Achievement Highlights | 2022-2023

INDUSTRIAL SYSTEMS OPTIMIZATION PROGRAM

CanmetENERGY in Varennes

Advancing Science and Technology

Our team of scientists and engineers brings together a broad range of expertise and is uniquely positioned in Canada to tackle complex problems related to large-scale energy systems optimization, and to advance the development and adoption of technologies that support industrial decarbonization objectives.

Natural Resources Canada | Ressources naturelles Canada

Canada

MAIN SCIENTIFIC ACHIEVEMENTS

Harness the
power of AI
to unlock new levels of
optimization

Big Data and Artificial Intelligence

- **A novel approach for industrial control systems improvement** based on a combination of causal reinforcement learning, digital twinning, and optimization techniques was developed. This approach allows for the autotuning and supervision of local controllers, generating **15% in energy savings potential** for a heat recovery network in a thermomechanical pulping (TMP) mill.

- **An AI-assisted maintenance tool** based on predictive and prescriptive machine learning methods was developed and tested on a kraft pulp mill black liquor concentrator, resulting in improved process energy performance, reduced maintenance costs, and energy savings of up to 12%.

- A novel **data fusion approach** using polygon generation and deep learning (DL) techniques to solve the integration challenge of multi-source, multi-format and timeseries data of forest operations was developed. This approach allowed extracting higher levels of information from these datasets, which improved the harvesting wood volumes prediction accuracy from 52% to 89%, thus allowing better leverage of valuable data to optimize forest value chains.

Leverage **biomass** to provide **sustainable** and renewable resources and **lower GHG emissions**

Biomass Conversion

- In the context of unlocking the potential of **lignin as sustainable raw feedstock**, a solvent-free continuous catalytic hydrodeoxygenation conversion process of lignin into aromatic was developed. Preliminary results are promising, seeing as a selectivity of 87.5% toward aromatic hydrocarbons was achieved.

- A case study was performed to assess the **production of renewable diesel and/or aviation fuel** at industrial scale. It considered gasification with Fischer-Tropsch process (GFT) and hydrothermal liquefaction (HTL) as production pathways targeting a production of up to 740,000 litres of renewable fuels per day. The carbon intensities of GFT and HTL products were 38 g CO_2/MJ and 26 g CO_2/MJ, respectively.

- The benefits of using **biomass in industrial process** were demonstrated, with a potential GHG reduction of 15 million tonnes of CO_2-eq emissions annually. Using biomass in high temperature applications generating CO_2 emissions is especially promising, since it would allow for the generation of negative emissions credits when used with carbon capture technology.

CO_2 Capture, Utilization and Storage (CCUS)

- An industrial case study was carried out to assess the environmental and economic impacts of implementing a **Power-to-X** system (X stands for low carbon chemicals or fuels). Results demonstrated significant environmental benefits, enabling CO_2 emissions reduction from steel and methanol production processes by up to 57%.

- **Dimethyl ether (DME)** is an attractive product that can be utilized as an intermediate chemical or as an alternative fuel. Two **production pathways using captured CO_2 as feedstock** and the natural gas-based conventional route were modeled and compared from an energy, economic and environmental perspective. The direct CO_2-to-DME pathway, without the production of methanol as intermediate product, appeared to be an interesting alternative to CO_2 utilization in valuable product, consuming less natural gas than the conventional process at an attractive production cost.

- **Artificial intelligence and process knowledge were used to accelerate the sizing and costing of two solvent-based CO_2 capture technologies**. Machine learning-based surrogate models were trained on data generated by thousands of simulations to predict equipment sizing and process performance with errors of less than $\pm$10%, for a wide range of flue gas conditions and capture rates. Combined with our equipment costing model, the tool can predict design parameters, Capex, Opex and capture cost in seconds, and can be used to quickly and accurately estimate the cost of CO_2 capture for emitters across Canada.

- **Bioenergy with CCS (BECCS)** represents a unique opportunity for Canada to generate negative emissions from pulp and paper, cement and iron and steel operations. A complete model of an amine-based CO_2 capture plant, including the flue gas conditioning and CO_2 capture units, was developed for a typical Canadian kraft mill to establish the cost and the additional energy required to capture CO_2 from the recovery boiler, the power boiler and the lime kiln. A utility system analysis was conducted using our COGEN software to determine the most suitable energy source to supply steam to the capture unit.

Hydrogen Production and Use

> A harmonized system boundary and methodology was established to assess the environmental impacts of five **hydrogen production pathways** by conducting process simulations. These comprehensive mass and energy balance models targeted the production of 160 tonnes per day of hydrogen product with 99.9 wt% purity, with and without carbon capture. A life cycle impact assessment was then conducted to determine the carbon intensity of these five production pathways.

> Systems boundaries, operating conditions and performance of hydrogen production through integrated steam methane reforming with carbon capture were validated with an industry partner investing in a **net-zero hydrogen energy complex** in Alberta.

> Various industrial **applications for green hydrogen** utilization were investigated, including high temperature heat production, DRI steel production, replacement of grey H_2 in refineries, and methanol utilization in maritime transportation. Few of these applications have a GHG reduction potential as high as direct electrification.

Industrial Decarbonization Pathway Assessment

> The techno-economic viability of several strategies to achieve **net-zero emissions in steelmaking** was developed, starting from a DRI and iron pellet plant baseline to a non-emitting factory in 2050. This supported our industrial partner's strategic investment plan for decarbonizing its operations.

> A simulation platform was developed to assess potential configurations for **carbon negative kraft mills**. Ten new technologies and processes were added to a reference mill in order to propose decarbonization roadmaps to eliminate fossil fuel utilization.

DEVELOPING METHODOLOGIES AND DECISION SUPPORT TOOLS

We develop and maintain a suite of software, methods, as well as modelling and decision support tools that enable the optimal design and operation of industrial processes through various lenses.

- Designed to quantify the techno-economic viability and environmental footprint of **biorefinery strategies, the I-BIOREF software platform** was expanded with a series of socio-economic, policy, and sustainability decision-making metrics. It now includes more than 70 multidisciplinary metrics for the assessment of biorefinery implementation in various integrated and stand-alone contexts across multiple locations.

- The potential of the advanced **data analytics software EXPLORE** was expanded with advanced modelling of batch evolution capability, allowing to optimize the operation of batch processes found in energy intensive sectors such as iron & steel and chemicals sectors.

- A novel method and tools, combining the use of machine learning and commercial process simulators, were demonstrated to **accelerate materials and process design**. First applications on CCUS and biofuels production technology and processes have shown promising results.

- **A multicriteria analysis tool (MCA) for biomass allocation** was developed. The most important criteria used are GHG impacts, the existence of better alternatives, the regional availability of the resource, the compatibility of the application with BECCS, and technical and economic considerations.

- The **National CCUS Assessment Framework (NCAF)**, developed by CanmetENERGY and its partners, is a powerful framework for the holistic assessment of the decarbonization potential of CCUS, its costs and the impact of policies. Our team developed a high-performance optimization model for the **cost-optimal design of CCUS value chains** with multimodal transportation to connect emitters and storage locations. It was successfully validated on six U.S. DOE reference cases.

- **Using our multicriteria analysis (MCA) and costing tools for the techno-economic evaluation of CO_2 utilization technologies**, we showed that the high cost of green H_2 from electrolysis is an important barrier to the implementation of CCU technologies. Process and techno-economic models developed for a methane pyrolysis process showed that this H_2 production technology is an alternative to SMR with CCS. In comparison to water electrolysis, it helps significantly reduce the production costs of CO_2-based products.

- Building on a suite of calculation tools developed to quantify the energy, economic and environmental benefits of process electrification, biomass and hydrogen utilization in high temperature processes, an **Order of Merit multi-criteria methodology and tools** were introduced to help select the most GHG impactful uses of these scarce resources.

BUILDING CAPACITY

To allow for effective technology transfer to the industry and its partners, CanmetENERGY develops **innovative software solutions** that include the most recent advancements from our research activities. Our software suite includes:

Our Software Suite

EXPLORE

For improving process operation with the power of advanced data analysis

I-BIOREF

For assessing the economic viability and environmental impacts of biorefinery technologies

INTEGRATION

For optimizing heat recovery in plants

COGEN

For maximizing efficiency and revenues from cogeneration systems

In collaboration with **Quebec government departments MEIE and MELCCFP**, we are transforming the energy management market by providing technical courses and support on **process integration and data analytics**.

1 180 People trained to use the EXPLORE and INTEGRATION software (since 2017)

105 Training courses and workshops delivered

650 Engineers trained

530 Students, teachers and researchers trained in 6 Quebec universities

50+ Companies use our software on a regular basis

350+ Hours of technical support for the use of EXPLORE and INTEGRATION

SUPPORTING POLICY

Our techno-economic analyses expand the decision-making toolkit for policy makers and help them efficiently design and implement Canada's decarbonization strategy. The decision support tools we develop allow for optimal decision making in complex scenarios, including the efficient allocation of limited resources such as hydrogen, biomass and clean electricity.

- Modelling and technical support was given to NRCan's Fuel Sector to **estimate the future needs for hydrogen in Canada** and to provide revised numbers to the Commissioner of the Environment and Sustainable Development. Support was also provided to the government of Quebec to analyze and evaluate the opportunities linked to the use of hydrogen in decarbonization efforts.

- The literature synthesis of modelling-based **net-zero studies** was strengthened and highlights BECCS and direct end-use electrification as the highest-merit decarbonization strategies for industry. A strategy was developed to sequence decarbonization projects around carbon substitution, reutilization, sequestration and elimination—the latter two being favored to reach net-zero emissions.

- Reports highlighting the importance of **using biomass as a fuel substitute in industrial sectors** were delivered to the Canadian Forest Service, Environment and Climate Change Canada, and the NRCan Fuel sector.

- Modelling work was performed to estimate the GHG reduction potential of the **most effective industrial electrification opportunities** in Quebec, in support of the MEIE and the MELCCFP. It was demonstrated that industry could increase its electricity demand by 45% while reducing its GHG emissions by 75%, resulting in 30 TWh per year of additional electricity consumption in Quebec.

- In collaboration with INRS, two Quebec government departments (MEIE and MELCCFP) and federal organizations, we organized the **first Quebec workshop on CCUS** entitled "Captage, utilisation et stockage du CO_2 (CUSC) au Québec : état de la situation et perspectives". Over 100 participants from industry, academia and government attended the event and exchanged with experts from Quebec and other provinces on the opportunities and challenges of CCUS deployment in Quebec.

- Modelling hypotheses, technology performance data and **decarbonization scenarios** were provided to the Canadian Energy Regulator modelling initiative and other modelling platforms such as LEAP and NATEM.

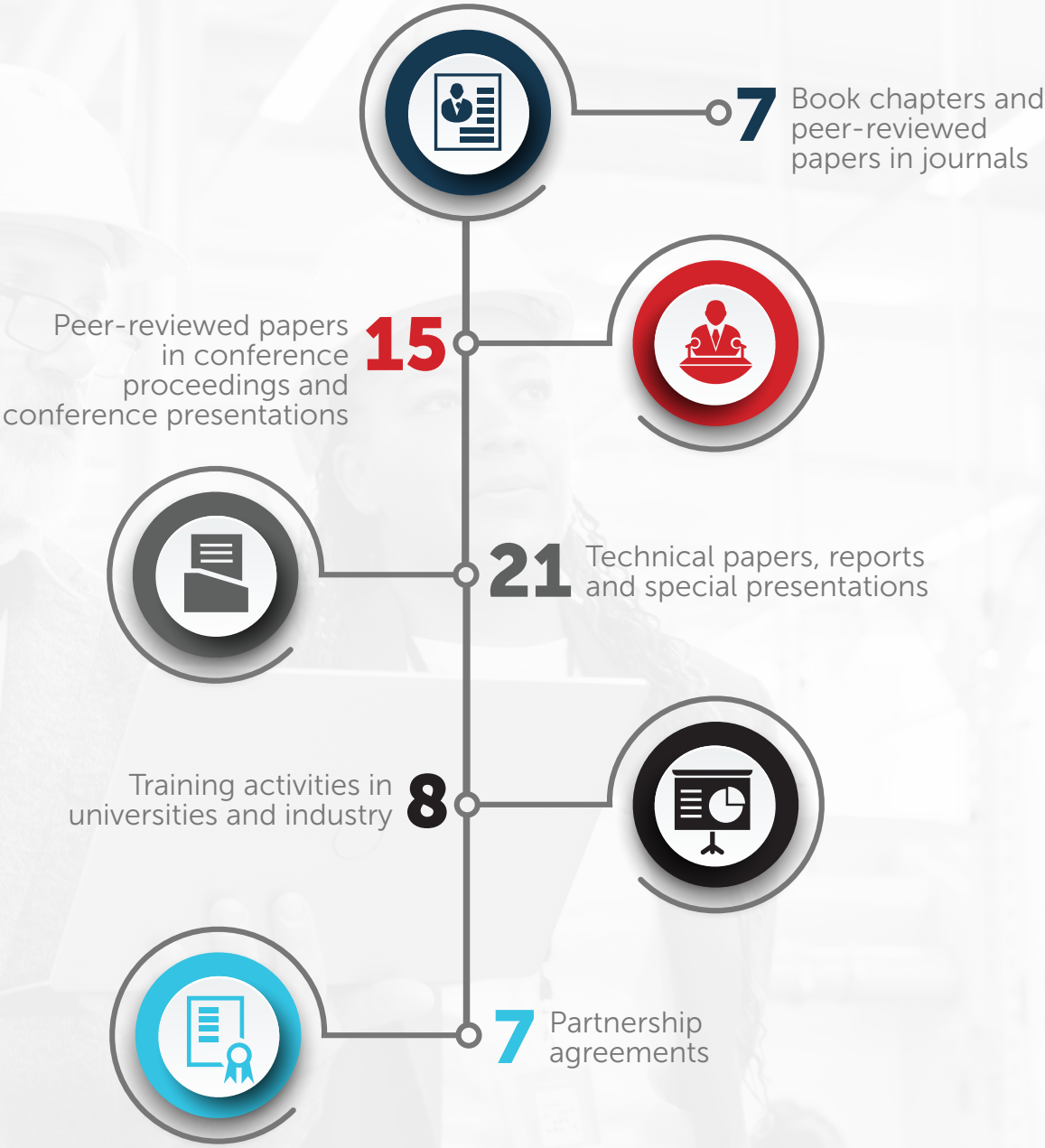
GLOBAL OUTREACH

We continue to play a leadership role by supporting **science, technology and policy development** through participation in **national and international expert committees** and other consultation initiatives.

In Canada, we have supported:

- The Canadian Forest Service in honing their vision for the future of the forestry sector and in contributing to **Canada's climate plans** for net-zero emissions by 2050.
- Environment and Climate Change Canada in designing the **Clean Fuel Regulations** by evaluating their potential impact on the forestry sector.
- Canadian Energy Regulator (CER) in providing data and modelling hypotheses for their new projections of ***Canada's Energy Future 2023: Energy Supply and Demand Projections to 2050***.
- MEIE/MELCCFP by developing fact sheets with detailed energy mapping and Sankey diagrams for nine industrial sectors, with an evaluation of the GHG reduction potential for electrification and bioenergy projects.
- A workshop bringing together over 50 representatives from the forest industry, the research and development community, and solution development companies in Quebec City. This event allowed identifying the needs and challenges of **developing and implementing digital solutions** to reduce GHG emissions and increase productivity of the forest industry. Several discussions are underway for demonstration projects.
- Internationally, we are co-chairing the executive committee of the **International Energy Agency's program on Industrial Energy-Related Technologies and Systems**. We are also leading two research tasks on Industry-Based Biorefineries Towards Sustainability and Digitalization, Artificial Intelligence and Related Technologies for Energy Efficiency and GHG Emissions Reduction in Industry, joined by over 50 experts from 12 different countries.

TRANSFERRING KNOWLEDGE



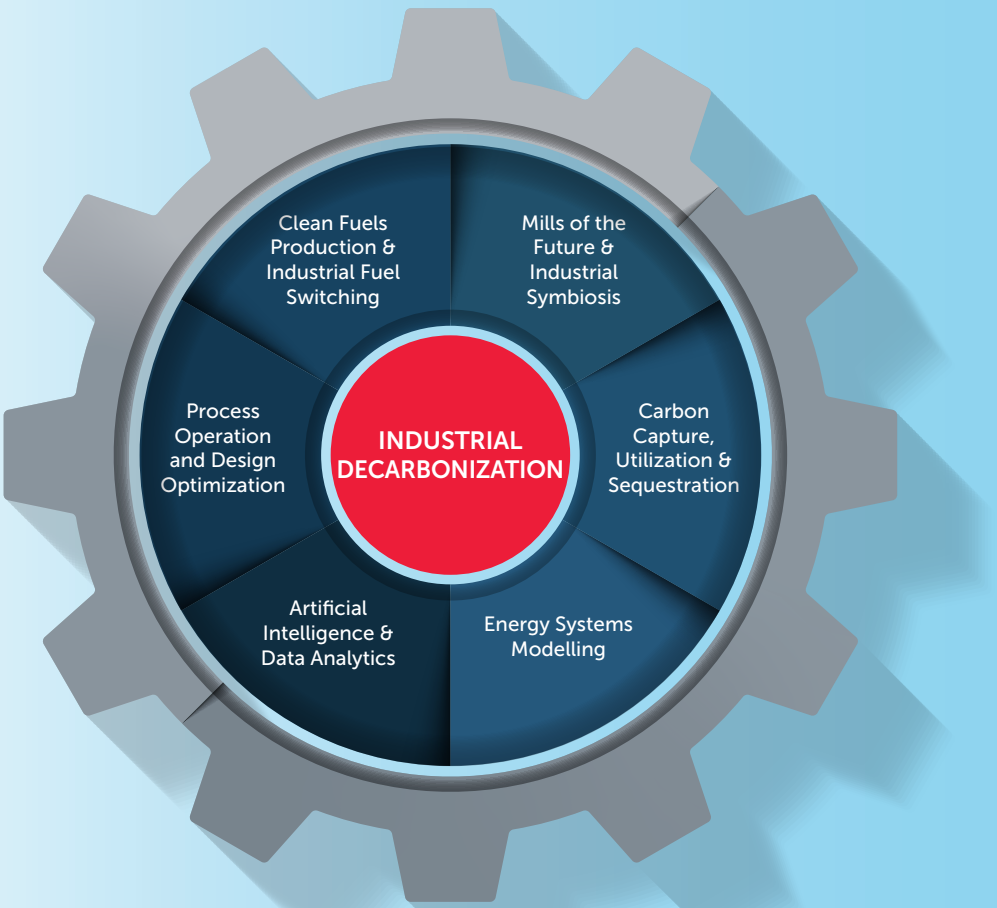
TOTAL SINCE 2015

47	179	140	65	41
Book chapters and peer-reviewed papers in journals	Peer-reviewed papers in conference proceedings and conference presentations	Technical papers, reports and special presentations	Presentations for university and industry training	Partnership agreements

PARTNERS AND COLLABORATORS

Our team of scientists and engineers has established strong partnerships and collaborations to achieve its objectives.

FUTURE PERSPECTIVE



CanmetENERGY in Varennes

CLEAN ENERGY | RESEARCH | INNOVATION | LEADERSHIP

CanmetENERGY in Varennes, located near Montreal, leads innovative science and research activities to develop and implement solution pathways that create value as well as a sustainable energy future for Canadians. In pursuit of our mission, we:

- Apply our science and technology (S&T) expertise to test, develop, demonstrate and implement clean energy technologies
- Share our knowledge and expertise through collaborations with partners, including non-government organizations, academia, industry and all levels of government

Science at the service of all Canadians.

For more information, please visit our website or contact us:
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ISSN 2564-1859

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