Hydro-Québec's Research Centre

Annual Review 2024

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Introduction

2024: A year of transition and reflection for the CRHQ

2024 was a pivotal year for the Hydro-Québec's Research Centre (HQRC). We transitioned toward a new innovation model with the creation of the Direction principale – Excellence opérationnelle, stratégies d'innovation et solutions technologiques and harmonized our projects with the objectives set out in the Action Plan 2035. The common goal of these strategies is to strengthen Hydro-Québec's leadership position in energy transformation and to continue striving for excellence in research and innovation.

Throughout the year, the HQRC demonstrated the scientific and financial value generated by the projects described on the following pages. Every $1 invested in research and development at the HQRC now produces close to $3 in benefits for Hydro-Québec. Our initiatives have improved our strategic positioning and showcased our ability to respond to the challenges of the power system of tomorrow. These results are a testament to the positive impact of our research activities for the organization and for Québec's prosperity.

We also carried out an in-depth reflection of the update to our master plan in 2024. This involved reassessing our research and development themes to ensure they remain relevant with respect to emerging needs and operational requirements. The process helped define clear directions, in addition to nine themes involving ambitious objectives for the coming years.

In conclusion, 2024 was a successful transition year. This report on the HQRC's activities highlights the achievements contributing to the objectives of Hydro-Québec's Action Plan 2035. By reviewing our areas of research, we have established the foundations for sustainable growth and continued progress. We firmly believe that these efforts will generate results and that we will continue to be a major industry leader in innovation, in Québec and beyond.

Christian Bélanger
Senior Director – Research & Innovation

Improve service quality

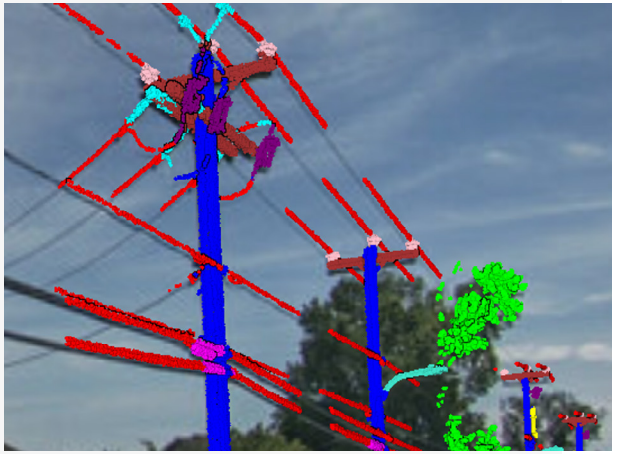
Détective project

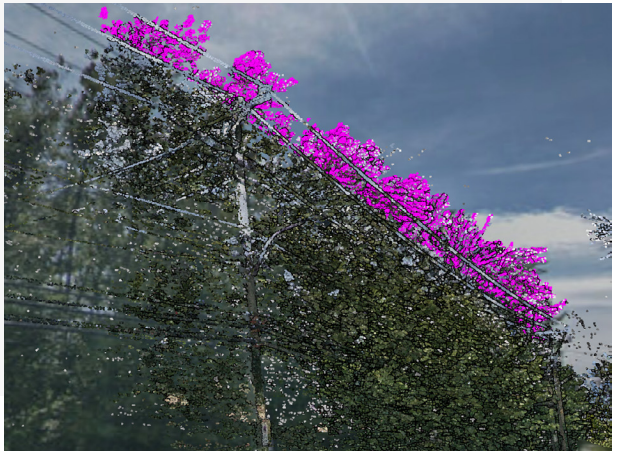
Smart maintenance of the overhead distribution system

The Détective project is a major breakthrough in the proactive management of Hydro-Québec's overhead distribution system. By integrating artificial intelligence, high-definition imaging and LIDAR (from external captures or from our vehicles), we can better understand our system, thereby improving risk management. Management of the overhead distribution system involves several issues. For instance, vegetation is responsible for 40% of outages, while 27% of outages are caused by aging or failing assets. Multiple environmental risks also come into play, as well as a regulatory requirement involving 150,000 visual inspections and sampling to identify transformers that may contain polychlorinated biphenyls (PCBs), and over 5,300 yearly site visits to respond to customer requests.

The Détective project helps reduce travel through remote inspections and surveys when engineering work is required. It favours more specific interventions, including pruning and equipment replacement, which increase operational efficiency. Several innovations were implemented in 2024. For example, the mapping of over 500 km of our system, georeferenced to the nearest 5 cm on average, enabled automatic location capabilities to be developed for 10 types of overhead assets and recognition of 150 species of trees with 83% accuracy, greatly exceeding previous standards. Détective also allows for the automatic geolocation of poles and conductors (with accuracy ranging from 85 to 98% depending on the area), identification of branches to be pruned, automatic reading of location codes (LNLNL) and detection of other distribution assets such as insulators, cutout switches and transformers.

Détective is a strategic tool in Hydro-Québec's arsenal for preventing failures, optimizing resources and strengthening grid reliability to better manage performance and ensure it meets our customers' expectations.





Climatology

Anticipating runoff to adapt our generation strategies

Management of our energy reserves is a key component in the short- and medium-term security of supply, and it is dependent upon various criteria. More specifically, Hydro-Québec must be in a position to fulfill its commitments when a major (and likely) drought occurs over several consecutive years. Since the 1990s, Hydro-Québec has consistently ensured that it can compensate for runoff fluctuations. Given the record annual energy deficit in 2023, our research teams conducted analyses to generate a probabilistic energy inflow projection for 2024.

These estimates allowed Hydro-Québec to opt for a generating strategy better suited to the hydrological context. To minimize potential expensive energy purchases, the 2024 generating strategy was therefore adjusted, specifically with a reduction in planned net sales. This generating strategy was revised twice during the year based on the development of hydraulic conditions.

ReCIVE – Résilience cybernétique des infrastructures des véhicules électriques (cyber resilience of electric vehicle infrastructure)

Cyber security of electrical vehicle integration

The ReCIVE project is part of a strategic plan for the secure, resilient and optimal integration of electric vehicles (EVs) into Québec's power grid. This initiative centres on three main objectives: to identify and document vulnerabilities specific to the EV ecosystem; to generate models of the impacts of such vulnerabilities on grid stability through a co-simulation platform; and to develop threat-specific mechanisms for detecting, monitoring and responding to cyberattacks. ReCIVE also aims to define attack categories based on their impacts and to develop dynamic detection and mitigation strategies that can be transferred to operational environments. The results will provide data for decision-making tools to orient future actions involving energy cybersecurity.

In 2024, the team completed a key phase with the implementation of a cloud-based co-simulation environment capable of simulating the effects of an attack on the grid. Two specific technical analyses have been carried out: one concerning security by design of charging stations, and the other concerning vulnerabilities involving the integration of EVs. We have also developed an interactive map that shows performance indicators for charging stations throughout Québec. These achievements are an important milestone toward safer and more resilient energy infrastructure.

Short-term demand forecasts

Our work on demand forecasts extending as far as the UN

Our teams have been working with artificial intelligence for several years to improve short-term demand forecasts for the energy trading teams and for the Direction – Planification de la conduite du système énergétique. In 2024, this innovative work was presented to several forums, including Sustainable Energy Week of the United Nations Economic Commission for Europe.

Help our customers make better use of electricity

Decarbonization modelling

Analyzing data to help make better decisions

The decarbonization modelling project involves the development of energy roadmaps representing the energy and power impacts of various technological choices allowing Québec to become carbon-neutral by 2050. The results of this work will help Hydro-Québec anticipate medium- and long-term changes in energy demand to guide its strategic reflections.

The project analyzes various technological solutions for decarbonization by converting the use of fossil fuels, prioritizing energy efficiency measures and direct electrification technologies, and studying the impacts of indirect electrification and the use of other carbon-neutral energy sources such as biomass.

In 2024, the main projects helped develop about 10 decarbonization scenarios for Québec's five critical industrial sectors and carry out prospective analyses of the impact of biomass on energy and power needs. The reflection also took into account the relevant sociological aspects and a critical review of the industrial processes concerning the allocation of Hydro-Québec's new blocks of power. These deliverables contributed to the strategic planning of the organization, which is a key player in Québec's energy transition.

Energy habits – Lac-Mégantic

At the heart of Lac-Mégantic's energy transition

The combined efforts of our teams and of the Direction – Solutions d'innovations appliquées et expertises sectorielles, the commitment of the town of Lac-Mégantic and the support of the federal Smart Renewables and Electrification Pathways Program enabled the implementation of a living lab driving the energy transition in Lac-Mégantic. In 2024, two research projects were conducted on the sociology of energy. The first project involved analyzing energy habits in a mid-sized municipally fully committed to the energy transition, while the second project involved energy consumption in low-income households with access to efficient technologies.

On September 20, 2024, the governments of Québec and Canada, the Fonds de solidarité FTQ, the town of Lac-Mégantic, the Société d'aide au développement de la collectivité de la région de Mégantic, Hydro-Québec and the Chevaliers de Colomb de Lac-Mégantic inaugurated Le Chevalier, a building offering 21 affordable social housing units and a common room. Located at the heart of the Lac-Mégantic microgrid, the building integrates various innovative technologies (thermal storage combined with heat pumps, hybrid solar panels, etc.). The equipment is being monitored to determine its efficiency. In addition to the technological aspect of the project, the habits of the building's occupants are also the subject of a qualitative study. The aim of the study is to better understand the domestication process of these technologies, that is, the types of work, learning and innovation through which people begin to use unfamiliar equipment and integrate them into their daily lives. This research supports Hydro-Québec's efforts to become more familiar with the consumption habits of low-income households to help develop our marketing programs.

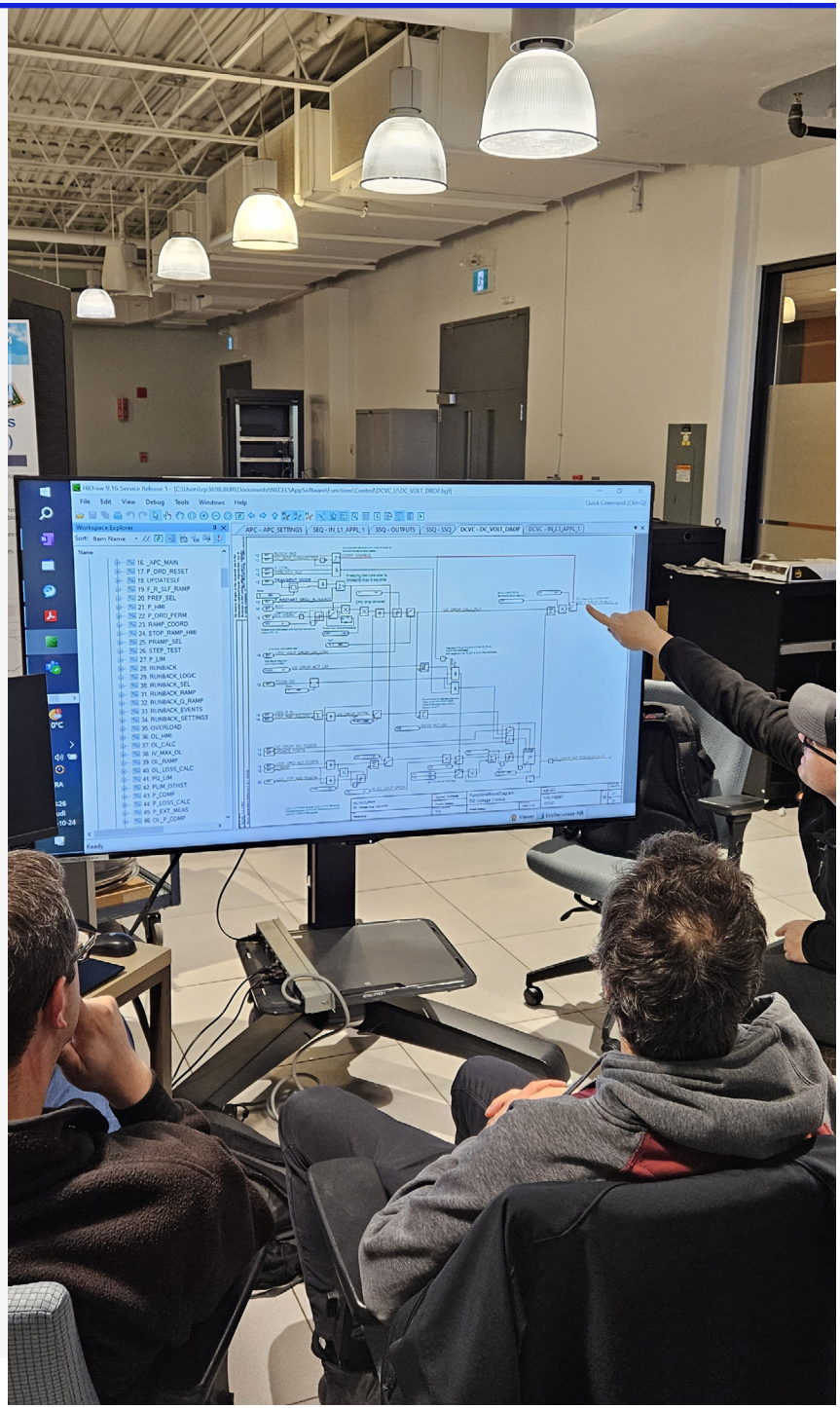
Increase our power generation capacity

HyperSim

Appalaches–Maine interconnection line: Successful simulation ahead of commissioning

The advantages of replica-based studies in our HyperSim simulator are clear: they enable the successful, rapid and secure introduction of critical equipment into Hydro-Québec's grid. Replicas are used throughout the facility's lifespan, which results in rapid restoration during system events and continuous optimization of activities.

The Appalaches–Maine interconnection line project, which will connect to the New England Clean Energy Connect (NECEC) in the United States, is unique in that it integrates new direct-current interconnection technology for the very first time in our system. Over the last 15 years, we have been conducting research and development that is critical for building the tools and expertise needed to meet this challenge. With the power and accuracy of HyperSim, the replica of the control system can be subjected to very realistic scenarios. In 2024, the replica was tested in a closed-loop system with HyperSim. Since then, specialists from our team and from the Systèmes de compensation et interconnexions of the Direction – Expertise, ingénierie et standardisation unit have been developing and testing corrective measures to be deployed prior to implementation of the interconnection at Appalaches substation in the fall of 2025.



SimP

SimP: Successful testing of the first cell at full power

In October 2024, construction of the new SimP research and testing infrastructure reached an important milestone with its full-power testing of the first cell of its power amplifier. This cell—one of 24 required for the three-phase 25-kV/7.5-MVA power amplifier—is the culmination of several years of research and development, which optimized its design and performance. Using closed-loop algorithms developed by the HQRC, SimP will provide, among other things, a better understanding of and control over the impact of distributed energy resources (DER) and inverter-based resources on power grids with an unprecedented level of detail.

This completely unique infrastructure will offer Hydro-Québec a testing environment that is essential to planners and operators because it reduces the risks involving the integration of inverter-based resources, including wind power, while ensuring that systems remain reliable. SimP will enable research to proceed on advanced control algorithms of these resources, such as grid-forming strategies aimed at optimizing costs and performance of the transmission and distribution systems. Work on SimP is continuing in 2025, and commissioning is expecting in the summer of 2026.

DIAAA (advanced generator diagnostics)

Full potential of generator diagnostics

In 2024, we deployed the final tool of the DIAAA (advanced generator diagnostics program), which improves maintenance of hydropower generators through an integrated diagnostic approach.

DIAAA integrates tools such as visual inspection, measurement of magnetic flux in air gaps, analysis of ampere-turns, ground insulation resistance of rotor windings, as well as the testing of partial discharges, polarization/depolarization current and ozone measurement.

The platform is accessible through a Web interface and allows continuous monitoring of the generators' stator and rotor status through a combination of online and offline diagnostic tools (requiring disassembly or shutdown). It automatically calculates a health index for each generator based on the results obtained from various diagnostic tools and assigns a level of confidence according to the quality and quantity of available data.

In addition to facilitating maintenance planning and reducing unscheduled shutdowns, DIAAA paves the way to the development of digital twins to simulate and predict the behaviour of generators in real time. This innovation is major advancement in the proactive and sustainable management of electricity generation equipment.

Award presented to the DIAAA team at the ADRIQ's Prix Innovation gala

The InovÉÉ award was presented to the DIAAA project team at the 2024 Prix Innovation gala hosted by the Association pour le développement de la recherche et de l'innovation du Québec (ADRIQ). It shares the award with École de technologie supérieure and the firm Opal-RT. The award recognizes the project's excellence in partnerships with the university community and international scientific outreach. The DIAAA team has written a total of 32 scientific articles and supervised 11 Masters students and 7 Ph.D. students.

Become an agile, innovative and transparent organization

Self-cleaning dam drains

Cleaning solutions for dam drains

Hydro-Québec's concrete dams are equipped with drains to reduce the lifting force. Solid calcite deposits gradually obstruct the drains, which reduces their effectiveness and requires mechanical cleaning. We are currently implementing solutions from a research project to help us understand more about these deposits and how to manage them. These are some of the solutions implemented in 2024:

1

Calcite inhibitors

Polysuccinimide pellets, which release polyaspartic acid, have been tested at Beauharnois generating station and Daniel-Johnson dam. We have demonstrated that they decrease the formation of calcite crystals and help eliminate them.

2

ECHOTRON inspection tool

In association with Mecanum Inc., Hydro-Québec has developed an acoustic inspection tool for drains, which is faster and more effective than visual methods.

3

HQDrain software

This software, developed at the HQRC, predicts the obstruction of drains by calcite. It helps predict and treat potential blockages before they become a problem.

These initiatives contribute to the security and durability of Hydro-Québec's concrete drains.

Linux Foundation Energy

Participation in the Linux Foundation Energy community

In 2024, the HQRC completed several important steps as part of its commitment to the Linux Foundation Energy community and the advancement of strategic energy transition projects. In April, the HQRC officially became a general member of LF Energy, demonstrating the research centre's clear intention to become involved in the open source energy ecosystem. In September, the HQRC took part in LF Energy's international summit for the first time, where several initiatives were showcased. These included the GridFM strategic project, which involves generative models and AI, and is the very first Hydro-Québec project to join LF Energy. This major advancement was made official in October, and the project received a great deal of support, including the participation of IBM and the European university community.

VoltAIRE (GridFM)

VoltAIRE's valuable partnerships

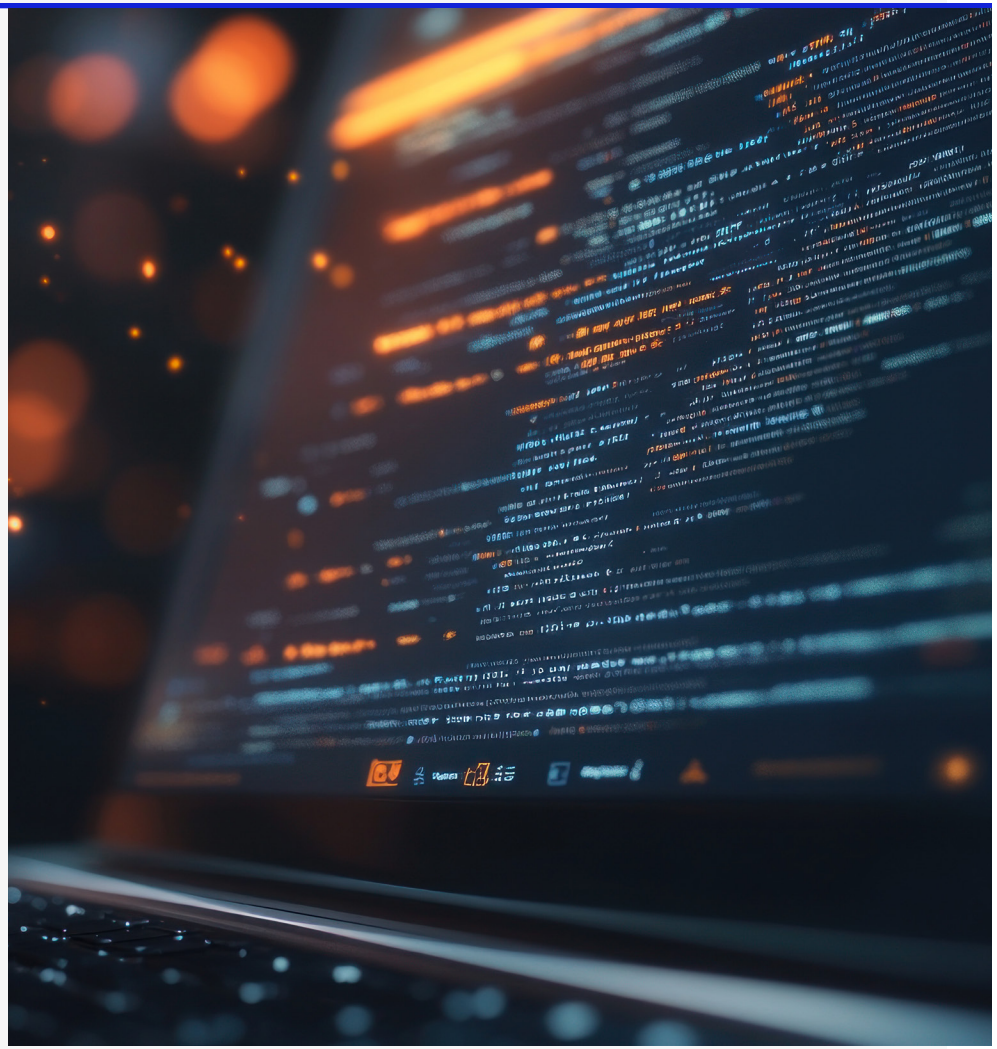
The objective of the VoltAIRE project is to develop a generative model for power grids (GridFM) in partnership with IBM. GridFM will be used in conjunction with a generative model for weather (WeatherFM), primarily for planning applications involving the transmission system. Congratulations to our research colleague François Miralles, who put together an entire ecosystem of partners surrounding this project, which is Hydro-Québec's first LF Energy open source project. Work involving our electrical data can be used in other innovative projects and with our partners from MILA and Polytechnique.

Exploratory work involving large language models (LLM)

AI up close

The emergence of large language models (LLMs) marked a turning point in the evolution of artificial intelligence and its democratization. The models have become indispensable catalysts for technological, economic and social transformations. The exploratory work conducted in 2024 helped determine and document important opportunities and issues involving LLMs for Hydro-Québec.

Advocating for the use of various AI tools in scientific research, the team obtained access to Scopus AI and Science Direct AI for the entire organization and supported deployment of Github Copilot at the HQRC. It has documented the cybersecurity issues concerning the deception capacity of new models, garnering the interest of the Direction principale – Cybersécurité and leading to the development of an attack scenario for the HQRC's Cybersécurité des réseaux électriques (CySRE, power grid cybersecurity) project. The team has also examined the risks involving the development of increasingly powerful intelligent agents, as identified by specialists in the field, and analyzed their implications for a critical organization such as Hydro-Québec. Lastly, LLMs that have been adopted on a wide scale by technology giants have and will continue to have a significant energy impact on utilities such as Hydro-Québec, both in its role as a customer and as a supplier of electricity.



The exploratory activities surrounding this topic were documented for the first time in 2024 to help better understand energy issues and as a basis for the organization's strategic reflection. As LLMs continue to evolve rapidly and give rise to new issues and new possibilities, we are continuing our work in 2025 to better understand LLMs and prepare for them to the greatest extent possible.

RIAUPEL brings home GOLD at the OCTAS awards

The RIAUPEL project (automated robotic vehicle that inspects transmission substations) won GOLD at the 2024 OCTAS awards in the robotics category (large corporations, Crown corporations and paragovernmental corporations). The project develops and deploys robotic vehicles in power transmission facilities to automate routine and thermographic inspections.

In December 2023, a prototype was deployed at La Grande-2 substation, which is the Robert-Bourassa generating station switchyard (the largest belonging to Hydro-Québec). With its visual and thermographic capabilities, the robot helps remotely monitor power transformers, breakers, reactors and disconnect switches—all of which are essential for power transmission.

Report on Free Electrons 2024

Free Electrons: An “electrifying” program

In 2024, Hydro-Québec participated for the second year in the Free Electrons program, an international collaboration in the energy industry. Hydro-Québec hosted the Master Module in Montréal in mid-July. The event gathered 75 people from 15 finalist start-up companies, as well as representatives from six other power companies that are members of Free Electrons.

Following our participation in the Free Electrons program, we ran five pilot projects in 2024. The work will continue in 2025, with six other pilot projects being carried out by our colleagues from various groups within Hydro-Québec. Two other projects are in the development stage.

Two years and several pilot projects later, an initial solution arising from Free Electrons was integrated into Hydro-Québec’s activities. The Salient solution, which predicts temperature and precipitation using a hybrid physics-AI model over a span of 2 to 52 weeks, is currently being used by weather teams of the Direction – Planification et conduite du système énergétique.

Review of our contributions to science

Our patents

HQRC's diversified patent portfolio

214 patents and pending applications
153 issued patents and 61 pending patents (in 57 patent families)

2 new inventions
innovations protected by patent applications in 2024

16 patents
newly issued patents in 2024

Our scientific publications in 2024

Every year the HQRC publishes an average of 150 journal articles, conference papers, book chapters and other scientific content. 2024 was an especially productive year with 204 scientific publications, compared to 168 in 2023.

The 204 publications distributed by scientific publishers included 126 journal articles, 77 conference papers and a book chapter. Several of these were co-authored with our university partners, demonstrating a true spirit of cooperation and synergy among the teams. Of the 204 publications, 95 of them (47% of all publications in 2024) were jointly authored.

In terms of performance, 43 of our scientific publications in 2024 were published in the top 10% of the highest ranking journals in the world according to the Source Normalized Impact per Paper (SNIP), an impact factor weighting citations according to discipline, which allows for a better comparison among journals.

126
journal articles

95
publications co-authored with our university partners

77
conference papers

A closer look

Technology watch and positioning

A few examples:

- Efficient electrification
- Energy and society
- Integrating distributed energy resources (DER)
- Energy storage systems (ESS)
- Power transformers

Exploratory activities

Several exploratory activities were carried out in 2024: 10 projects were completed, and 14 new projects were launched and will continue in 2025. Examples of projects completed in 2024:

- Energy storage in cased wells
- Integration of small modular reactors
- Use of marine energy to generate electricity
- Study of generator flexibility