Author: Kelly Atkinson
Date: 18 November 2024

Net Zero Emissions Steel R&D: Carbon Capture, Utilization, and Storage

CISERA

Background

In response to the CSPA call for climate action (Canada's Steel Industry: A Sustainable Choice), CCRA has developed a research program to address the technical challenges in achieving net-zero emission steel production by 2050 (New Era for CCRA). In the CCRA research program, activities are categorized into 5 pillars for promoting collaboration between research groups and with industrial partners. Carbon capture, utilization, and storage (CCUS) is one of the R&D pillars.

Most steelmaking facilities in Canada are transitioning from the conventional blast furnace-basic oxygen furnace (BF-BOF) production route to electric arc furnaces (EAF), sometimes coupled with direct reduced iron (DRI) production upstream. Transitioning to DRI-EAF has the potential to reduce steelmakers' CO_2 emissions by up to 68%; CCUS is one tool available to eliminate the remainder and attain net-zero. While post-combustion CCUS technologies have been developed commercially for application in industries such as power generation, they are not currently compatible with the dynamic nature of some of the process gas streams from steelmaking, particularly from the EAF. Research and development of new candidate carbon capture technologies is required to be able to apply CCUS to the EAF and achieve net-zero by 2050. Development of CO_2 utilization technologies, as well as de-risking of CO_2 transportation and storage, will be required to enable Canadian steelmakers to pursue these decarbonization strategies with confidence.

Goal Statement

- Create a technology roadmap and decarbonization strategy for hard-to-abate CO_2 emissions from Canadian iron and steel production
- Advance the technology readiness level of priority emerging carbon capture technology(ies) to TRL6 for dynamic applications
- Demonstrate how application of CCUS for iron and steel production fits into the bigger picture of decarbonization of Canada's industry via CCUS and hydrogen production/utilization
- Advance the development of CO_2 utilization technologies
- Address key knowledge gaps in CO_2 transportation safety, geological storage in Central and Eastern Canada, and quantification of CO_2 emissions from storage wells

Specific Objectives

- Develop a model of the EAF in order to generate off-gas profiles for different operating scenarios, including different iron supplies (scrap, conventional DRI, H_2-CRI, etc) and different carbon charge sources (fossil fuels, bio-based fuels)
- Evaluate 2-3 candidate carbon capture technologies via bench-scale testing, including fixed bed chemical looping and inertial CO_2 separation
- Develop tools to predict the cost and environmental impact of CO_2 capture/removal, transportation, utilization, and storage Canada-wide for various scenarios
- Develop CO_2 utilization processes in the areas of conversion and mineralization with higher efficiencies and lower energy consumption than existing conversion and mineralization technologies

Projects Overview

Dynamic Carbon Capture for Iron and Steel Production

Electric Arc Furnace Model Development

Knowledge of the off-gas properties from the EAF is required to be able to design, model and test suitable carbon capture technologies. The project will acquire representative operating data from Canadian EAF facilities (off-gas composition, flow, temperature, and pressure vs. time); build a stochastic model to predict EAF off-gas based on operating data for various operational archetypes; and evaluate how EAF off-gas properties will be affected through the use of biogenic reductants in the EAF.

Screening of Candidate Carbon Capture Technologies

A literature review will identify technologies that have the potential to meet the needs of the EAF. Membrane separation, fixed bed chemical looping, and inertial separation of CO_2 have all been shortlisted for evaluation at this stage, with more to be added as they are discovered or conceived. The strongest candidates will be evaluated by building detailed optimized process simulations and conducting techno-economic and life cycle assessment (TEA-LCA) in order to down-select 2-3 technologies for evaluation with bench-scale testing.

Fixed Bed Chemical Looping Technology Development

Fixed bed chemical looping (CL) is an oxy-fuel process with the potential for turn-down that can meet the needs of the EAF. It can be applied to buffer the oxygen from the EAF off-gas stream during oxidizing periods and recover energy during reducing periods. The resulting CO_2 stream will be concentrated (compared energy recovery *via* air-fired combustion), allowing this technology to be effectively paired with further CO_2 capture/purification technologies to meet the product specifications required for transportation and storage. The projet will include building a detailed model of a CL reactor with EAF off-gas as the feed, followed by bench-scale testing and model validation with simulated EAF off-gas.

Inertial CO_2 Separation Technology Development

This technology uses supersonic nozzles to de-sublimate CO_2 from a gas stream, followed by a section that removes the solid CO_2 particles via centrifugal force. Within this project, a technology developed by a collaborator will be scaled up to 5 tonnes per day of CO_2 capture at CE-O and evaluated against the dynamic needs for carbon capture from the EAF.

Technology Roadmap for CCUS at Canadian Iron and Steel Facilities

This task is the synthesis of all modelling and experimental results from previous tasks to create clear and concise guidelines for policy development and dissemination of carbon capture knowledge to industry.

National CCUS Assessment Framework (NCAF)

This project supports the development of a strategy to implement CCUS in Canada in a cost-effective manner. It aims to develop rigorous datasets, network models, and tools that translate process, techno-economic, and life cycle/environmental data for carbon management into a clear, consistent, and accessible format. It will enable predicting the cost and environmental impact of CO_2 capture/removal, transportation, utilization, and storage in order to support development of technical guidelines, policy/market decision-making, infrastructure investment, and industry technology adoption.

Advanced CO_2 Utilization through Conversion and Mineralization

This project will develop CO_2 utilization processes in the areas of conversion and mineralization, with at least 5-10% higher efficiency and 10-15% lower energy use compared to the incumbent processes. One activity specifically targets optimization of aqueous-based CO_2 mineralization of metal slags.

Projects Overview

Investigation of Safety for Accidental CO_2 Release During Transport

Examine key leak scenarios; based on release-, terrain-, and wind-types; and model the resulting CO_2 dispersion to address the key questions:

1. Over what distance from the release is the threat to human health a concern,
2. Where should leak detection and monitoring devices be placed, and
3. What release mitigation measures should be employed?

Develop a tool for broad use by planners, regulators, and the public safety community that estimates the distance over which the threat to human health exists. Support planning and regulation of leak detection and release mitigation.

CO_2 Storage in SW Ontario and Eastern Canada

Address knowledge gaps in three key areas in support of geological CO_2 sequestration by

1. investigating the potential for CO_2 storage in oil and gas reservoirs and saline aquifers in Central and Eastern Canada, including offshore Atlantic reservoirs;
2. Carrying-out field work R&D in shallow reservoirs to better understand CO_2 migration in the shallow subsurface and to better understand the storage potential in basaltic rocks; and
3. Investigating wellbore leakage in abandoned oil and gas wells and developing options to mitigate leakage.

Advancement of Canadian Energy Sector Emissions Measurement, Reporting, Verification, and Mitigation

Investigate volatile organic compound losses due to weathering in storage tanks, methane emissions from de-pressurized energy products (including storage tanks, phase separators, recycled water streams) and develop a new method for real-time methane, carbon dioxide and volatile organic compound quantification from wells, reservoirs and other point-sources. Models will be developed for black carbon and benzene emissions from flares in the gas sector.

Project Team

Research Area	Canmet Lead
Dynamic Carbon Capture for Iron and Steel Production	Nicole Bond, CanmetENERGY-Ottawa nicole.bond@NRCan-RNCan.gc.ca
National CCUS Assessment Framework	Robert Symonds, CanmetENERGY-Ottawa Philippe Navarri, CanmetENERGY-Varennes robert.symonds@nrcan-rncan.gc.ca / philippe.navarri@nrcan-rncan.gc.ca
Advanced CO_2 Utilization through Conversion and Mineralization	Kourosh Zanganeh, CanmetENERGY-Ottawa kourosh.zanganeh@NRCan-RNCan.gc.ca
Investigation of Safety for Accidental CO_2 Release During Transport	Allan Runstedtler, CanmetEnergy-Ottawa allan.runstedtler@nrcan-rncan.gc.ca
CO_2 Storage in SW Ontario and Eastern Canada	David Ryan, CanmetENERGY-Ottawa david.ryan@nrcan-rncan.gc.ca
Advancement of Canadian Energy Sector Emissions Measurement, Reporting, Verification, and Mitigation	Brian Crosland, CanmetENERGY-Ottawa brian.crosland@nrcan-rncan.gc.ca