
6. Numerical Simulations*
7. Risk Assessment Management Framework
8. Commercialization / Economic Analysis

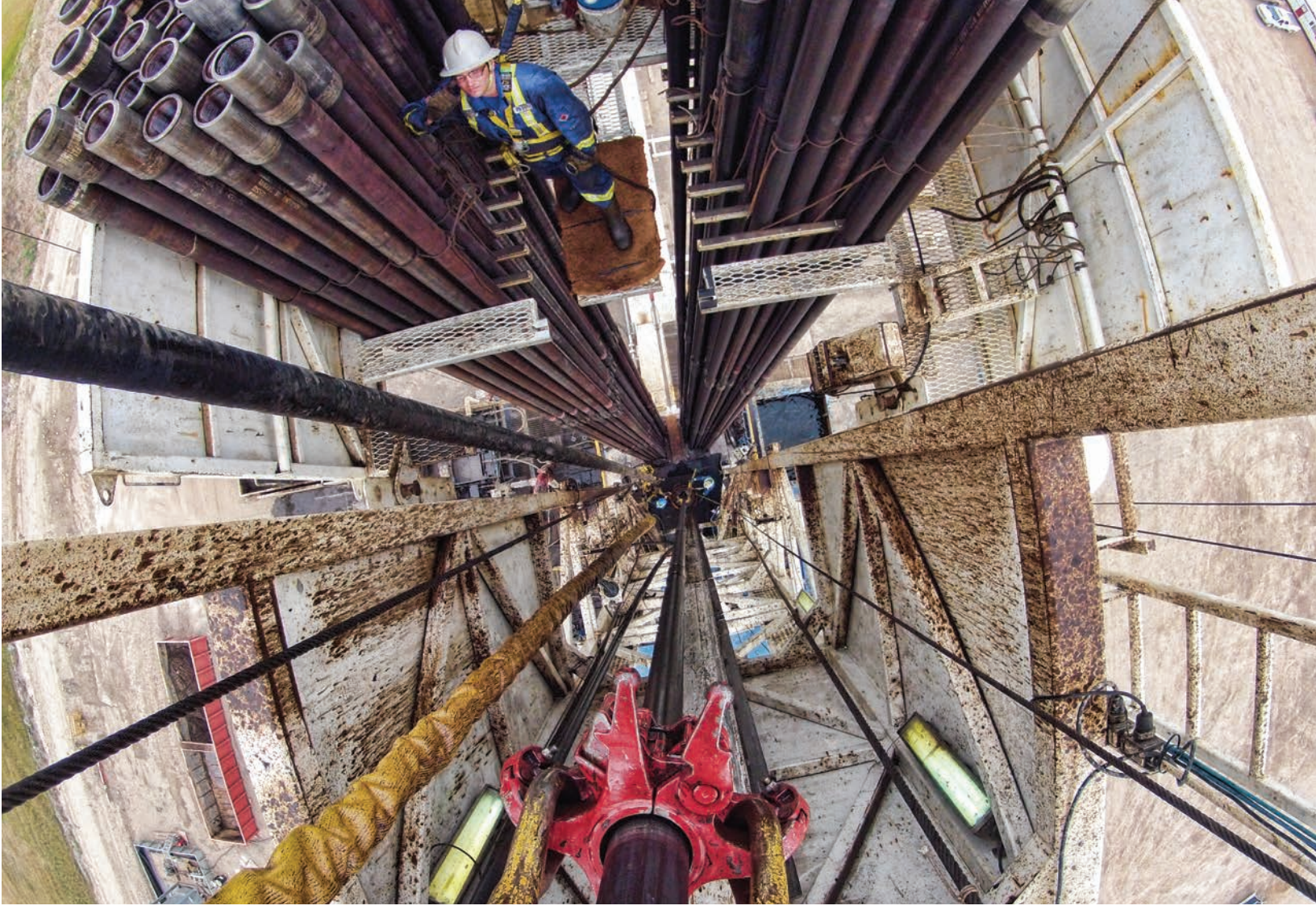
The Aquistore team has also undertaken comprehensive associated public communications, knowledge-sharing and outreach activities.

*These portions of the technical and monitoring program are considered the Measurement, Monitoring and Verification (MMV) activities.

**FIGURE 22 | REGIONAL GEOLOGY AT THE SASKPOWER CARBON STORAGE AND RESEARCH CENTRE**

*Courtesy of the PTRC*





**DURING 2011–2012,** PTRC and its team of research scientists and engineers from across North America and globally conducted a rigorous site selection process to determine the appropriate target reservoir (a deep saline aquifer) that would provide safe and reliable storage for hundreds of years. The storage reservoir selected for the site was in the Deadwood and Winnipeg formations, which are predominantly sandstone formations with suitable injectivity, porosity, and permeability properties. The reservoir underlies an impervious shale caprock seal in the upper Winnipeg formation that will assure the injected carbon dioxide remains in place. A pre-Cambrian basement metamorphic formation underlies the reservoir, forming an impenetrable barrier to any $CO_2$ flow away from the storage reservoir. Figure 22 is an artist's interpretation of the geology at the site, including the injection horizon, aquifers, and aquitards.

Traditionally, $CO_2$ is tracked underground using 2D and 3D seismic surveys as a primary monitoring tool; this has certainly been the case over the past 30+ years of $CO_2$–EOR operations in North America. A 3D baseline seismic survey was performed by the Aquistore geophysics team in early 2012 as part of the detailed site characterization, prior to drilling and completion of the injection well and the observation well in September 2012 and January 2013, respectively. Before this initial seismic survey was conducted, a permanent seismic array of geophones was installed across a 2.5 x 2.5 km area around the injection well at the $CO_2$ storage site. This permanent monitoring setup is unique to the Aquistore monitoring project. Typically, seismic surveys are conducted using temporary installation of portable geophones that are installed prior to each survey and then removed. This can

be problematic for repeatability of precise geophone location to enable accurate comparisons of time-lapsed seismic surveys. A permanent seismic array enables increased sensitivity for monitoring the subsurface $CO_2$, reduces surface interference effects, and could potentially lead to reduced operating costs for seismic surveys. An artistic interpretation of the activation of the geophone array at the SaskPower Carbon Storage and Research Centre is shown in Figure 23.

Approximately C$15 million was spent on drilling and instrumentation for the injection and monitoring wellbores. The distance between the two wells is 150 metres, which is expected to provide the data necessary to validate simulation models for predicting the extent of the $CO_2$ "plume" for several decades. The wells are 3.4 kilometres deep, and they are the deepest wells ever drilled in Saskatchewan. Wellbore logging, sampling and testing of the wells assured SaskPower that the target sandstone reservoir had appropriate storage capacity, injectivity and containment to meet its long-term storage needs for the site. Injection of the carbon dioxide into the deep saline aquifer occurs at depths between 3,173 metres and 3,366 metres through a section of perforated wellbore casing in the injection well. Carbon dioxide was first received from BD3 and injected in April 2015. As injectivity of the storage aquifer improves, it is expected that flow will increase significantly from the initially low injection rate. A detailed graphic of the injection well can be found in Figure 24.

**FIGURE 23 | ACTIVATION OF GEOPHONES IN PERMANENT SEISMIC ARRAY**

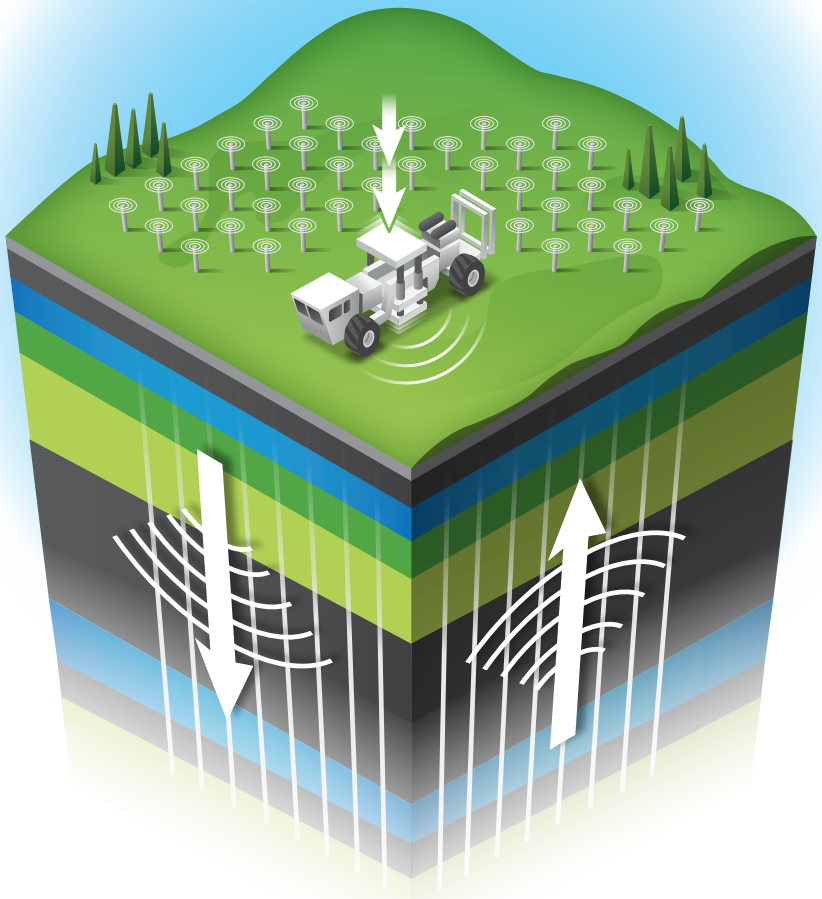
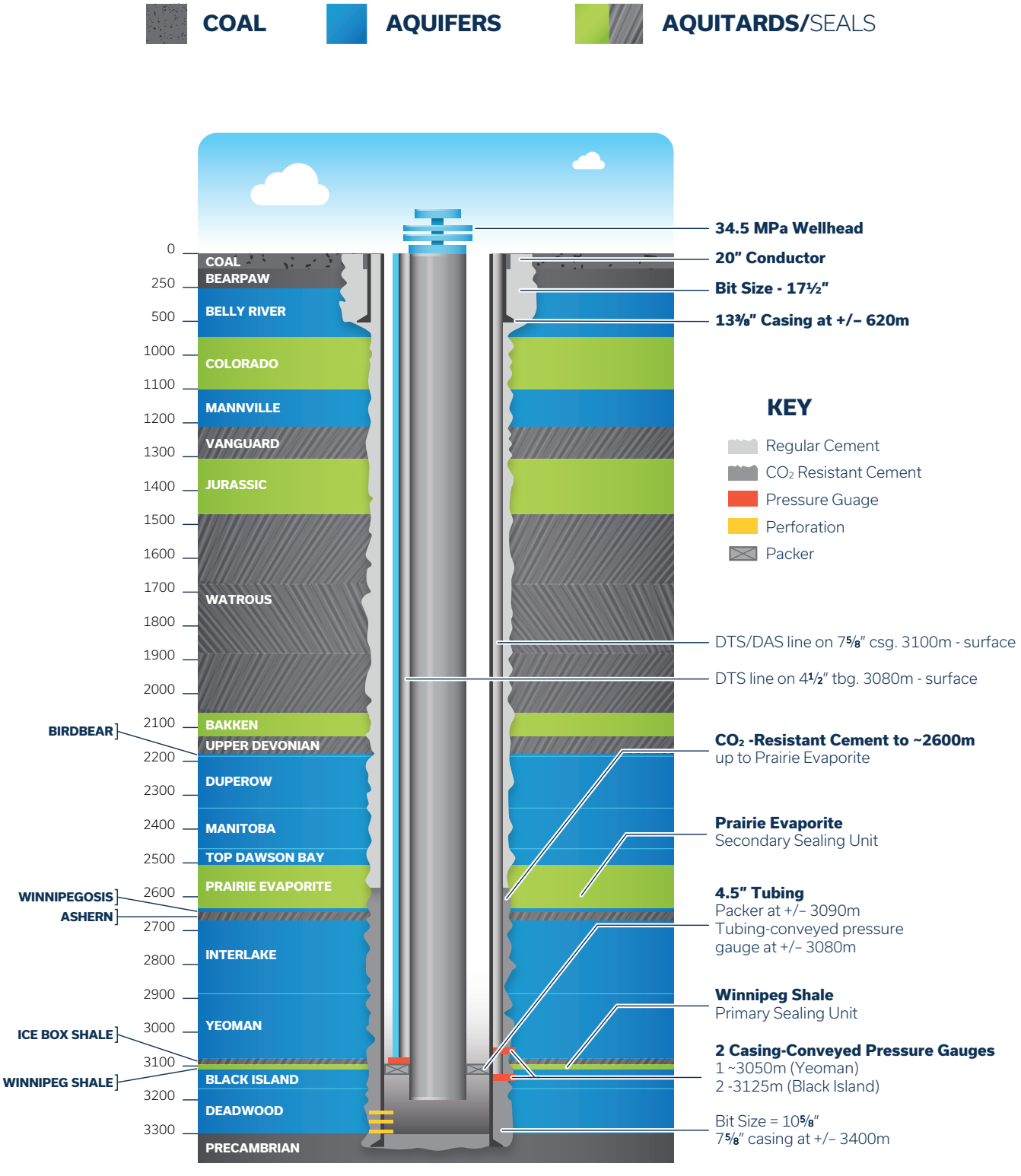


**FIGURE 24 | INJECTION WELL DESIGN AT SASKPOWER CARBON STORAGE AND RESEARCH CENTRE**

*Courtesy of the PTRC*



# **AQUISTORE** MONITORING TECHNIQUES

**FROM 2012–2015,** prior to injection, comprehensive baseline monitoring surveys of the reservoir and storage site were undertaken. A wide variety of proven and experimental techniques has been deployed in addition to the 3D seismic array, at permanent monitoring stations and using temporary monitoring techniques. Multiple monitoring technologies help to assure the public about safety and security of $CO_2$ geological storage, and are the basis for comparing (and proving) more experimental techniques with more generally accepted monitoring techniques. Table 5 lists the monitoring techniques utilized by the Aquistore Project as of mid-2015.

A qualitative risk assessment was undertaken by the Project using a panel of experts. The process involved building of a comprehensive Features, Events and Processes (FEPs) database and qualitative evaluation of likelihood and probability of various risks. Accordingly, the environmental impacts of $CO_2$ injection at the site were determined to be low due to the multiple sealing geological formations above and below the reservoir, and the absence of any significant faults or fractures and any aging oil or gas wells in the area.

**TABLE 5 | AQUISTORE MONITORING TECHNIQUES***

| TYPE | Surface | Shallow Subsurface | Downhole Instrumentation | Seismic |
|---|---|---|---|---|
| PURPOSE | Surface deformation | Ground water quality changes | Geophysical logging | Plume location |
| | $CO_2$ plume location | Near-surface atmospheric changes | Cross-well electrical and seismic tomography | Induced seismic activity |
| | | | Rock–fluid properties | Geological changes |
| | | | Reservoir fluid chemistry | |
| MONITORING TECHNOLOGY | Tiltmeters | Piezometers | Fibre-optic distributed temperature systems | Cross-well seismic tomography |
| | inSAR satellite interferometry | Groundwater chemistry monitoring | Fibre-optic distributed acoustic systems | Broadband seismography |
| | Electromagnetics | Soil-gas monitoring | Fluid recovery systems | Permanent areal seismic array |
| | GPS | Multi-species atmospheric surveys | Pressure gauges | Time-lapse 3D seismic imaging |
| | Gravimeters | | Temperature gauges | Continuous passive microseismic monitoring |
| | | | | Vertical seismic profiling (VSP) |

The Aquistore Project undertook a thorough series of public outreach activities beginning in February 2012. The communications plan included engaging:

- Individuals and the local community through "kitchen table" discussions, open houses and educational events. Knowledge dissemination is a key activity of the project and its many international researchers.
- Provincial stakeholders in the Legislative Assembly, local Members of Parliament, civil servants and regional media.
- National and international stakeholders in governments and governmental agencies, environmental non-governmental organizations (ENGOs), national and international media, scientific journals.
- PTRC employees and research partners.

Knowledge sharing has been extensive to date, including conference attendance and presentations, hosting industry conferences, tours of the SaskPower Carbon Storage and Research Centre, publication in peer-reviewed scientific journals and a high-profile social and printed media presence.

*Regular monitoring is undertaken over the same area at and around the $CO_2$ injection site.

# ABBREVIATIONS

This is not a comprehensive list.

**BD3** – Boundary Power Plant Station Unit 3

**CCS** – Carbon Capture, Transportation and Storage

**CCPC** – Canadian Clean Power Coalition

**CCTF** – SaskPower's Carbon Capture Test Facility (at Shand Power Station)

**CEPA** – The Canadian Environmental Protection Act

**CIC** – Crown Investments Corporation of the Government of Saskatchewan (owner of all Crown corporations such as SaskPower)

**$CO_2e$** – The climate forcing factor associated with a greenhouse gas expressed as "carbon dioxide equivalents". For example, the climate forcing factor of methane (CH4) is 21 times the factor for $CO_2$. Hence, one methane molecule is equivalent to 21 carbon dioxide molecules in terms of greenhouse impact on the climate.

**C$** – Canadian Dollars

**EC** – European Commission

**ECRF** – SaskPower's Emissions Control Research Facility (at Poplar River Power Station)

**EOR** – Enhanced Oil Recovery

**EU** – European Union

**GHG** – Greenhouse Gas

**GWh** – Giga-Watt-Hour, the energy unit of total power generation

**ICCS** – Integrated Carbon Capture and Storage, which is the name of the combined BD3 power plant retrofit project and the geological storage of its captured $CO_2$.

**IEAGHG** – IEA Greenhouse Gas R&D Programme

**MW** – Mega-Watt, the energy unit used for power-generating capacity

**PCC** – Post-Combustion Capture

**$PM_{2.5}$** – Fine Particulate Matter found in the air that is less than or equal to 2.5 mm (micrometres) in diameter and normally only observed by electron microscope. This material is often associated with energy combustion and the fine particulate matter is believed to cause serious health issues upon entering lungs of air-breathing animals.

**$PM_{10}$** – Coarse Particulate Matter found in the air that is less than or equal to 10 (mm) micrometres in diameter. It can be seen with the human eye in the air as soot, dust, dirt and liquid droplets. This material is often associated with energy combustion.

**PTRC** – Petroleum Technology Research Centre, a non-profit R&D corporation located in Regina, Saskatchewan

**R&D** – Research and Development

**QA/QC** – Quality Assurance and Quality Control

**SE** - Southeast

**SaskPower** – Saskatchewan Power Corporation

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[2] SaskPower's fiscal year runs from January 1 to December 31.

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[10] **http://www.economy.gov.sk.ca/PR-IC11**

[11] Pan Canadian was a subsidiary company of Canadian Pacific Railway until it merged with Alberta Energy Company in 2002 to form EnCana Corporation, an independent oil and gas corporation. In December 2009, Cenovus Corporation split from EnCana to operate as an independent integrated oil company, including all of the oil assets from the original firm. EnCana continues to operate the natural gas assets of the original firm and is a leading independent Canadian natural gas producer.

[12] Numac Energy Inc. was incorporated in Alberta in 1971 and was an independent oil producing company until it was purchased by Anderson Exploration Inc. in early 2010. Anderson was subsequently purchased by Devon Energy (USA) to form Devon Canada Corporation in late 2010. Numac, in partnership with Nexen Inc., operated a $CO_2$–EOR pilot at its Elswick Midale oil leases in 2001 using trucked $CO_2$ from the Air Liquide plant in Medicine Hat, Alberta. It ultimately decided not to proceed with full-scale operation of $CO_2$–EOR due to various technical issues it encountered during the pilot as well as poor economics due, in part, to the lack of a pipelined source of $CO_2$. The Elswick oil field is one of many potential $CO_2$–EOR targets in SE Saskatchewan.

[13] **http://www.economy.gov.sk.ca/adx/aspx/adxGetMedia.aspx?DocID=10290,10289,3384,5460,2936,Documents&MediaID=26122&Filename=SPRI+$CO_2$+Pilot+Injection+Test.pdf**

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[22] Beliveau, D. A. (1987, November 1). Midale $CO_2$ Flood Pilot. Petroleum Society of Canada. doi:10.2118/87–06-05

[23] The Midale and Weyburn oil fields are operated in the same geological formation, along with several surrounding oil leases/operations. Each of the two oil fields is owned by approximately 30 owners but each field was "unitized" in the 1960s to support water flooding infrastructure investment. Each unitized oil field is operated by one major oil company on behalf of the owners. Pan Canadian was an owner of part of the Midale oil field and consequently had access to the $CO_2$–EOR pilot program undertaken by Shell Canada.

[24] **http://www.dakotagas.com/$CO_2$_Capture_and_Storage/Pipeline_Information/index.html**

[25] Apache Canada began a commercial $CO_2$–EOR flood at Midale in 2006 using approx. 1800 tonnes per day of $CO_2$ supplied by DGC. At that time Apache Canada contributed data and sponsorship to the renamed IEAGHG Weyburn-Midale $CO_2$ Monitoring and Storage Project.

[26] Hitchon, Brian (Editor), 2012. Best Practices for Validating $CO_2$ Geological Storage: Observations and Guidance from the IEAGHG Weyburn Midale $CO_2$ Monitoring and Storage Project. Chapter 1. Updated data from Cenovus and PTRC as of 2014.

[27] Approximately one-third of the $CO_2$ injected in a given oil production cycle is "lost" to the reservoir. The uncertainty prior to the IEAGHG Weyburn $CO_2$ Monitoring Project beginning its work was, "Where does the $CO_2$ go?"

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