

PETROLEUM TECHNOLOGY RESEARCH CENTRE
2016-2017 ANNUAL REPORT

**THE PTRC ADVANTAGE
MOVING COLLABORATIVE
R&D TO THE FIELD**



The Petroleum Technology Research Centre (PTRC) was founded to facilitate R&D and field trials of innovative enhanced oil recovery technologies, with the dual goals of improving recovery rates and efficiencies from challenging oilfields while reducing the environmental footprint of extraction. Since 2000, the PTRC has also been a world-leader in demonstrating carbon dioxide utilization and storage – including CO₂ for enhanced oil recovery and CO₂ storage in deep sandstone and brine formations. 2018 marks the 20th anniversary of the foundation of the PTRC.

MISSION

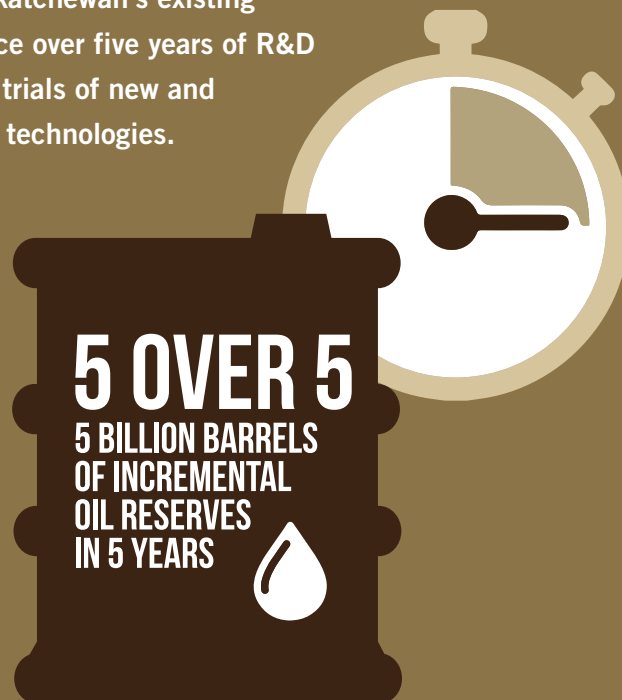
It is the PTRC's mission to initiate and deliver research programs to increase oil and gas reserves and production in Saskatchewan

VISION

PTRC seeks to be the organization of choice for collaborative petroleum research in Saskatchewan and Canada

THE FUTURE

The PTRC will realize 5 billion additional barrels of oil reserves from Saskatchewan's existing oil-in-place over five years of R&D and field trials of new and improved technologies.



LETTER FROM THE PRESIDENT AND CEO



I came to lead the PTRC in May of 2017, and while this 2016-17 Annual Report covers activities from before my arrival, the successes it highlights are ongoing and the starting point for the directions I see the company heading in 2018 and beyond. PTRC will be celebrating its 20th anniversary in 2018, and a quick review of its successes since 1998 has left me enthusiastic about the possibilities for our next twenty years.

When PTRC was founded back in 1998 its principal focus was, and remains, improving oil and gas recovery from Saskatchewan's (and Canada's) sometimes difficult-to-access heavy and tight oil deposits. Under my direction, the PTRC will continue this focus with renewed vigour, but with an additional awareness of the need to advance emerging technologies that mitigate emissions and lessen impacts on surface disturbance and fresh water.

This Annual Report highlights the significant economic impact PTRC research has had in such areas as the use of solvents and CO₂ in enhanced oil recovery (Husky Energy's Edam oil recovery project in the Lloydminster area would not have been possible without the PTRC's JIVE program). Projects in the Heavy Oil Research Network (HORNET) continue to investigate the challenges facing the

province's oil producers in areas like post-CHOPS heavy oil recovery and enhanced waterflooding. A new research program with a focus on tight/light reservoirs (in southwestern and southeastern Saskatchewan) is expected to lead to improved operating efficiencies, lower costs and improved oil and gas recovery.

2016-17 saw the Aquestore project achieve an important milestone, with over 100,000 tonnes of CO₂ injected from SaskPower's Boundary Dam Carbon Capture Facility into a deep saline formation. This achievement meant that the project's comprehensive seismic testing program kicked into high gear, imaging the CO₂ plume in the subsurface to a depth of 3.2 kilometres. The seismic runs at the Aquestore site used several imaging technologies that are leading edge – distributed acoustic sensing (DAS) and vertical seismic profiling (VSP) – to compare with results generated from the permanent seismic array of 650 geophones at the site. The ability to use these different imaging technologies has drawn new sponsors from the oil & gas and mining industries to the program. The Aquestore site is the most comprehensive field testing facility in the world for studying CO₂ injection and storage in a deep reservoir environment.

Heading into the next five years, the PTRC has set the

ambitious goal of conducting research and development in a broad range of Saskatchewan-based oil and gas fluid systems in concert with field trials of new technologies. The goal is to support technologies that, if successfully commercialized, could lead over the next five years to producing up to five billion barrels of additional oil from Saskatchewan's existing 50 billion barrels of oil-in-place. We call this our 5 over 5 strategy. With recovery rates in the Lloydminster heavy oil region, and the tight/light reservoirs in the Bakken/Viking ranging from 2-10% of the original oil in place, demonstrating technologies that improve operating efficiencies of production and increase oil recovery by a reasonable and achievable 10% will positively and substantially impact the economic bottom-line of the province. All of this will be done with strict stewardship to mitigate and manage the environmental impact of our industry.

I am pleased to be heading an organization of professionals that networks the finest researchers with leaders from industry and government. The PTRC's next five years look exciting.

A handwritten signature in dark ink, appearing to read 'Dan MacLean'.

Dan MacLean
CEO and President, PTRC

LETTER FROM THE CHAIR



At the end of fiscal year 2016-17 the PTRC said farewell to its former CEO – Mr. Ken From, who left to become the CEO of SaskEnergy – and welcomed Mr. Dan MacLean, who took the helm of the organization in May of 2017 with a renewed focus of supporting technologies geared to improving oil and gas recovery and operating efficiencies in Saskatchewan and Canada.

Dan comes to us from a previous position as the CEO to Tundra Energy in Manitoba, and a long, distinguished career with Chevron that took him to oil fields and operations around the world. His understanding of reservoir engineering, geology, and the challenges faced by upstream operators, is proving to be a boon to the PTRC. With the support of the PTRC Board, Dan will work with his staff and the world-class stable of researchers and operators in Saskatchewan to expand on the rich history of laboratory R&D with a move to supporting field trials. These trials are required to de-risk new oil and gas recovery schemes in complex geologic architectures while monitoring and managing the environmental impact of each new scheme.

PTRC continues to act as a facilitator and network manager between leading researchers, governments and companies to find solutions to

the most pressing challenges in the oil and gas industry. Its continuing work with the Aquistore project – not just the measurement and monitoring of injected CO₂ near the Boundary Dam Carbon Capture Facility, but the deployment of innovative technologies to do so – is proving to be important not just for the carbon capture and storage community, but for different kinds of industries interested in mapping the subsurface.

The approved projects in the Heavy Oil Research Network (HORNET) in 2016-17 ranged from the examination of different solvents and surfactants to enhance oil recovery to understanding at a microporous level the ways that foamy oil forms during CHOPS recovery from heavy oil reservoirs. This latter project, which included collaborating with the Synchrotron at the Canadian Light Source in Saskatoon, holds enormous potential for developing new recovery methods that could significantly increase recovery rates from existing wells in the Lloydminster area.

Dan and his staff at the PTRC are working diligently on directing new potential sources of funding towards field trials and additional laboratory R&D. The PTRC has identified as its goal over the next five years to realize 5 billion more barrels of incremental oil reserves from Saskatchewan's existing

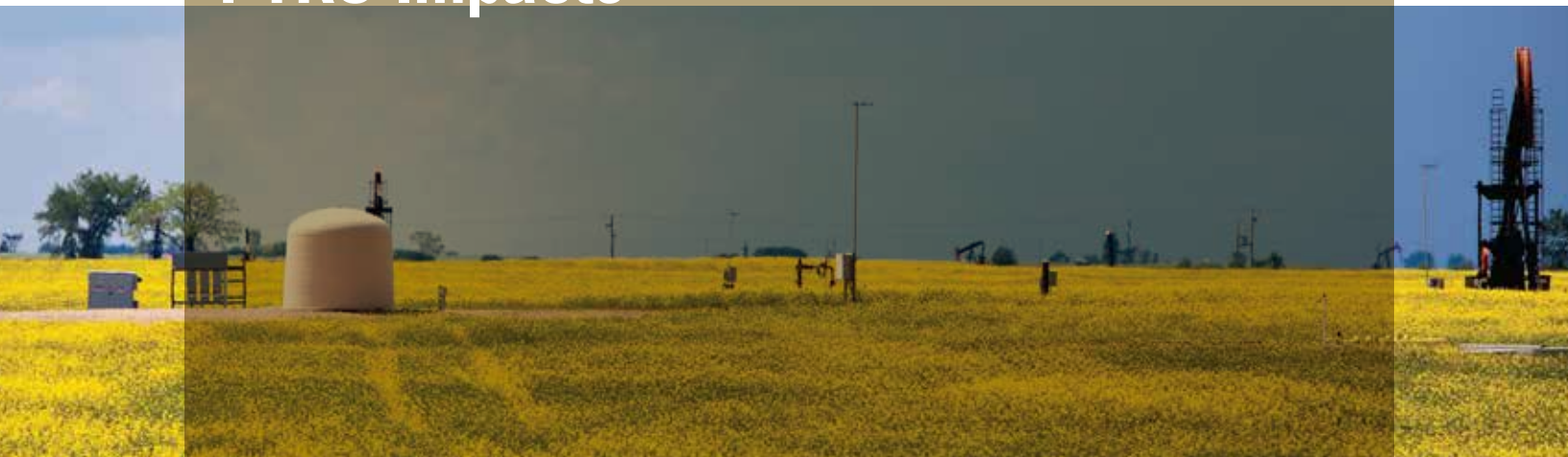
oil-in-place (5 over 5 strategy). An ambitious target, but one that's been set precisely because of the PTRC's past success and willingness to meet challenges head-on.

The future of the organization looks bright, and I'm pleased to support the efforts of PTRC's staff and extended network of research organizations to achieve their goal.

A handwritten signature in dark ink, reading "Brian Watt".

Brian Watt
Chair, PTRC Board of Directors

PTRC Impacts



CO₂ pipeline arriving at the Weyburn plant.



Cover of Weyburn results from the IJGGC.



IEAGHG WEYBURN-MIDALE CO₂ MONITORING AND STORAGE PROJECT

This 15-year, \$80 million field study to measure, monitor and verify the CO₂ being injected as part of CO₂-enhanced oil recovery at the Weyburn and Midale oil fields in southern Saskatchewan provided the confirmation of safety and storage monitoring that validated the ongoing operation of these fields.

PTRC's research into areas such as wellbore integrity, soil-gas and ground water monitoring, 4D seismic imaging, modeling and history matching of data contributed towards the oil field operators maintaining efficient and safe operations.

PTRC has become a world-leader in developing measurement, monitoring and verification plans for oil field operators thinking of injecting CO₂ and other solvents for enhanced oil recovery.

The Weyburn-Midale research led to over 300 peer-reviewed articles by researchers from around the world, the publication of a Best Practices Manual offering guidance for storage and utilization of CO₂ in depleted oil reservoirs, and a special supplement of technical papers in the International Journal of Greenhouse Gas Control (IJGGC).

The results from Weyburn-Midale continue to inform other CO₂ storage and CO₂-EOR projects worldwide.

Incremental oil production at the Weyburn and Midale oilfields will eventually surpass 220 million additional barrels of oil. The chart below demonstrates the economic impact of that increased recovery, which would not have been possible without PTRC-funded research confirming the safety of CO₂ storage. The figures below do not include the impact of jobs created, both direct and indirect, and taxes paid to different levels of government.

	WEYBURN FIELD	MIDALE FIELD
Original oil in place	1.4 billion barrels	515 million barrels
Oil recovery (pre-CO₂-EOR)	370 million barrels	154 million barrels
Projected CO₂-EOR	+155 million barrels	+67 million barrels
Increase in Recovery Rate	26% to 38%	30% to 43%
Projected CO₂ stored	35+ million tonnes (gross) 28+ million tonnes (net)	10+ million tonnes (gross) 8.5+ million tonnes (net)
Economic Value of Oil (\$60/bbl)	\$9.3 Billion	\$4 billion
Estimated Royalties to Province	\$1.86 Billion	\$800 Million



The physical model at the Saskatchewan Research Council's Energy Division remains a key tool for modeling oil reservoirs.



Husky's Edam JIVE pilot led to further field application of solvent injection.

JOINT IMPLEMENTATION OF VAPOUR EXTRACTION (JIVE) DEMONSTRATION PROJECT

This four-year, \$40 Million initiative involved three separate solvent vapour extraction field trials near Lloydminster involving Husky, CNRL and Nexen. The field demonstrations were supplemented with well-defined laboratory studies arranged by PTRC through the Saskatchewan Research Council that included scaled and mechanistic physical modeling and numerical simulations using real field data. The impacts of temperature, pressures and solvent concentrations were all studied.

All operations in the JIVE field trials experienced an increase in oil production, and Husky's field achieved high solvent recovery with the oil. The field trials were environmentally important for the heavy oil industry because solvent extraction uses less steam and heat, resulting in fewer greenhouse gas emissions during recovery.

JIVE informed Husky's decision to move forward with its solvent injection pilots at its Edam and Mervin fields, and the CO₂-injection demonstrations at Lashburn and Pikes Peak South. Construction jobs for these projects surpassed 500 over three years, and dozens of permanent operational positions were created. 1.8 million barrels of incremental oil were produced in the first two years of Pikes Peak pilot operations, with accompanying royalties to governments realized from these operations.

THE LARGEST FIELD LABORATORY IN THE WORLD FOR STUDYING CO₂ STORAGE AND OTHER ASPECTS OF THE DEEP SUBSURFACE

PTRC continues to move research to the field with the Aquistore CO₂ monitoring and storage research site. Aquistore consists of injection and observation wells – drilled to 3400 metres and rigged with extensive monitoring equipment – and numerous other monitoring technologies such as a 650-geophone permanent seismic array, DAS and DTS fibre-optic lines, tiltmeters, GPS and other monitoring equipment.

The field location is being used not just to measure the CO₂ being injected into a deep brine and sandstone formation, but by mining and oil/gas companies to test various technologies and their abilities to image the subsurface. Aquistore will be continuing its measurement and monitoring program over several years as CO₂ totals increase underground, and the extensive database of collected results will have a global impact on the development of carbon capture and storage regulations.



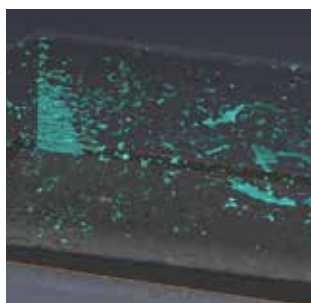
Injection well at Aquistore.



Aquistore field location as seen from above, with geophone array indicated.



Heavy Oil Research Network (HORNET)



HEAVY OIL RESEARCH NETWORK (HORNET)

The PTRC's Heavy Oil Research Network (HORNET) builds on over 20 years of demonstration field trials and research results by one of the world's leading enhanced oil recovery (EOR) organizations.



PILOT INNOVATIVE TECHNOLOGIES AND CONDUCT R&D THROUGH LEVERAGED GOVERNMENT FUNDING

The HORNET program leverages funding from different levels of government (including the Government of Canada and Innovation Saskatchewan) with industry participation to conduct field trials and R&D in key areas that will improve recovery rates in heavy oil reservoirs. Low recovery is a global problem for heavy oil but is of particular concern for Western Canadian reservoirs, which produce significant amounts of sand during production that reduces reservoir pressures.

The structure of HORNET means that, for a minimal investment, industry is given equal access to millions of dollars in research results per year. Paid sponsors directly

shape the research program by participating in the Technical Advisory Group, which reviews all projects submitted during the program's request-for-proposals process.

TARGETED RESEARCH DRIVEN BY INDUSTRY CHALLENGES

The HORNET program sponsors research in these key areas to improve heavy oil recovery rates:

- Cold Heavy Oil Production with Sand (CHOPS) and post-CHOPS
- Solvent use (including CO₂-EOR)
- Waterflood and chemical flood optimization
- Development of surfactants, polymers and alkalis for enhanced recovery
- Improvement and optimization of thermal technologies such as steam-assisted gravity drainage (SAGD)
- Reservoir characterization including computer modelling of wormholes for better EOR

HORNET's lab and bench-scale focus is to move technological innovation quickly to field application. Field trial consortia are being proposed to deploy new solvent recovery and surfactant technologies,

building on the knowledge gained from PTRC's former solvent field trials. HORNET research providers include scientists from the Saskatchewan Research Council's Energy Division, the University of Regina's Petroleum Engineering Department, and the University of Saskatchewan. Collaborative research is encouraged with researchers at institutions worldwide.

HORNET'S LIBRARY OF RESEARCH RESULTS

Enhanced oil recovery research sponsored by the PTRC has led to an extensive library of research papers. This library, which includes research conducted from 2000 to present, is a rich resource of enhanced oil recovery data and results. The databases managed by PTRC also include a link to hundreds of research papers that have been presented at the International Energy Agency Enhanced Oil Recovery's Annual Symposiums. Passwords to some of these materials are available from PTRC, with some results requiring sponsorship for access. Please contact PTRC if you have any queries.

The PTRC libraries are located at <https://steps.ptrc.ca/>



Light and Tight Oil



LIGHT & TIGHT OIL

The Petroleum Technology Research Centre is a not-for-profit company committed to R&D and field trials of innovative technologies to improve the efficiency and recovery rates of Canada's oil reserves. PTRC operates by leveraging government funding with industry (in-kind and cash) support, to develop research and field trials that directly address the most pressing challenges facing operators.

The Bakken and other tight hydrocarbon plays in Saskatchewan, Alberta, Manitoba, Montana and North Dakota are increasingly important for Canadian and North American energy self-sufficiency. The PTRC's

tight oil research and field trial program is seeking industry partners with an interest in developing innovative processes and technologies for demonstration.

Tight oil plays like the Bakken and the Viking formation (in southwestern Saskatchewan) also carry significant technological challenges, especially very steep declines in production and low recovery rates. PTRC is directing an industry-driven research program including field trials that will address the most pressing challenges facing producers.

PROPOSED AREAS OF RESEARCH

The PTRC's tight oil program is examining a number of potential demonstration and R&D projects:

- In the Bakken: CO₂ enhanced oil recovery trials examining how hydraulically fractured wells respond to CO₂ utilization.
- In the Viking: Surfactant development and modification, moving to field trials to improve recovery rates from declining wells.

- Alkali utilization to promote in-situ surfactant formation and interfacial tension reduction to achieve higher reservoir sweep efficiency.

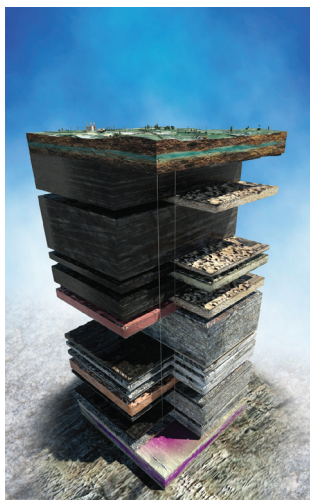
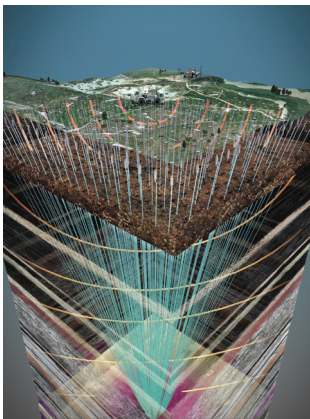
LEVERAGING RESEARCH DOLLARS AND FACILITIES

The PTRC receives funding from Innovation Saskatchewan to develop tight oil R&D and demonstration projects. \$500,000 in leverageable funds are currently available, in addition to PTRC's access to Government of Canada programs on behalf of industry partners.

PTRC works with a network of leading researchers from universities, the Saskatchewan Research Council and international research providers, to develop bench-scale and laboratory testing to optimize field demonstrations. Western Economic Diversification recently provided funding to PTRC for the installation of a high-resolution North Star Imaging X5000™ industrial X-ray CT-scanner at the Saskatchewan Research Council's Energy Division Lab. Starting in 2018, this equipment will be used to provide images of Bakken and other tight formation core samples at the micropore level.



Aquistore



AQUISTORE

PTRC's Aquistore Project is an independent research and monitoring effort studying the injection and storage of carbon dioxide (CO₂) from SaskPower's Boundary Dam Carbon Capture Facility into the Deadwood sandstone formation at a depth of 3.2 km beneath the surface of southeastern Saskatchewan.

Aquistore has been receiving carbon dioxide intermittently since 2015, and the stop-and-start nature of the injection makes the project of particular interest to industries planning to capture CO₂ for sale to third parties and in need of buffer storage when markets are not available. Most of the CO₂ captured from Boundary Dam is sold to nearby oil fields for enhanced oil recovery, but the Aquistore injection well acts as disposal when those oil fields are unable to take the produced CO₂.

As governments develop environmental regulations governing CO₂ storage, the research findings and monitoring activities at Aquistore will prove crucial for demonstrating CO₂ containment and permanent storage for regulators.

WHY AQUISTORE?

PTRC has over fifteen years of project experience at measuring, monitoring and verifying carbon dioxide storage in a depleted oil field through the IEAGHG Weyburn-Midale CO₂ Monitoring & Storage Project (2000-2015). Aquistore's research program was developed by a scientific and engineering research committee (SERC) made up of many of the same world-leading experts who developed the Weyburn Project.

Aquistore has four main aims:

- to advance surface and subsurface CO₂ monitoring technologies
- to advance our understanding and mitigate uncertainties of long-term stored CO₂
- to demonstrate CO₂ storage in deep saline formations as a permanent, safe and viable strategy to reduce emissions
- to reduce operational costs for emerging commercial CCS operations via Aquistore's integration in an industrial-scale, full-chain CCS project

THE LARGEST FIELD LABORATORY IN THE WORLD FOR MONITORING CO₂ UNDERGROUND

Located near the community of Estevan, Saskatchewan, Aquistore is a \$30 million multi-dimensional, full-scale geological field laboratory and the most extensive collection of measurement and monitoring technologies ever assembled for the examination of injected CO₂.

The project drilled two state-of-the-art 'smart' wells in 2012 - an injection and an observation well located 150m apart. An extensive risk assessment and public engagement process informed the project development, and over 30 monitoring technologies are now collecting real-time data as CO₂ injection progresses. The project is also making significant strides in the validation of predictive long-term modelling and those models are compared with incoming data to verify the CO₂ is behaving as predicted.

AQUISTORE MEASUREMENT AND MONITORING TECHNOLOGIES

	SURFACE	SHALLOW SUBSURFACE	DOWNHOLE INSTRUMENTATION	SEISMIC
MONITORING TECHNOLOGIES	Tiltmeters	Piezometers	Fibre-optic distributed temperature systems (DTS)	Cross-well seismic tomography
	inSAR satellite interferometry	Groundwater chemistry monitoring	Fibre-optic distributed acoustic systems (DAS)	Broadband seismography
	Electromagnetics	Soil-gas monitoring	Fluid recovery system	Permanent 650 geophone areal seismic array
	GPS	Multi-species atmospheric surveys	Pressure gauges	Time-lapse 3D seismic imaging
	Gravimeters		Temperature gauges	Continuous passive microseismic monitoring
	Inherent tracers		Pulsed neutron decay (PND) and cross dipole sonic logging	Vertical seismic profiling (VSP)
			Borehole gravity	Accurately controlled, routinely operated signal system (ACROSS)
PURPOSE OF MONITORING	Surface deformation	Ground water and soil changes	Geophysical logging to measure changes from injection	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	



AQUISTORE MEMBERSHIP

The field laboratory at Aquistore has drawn international sponsorship to gain access to data and results from the ongoing research program. This has included oil & gas companies, mining firms, universities, and research companies interested in the deep subsurface, even beyond the measurement of CO₂. Aquistore welcomes new sponsorship to continue its work and expand its areas of research.

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COLLABORATIONS

Australian National Low Emissions Coal
R&D (ANLEC)

Battelle National Laboratory

British Petroleum

Canadian Natural Resources Ltd

Canadian Light Source

Carbon Capture Project (CCP4)

Chevron

Commonwealth Scientific and
Industrial Research Organisation
(CSIRO)

Consumers Co-operative Refinery
Limited

Devon Canada

Deep Earth Energy Production (DEEP)

Enbridge

Energy and Environmental Research
Centre (EERC)

EV Canada

ExxonMobil

FMC Technologies

GeoForschungsZentrum (GFZ)

Geological Survey of Canada

Global Carbon Capture and Storage
Institute

Golder and Associates

GroundMetrics

Harris Corporation

Husky Energy

IEAEOR

IEAGHG

Illinois Basin – Decatur Project

Illinois State Geological Survey

Innovation Saskatchewan

Institut national de la recherche
scientifique (INRS)

International CCS Knowledge Centre

Japan Oil, Gas and Metals National
Corporation (JOGMEC)

Korea National Oil Corporation (KNOC)

Lawrence Berkley National Lab

Midwest Geological Sequestration
Consortium

Mosaic

Natural Resources Canada

The Netherland's Association for
Applied Research (TNO)

Optasense

Outerlimits Geophysics

OYO Corporation (Japan)

Perm Inc.

Prairie CO₂ Reduction Partnership
(PCOR)

Research Institute of Innovative
Technology for the Earth (RITE)

Saskatchewan Geological Survey

Saskatchewan Ministry of Environment

Saskatchewan Ministry of the Economy

Saskatchewan Research Council

SaskEnergy

SaskPower

Schlumberger Carbon Services

Scintrex

Scottish CCS

Silixa

South African National Energy

Development Institute (SANEDI)

South African Centre for Carbon

Capture and Storage (SACCCS)

St. Francis Xavier University

Sustainable Development Technologies
Canada (SDTC)

TIPM Laboratory

TRE Altamira

UK CCS Research Centre

United States Department of Energy
(USDOE)

University of Alberta

University of Bristol

University of Calgary

University of Manitoba

University of Ottawa

University of Regina

University of Saskatchewan

University of Strathclyde

University of Texas Bureau of Economic
Geology

Weatherford

Western Economic Diversification
Canada

