Clean Energy, 2022, 883–890

https://doi.org/10.1093/ce/zkab056
Homepage: https://academic.oup.com/ce

Clean Energy Research Centre Profile

CO_2-capture research and Clean Energy Technologies Research Institute (CETRI) of University of Regina, Canada: history, current status and future development

Paitoon (PT) Tontiwachwuthikul[1,*], Malcolm Wilson[1] and Raphael Idem[1]

[1]Clean Energy Technologies Research Institute, University of Regina, Regina, Saskatchewan, Canada

*Corresponding author. E-mail: paitoon@uregina.ca

Summary

Clean Energy Technologies Research Institute (CETRI) was formerly known as the International Test Centre for CO_2 Capture in the early 2000s. The original focus of the centre was to help lower the carbon intensity of the current energy sources to low-carbon ones in Canada. Currently, CETRI's mandates have expanded and now include most of the low-carbon and near-carbon-free clean-energy research activities. Areas of research focus include carbon (CO_2) capture, utilization and storage (CCUS), near-zero-emission hydrogen (H_2) technologies, and waste-to-renewable fuels and chemicals. CETRI also brings together one of the most dynamic teams of researchers, industry leaders, innovators and educators in the clean and low-carbon energy fields.

Graphical Abstract

Home of CO_2 capture research and Clean Energy Technologies Research Institute (CETRI), University of Regina, Canada.

Received: 11 November 2021; **Accepted:** 13 November 2021

History

In the late 1980s, the government of Saskatchewan commissioned its Department of Energy and Mines to look into the large source of CO_2 for enhanced oil-recovery (EOR) operations. The major objective was to extend the operations of the Weyburn Oil field [1]. This event was one of the origins of major CO_2-capture research in Canada. As a result, the department worked closely with the University of Regina (UR)'s Energy Research Unit to set up a small CO_2 research group within the University of Regina's engineering in the early 1990s [2] (Fig. 1). In 1997, Canada signed up to and joined the Kyoto Protocol for climate change in order to reduce carbon emissions. This was the key factor that enabled us to create the International Test Center for CO_2 Capture (ITC), Petroleum Technology Research Center (PTRC) and Weyburn International Energy Agency (IEA) carbon capture and storage (CCS) programme (Fig. 2), which is still one of the world's largest carbon capture and storage (CCS)-enhanced oil recovery (EOR) projects.

Early development

In the early 2000s, the centre acquired a number of major grants and supports from both provincial and federal governments to build major facilities for CO_2-capture research for western Canada (Fig. 3). The key supporters were the Saskatchewan Ministry of Energy & Resources, Western Economic Diversification, Natural Resources Canada, Natural Sciences and Engineering Research Council of Canada (NSERC) and Canada Foundation for Innovation (CFI) (Fig. 4). One of these major grants was $5.6 million to build the Greenhouse Gas Building to host the International Test Center for CO_2 Capture (Fig. 5), which has been renamed as CETRI. We also received $3 million extra to build the two pilot plants at the University of Regina and the Boundary Dam power plant to continue CO_2-capture research with industrial partners [3] (Fig. 6). The Boundary Dam pilot was a reconstruction of the pilot plant sponsored by Saskatchewan, the federal government and three oil companies to successfully test chemically based CO_2 capture from a coal-fired electrical generating station in 1988. We also secured a CFI grant of $4.5 million for many of the processes and analytical equipment in the centre.

Not only were the University of Regina and Ministry able to obtain funding for the pilots, the ITC building and equipment; they were also able to fund part of the construction cost of the PTRC building along with some laboratory equipment for the petroleum research. The PTRC became the lead research agency for the IEA GHG R&D Programme Weyburn CO_2 Storage Program.

This cooperation was an excellent example of government, academia and industry collaboration. As the government funded the capital investment to allow research to proceed, industry provided the operational funding for the research and demonstration work, and the University of Regina provided the research and analytic capability. The ITC operated for a number of years with this model and extensive international support.

Transformation into CETRI

In 2015, the ITC expanded its research and was renamed as the Clean Energy Technologies Research Institute (CETRI). CETRI was built from our past successes of CCUS research and now includes most of the low-carbon and carbon-free clean-energy research activities at the University of Regina. Areas of research focus include decarbonization and near-zero-emission hydrogen (H_2) technologies, carbon (CO_2) capture and utilization, and waste-to-renewable fuels and chemicals, bringing together one of the most dynamic teams of researchers, industry leaders, innovators and educators in the energy field.

At CETRI, we adopt a comprehensive approach to clean-energy research that includes feasibility and proof-of-concept studies, bench-scale and pilot-plant testing, process simulation and optimization, and pre-commercial demonstration. We offer technical, scientific and hands-on learning opportunities for existing and prospective researchers in a diverse and inclusive environment. Our labs and facilities are also utilized to provide analytical services to external clients. We not only develop our own technologies, but our labs, pilot facilities and expertise are utilized to test and analyse technologies developed by external clients (Fig. 7).

Cutting-edge breakthroughs in CO_2 capture

A recent energy report by the IEA stated that 'Reaching net zero will be virtually impossible without CCUS' [4]. Our new patented breakthroughs in catalyst-aided amine capture will, for the first time, enable CO_2 capture to be accomplished using hot water rather than steam, eliminating the need to divert steam or energy from the primary purpose of a facility [5]. This means, for example, that all of the steam and most of the energy generated from a carbon-based electricity-generation plant will still be utilized for electricity production, with minimum carbon emissions. Conventional amine-based capture technologies require significant energy to be diverted for the capture operations [6].

This game-changing technology will dramatically lower the costs of post-combustion capture [7]. It is expected that this technology will, for the first time, achieve a reduction in the energy requirements and equipment size of amine-based CO_2-capture plants to a level at which a business case can easily be made for CCS to be implemented based on economic benefits rather than purely on environmental regulations (Fig. 8) [8, 9].

Fig 1: Fundamental research into CO_2 capture began at the University of Regina in the early 1990s.

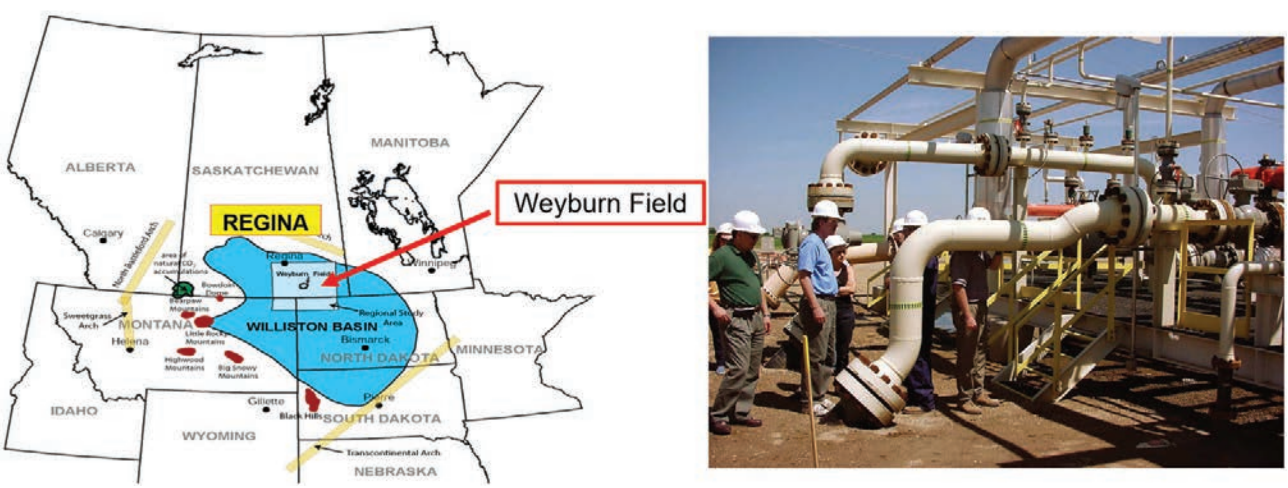

Fig 2: The IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project in Saskatchewan, Canada (the world's largest carbon capture for CCS and EOR programme) [1].

Fig 3: The original pilot plant for CO_2 capture at Boundary Dam, Saskatchewan, Canada [3].

Fige 4: Specially designed marble certificate from the Government of Canada and the Government of Saskatchewan to establish CO_2 research facilities at the University of Regina.

The ultimate achievement is that of simplifying operations and lowering costs to a point of breaking down the economic and implementation barriers to widespread deployment of CCS as a key technology for making large-scale reductions in CO_2 emissions.

Bridging into future clean energy and zero emissions …

Recently, we have also expanded into new areas and developed a number of exciting new research programmes in clean and green energy production. Among the most advanced of these programmes is a new pilot demonstration programme for catalyst-aided, feed-flexible, process-flexible hydrogen production (Fig. 9). This revolutionary technology utilizes a unique, patented catalyst to convert any feed fuel into clean-burning hydrogen. A portion of the CO_2 that is produced as a by-product during hydrogen production is actually recycled into the process, with the remainder being available for storage or used in secondary processes such as enhanced oil recovery. Fuels that can be used to produce hydrogen in this process include low-grade natural gas, biofuels (such as crude ethanol), biogas (such as waste gases from landfills) and a number of by-products of various industrial processes (such as glycerol) and fossil-oil by-products of fermentation processes.

Fig 5: CO_2-capture pilot-plant facilities and design space at CETRI.

Fig 6: Pre-commercial (indoor) capture demonstration plant (1 ton per day of CO_2 capture) equipped with gas turbine, gas boiler and state-of-the-art monitoring and control systems.

Most of these fuels represent unwanted by-products of existing industrial processes. Our technology will enable them to be used to produce hydrogen while capturing CO_2, all in a single plant and without disrupting existing plant operations or requiring a change in fuel sources. This is a remarkable step forward in enabling hydrogen to become a primary fuel in parts of the world where generating hydrogen from water through electrolysis is not feasible.

One of the practical ways to reach net-zero emissions is to use bioenergy together with carbon capture and storage as mentioned in IEA reports [4]. Over the next 5–10 years, this concept would and could lead us to achieve net-zero (or even negative) emissions when we use energy from carbon sources [10].

Past and current major research-and-development activities

- European CO_2 Test Centre Mongstad (2007–08): feasibility study and staff training of the world's first CO_2-capture demonstration project with Statoil (Norway).
- CO_2 capture from Gas Turbines (Pilot Testing and Process Optimization) (2009–10), supported by Shell International (The Netherlands).

Fig 7: Facilities at CETRI for clean-energy research that includes feasibility and proof-of-concept studies, bench-scale and pilot-plant testing, process simulation and optimization, and pre-commercial demonstration.

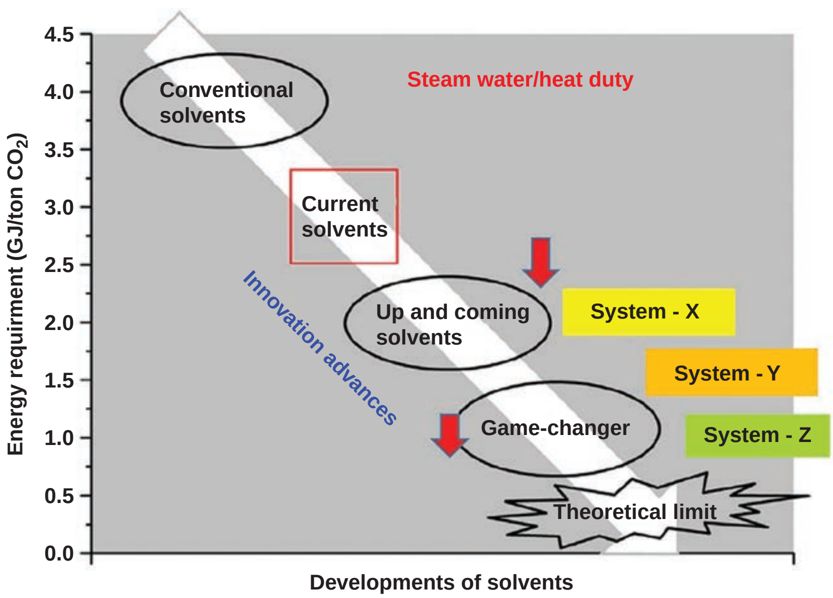

Fig 8: The energy requirement of post-combustion capture technologies from the past, present and future developments [9].

- Testing and evaluations of novel solvents for CO_2-capture technologies (2010–11), supported by Exxon (USA).
- Testing of commercially available solvents at the Multi-Purpose Technology Development CO_2 Capture Plant at the University of Regina (2008–09), supported by a research consortium of Suncor Energy (Canada), ConocoPhillips (USA) and Statoil (Norway).
- Testing and evaluations of the BD Pilot Plant for CO_2 Capture Processes (2010–11), supported by Doosan Power Systems (UK).
- Biogas Upgrading project (2012–15): development of separation technologies for improving the biogas separation process as a renewable energy replacing natural gas, supported by PTTPLC (Thailand).
- Advanced CO_2 Separation Technology Natural Gas Processing (2015–19), supported by Qatar National Research Fund (QNRF)—a member of Qatar Foundation (Qatar).
- CCUS Comprehensive Technical Training (2019) for SINOPEC (China).
- Development of Advanced Solvents for Modular Carbon Capture Units (currently in operations) for Entropy Inc. and its consortium (Alberta, Canada).

Key awards and recognitions

- 2006 Synergy Award for Innovation from NSERC (Fig. 10).
- 2008 Award of Innovation, Saskatchewan Innovation Place, for Carbon Capture Research.
- Top Researchers in Carbon Capture, Usage and Storage Technologies (2020), recognition by Fairforce of Finland.

Fig 9: 3D rendering of the new hydrogen pilot plant to be housed in the same facility as the CO_2 capture.

Fig 10: The CO_2 research team at ITC (precursor of CETRI) was recognized nationally with the Natural Sciences and Engineering Research Council's prestigious Synergy Award for Innovation in 2006.

- One of Top-ten Cited Articles in 2018–2019 in *International Journal of Greenhouse Gas Control* by Elsevier [9].

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We would like to acknowledge the research support over the past many years to build these research facilities at CETRI. These major infrastructure supports were obtained from the following organizations: Government of Canada, Provincial Government of Saskatchewan, NSERC, CFI, Saskatchewan Ministry of Energy & Resources, Western Economic Diversification, Natural Resources Canada and Saskatchewan Power Corporation.

References

[1] Brown K, Whittaker S, Wilson M, *et al*. The history and development of the IEA GHG Weyburn-Midale CO_2 Monitoring and Storage Project in Saskatchewan, Canada (the world largest CO_2 for EOR and CCS program). *Petroleum*, 2017, 3:3–9.

[2] Tontiwachwuthikul P. Research and development activities on high efficiency separation process technologies for carbon dioxide removal from industrial sources at University of Regina, Canada. *Energy Conversion and Management*, 1996, 37:935–940.

[3] Idem R, Wilson M, Tontiwachwuthikul P, *et al*. Pilot plant studies of the CO_2 capture performance of aqueous MEA and mixed MEA/MDEA solvents at the University of Regina CO_2 capture technology development plant and the boundary dam CO_2 capture demonstration plant. *Industrial & Engineering Chemistry Research*, 2006, 45:2414–2420.

[4] International Energy Agency. *CCUS in Clean Energy Transitions*. Paris: IEA, September 2020. https://www.iea.org/reports/ccus-in-clean-energy-transitions (3 November 2021, date last accessed).

[5] Idem R, Shi H, Gelowitz D, Tontiwachwuthikul P. *Catalytic method and apparatus for separating a gaseous component from an incoming gas stream*. United States Patent US; 9,586,175B2. 7 March 2017.

[6] Tontiwachwuthikul P, Idem R. *Recent Progress and new Developments in Post-Combustion Carbon-capture Technology with Reactive Solvents*. London: Future Science Limited, 2013.

[7] Liu H, Idem R, Tontiwachwuthikul P. *Post-combustion CO_2 Capture Technology: By Using the Amine Based Solvents*. Cham: Springer International Publishing, 2019.

[8] Liu H, Tantikhajorngosol P, Chan C, Tontiwachwuthikul P. Technology development and applications of artificial intelligence for post-combustion carbon dioxide capture: Critical literature review and perspectives. *International Journal of Greenhouse Gas Control*, 2021, 108:103307.

[9] Liang ZH, Rongwong W, Liu H, *et al*. Recent progress and new developments in post-combustion carbon-capture technology with amine based solvents. *International Journal of Greenhouse Gas Control*, 2015, 40:26–54.

[10] Kemper J. Biomass and carbon dioxide capture and storage: a review. International. *Journal of Greenhouse Gas Control*, 2015, 40:401–430.