Energy Storage Applications and Potential in Newfoundland and Labrador

A Discussion Paper

econext

Accelerating Clean Growth

Newfoundland & Labrador

Energy Storage Applications and Potential in Newfoundland and Labrador

Prepared for econext

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List of Acronyms

AC/DC	Alternating Current/ Direct Current
ACAES	Adiabatic Compressed Air Energy Storage
BESS	Battery Energy Storage Systems
CAES	Compressed Air Energy Storage
CEPA	Canadian Environmental Protection Act
CER	Clean Electricity Regulations
CHP	Combined Heat and Power
CSP	Concentrating Solar Power
DCAES	Diabatic Compressed Air Energy Storage
EU	European Union
EV	Electric Vehicle
GES	Gravity-based Energy Storage
HES	Hydrogen Energy Storage
HVDC	High-voltage DC
IPP	Independent Power Producers
ITCs	Investment Tax Credits
LDES	Long Duration Energy System
LHS	Latent Heat Storage
MJ	Mega-Joule
MPa	Mega-Pascal
MW/GW	Megawatts/ Gigawatt
MWh/GWh	Megawatt-Hours/ Gigawatt-Hours
NL	Newfoundland & Labrador
ORER	Offshore Renewable Energy Regulations
PSH	Pumped-storage Hydroelectricity
PPA	Power Purchase Agreements
PV	Photovoltaic
RTE	Round Trip Efficiency
SDG	Sustainable Development Goals
TCS	Thermochemical Storage
TES	Thermal Energy Storage
UPSH	Underground Pumped-storage Hydroelectricity

1 Introduction

Renewable energy (RE) sources, including solar, wind, hydropower, biomass, and geothermal, are increasingly integrated into the global energy mix to combat environmental and climate challenges driven by fossil fuel dependence. Renewable and clean energy sources are considered the most viable and essential to keeping the global temperature rise below the critical 1.5°C threshold outlined by the Paris Agreement [1]. However, one of the key technical challenges with renewables is their intermittency: sources like solar, wind, and ocean energy are inherently variable, often following daily or seasonal cycles, and cannot supply power at a constant, controllable rate. To overcome these intermittent issues and ensure a stable and reliable energy supply, a range of energy storage technologies is crucial (Figure 1). Energy storage systems convert energy, such as electricity, which is otherwise difficult to store, into a form that can be stored and used later. Modern energy storage technologies take on many different forms, with the ability to store energy for a wide range of time periods, from seconds to months. Such technologies include:

- Electrochemical (batteries)
- Electrical (Super-conducting magnetic energy storage, Super-capacitor)
- Mechanical (pumped-storage hydro, compressed-air energy storage, flywheel)
- Thermal (Latent heat and sensible heat)
- Gravity
- Chemical (hydrogen)

Over the past decade, Newfoundland and Labrador (NL) has experienced significant developments in the energy sector, particularly in upstream oil and gas, RE generation, and energy storage. The province has been a notable player in Canada's energy industry, with offshore oil production contributing substantially to the provincial economy for nearly three decades. However, there has been a gradual shift towards diversifying the energy portfolio to include more renewable sources.

This research aims to explore the potential role of energy storage in NL, with a focus on highlighting current initiatives, increasing awareness of emerging opportunities, and examining innovative storage technologies. The study has been carried out with guidance and feedback provided by international renewable energy experts. It places a particular emphasis on the development of compressed air and hydrogen storage, as these technologies present exciting opportunities for NL.

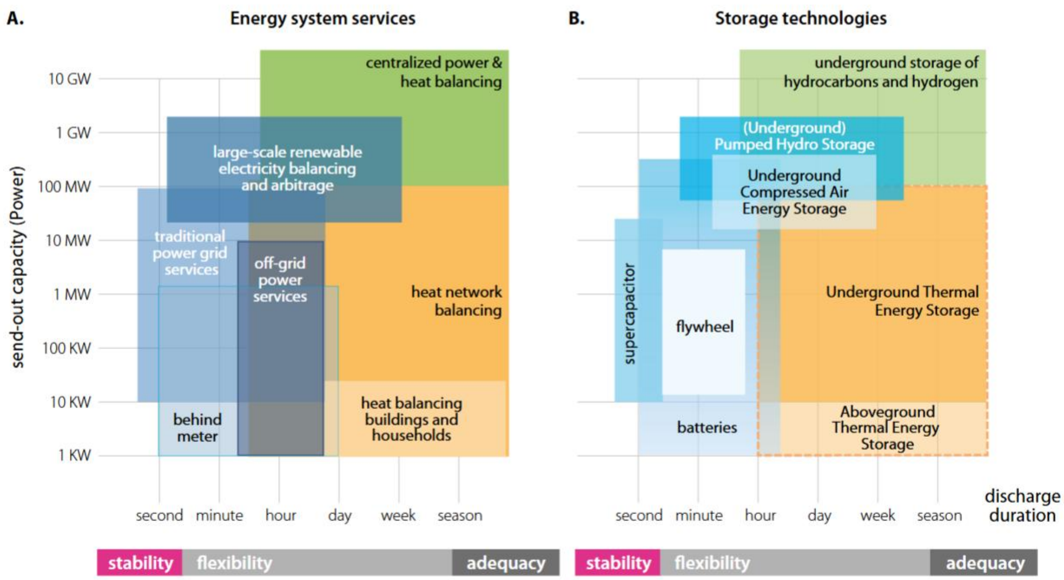

Figure 1 a) Energy system (balancing) services mapped according to their power (Watt) and relevant timescale for discharge. The types of services can be classified as stability, flexibility and adequacy based on their duration: stability is defined as the response to very short and fast fluctuations (especially in the power system); flexibility represents response to load and supply variations up to the seasonal timescale; adequacy (security of supply) determines the ability to adapt to long-term trends and emergencies. b) Above- and underground storage technologies that can provide the energy system services. The colour code indicates to which grid the energy system service and storage technology belongs electricity (blue), gas (green) and heat (orange) [2].

1.1 Benefits of Energy Storage

1.1.1 Grid-Level Applications

Energy storage systems at the grid level can play a critical role in enhancing the reliability, flexibility, and efficiency of modern electricity networks. Among key applications, load shifting and peak shaving enable utilities to balance supply and demand by storing excess electricity during low-demand periods and discharging during peak times, thus reducing the need for peaking power plants and minimizing energy costs [3]. Energy storage also alleviates congestion in transmission corridors by providing localized energy support, thereby deferring infrastructure upgrades. In terms of grid stability, advanced storage technologies contribute to frequency regulation and provide synthetic inertia, supporting system resilience amid increasing renewable penetration [4]. Moreover, storage assets can serve as reserve capacity and offer black start capabilities, allowing portions of the grid to be re-energized independently during outages. Finally, storage supports curtailment reduction strategies by absorbing surplus renewable generation that would otherwise be wasted, thus improving the utilization rate of wind and solar assets.

1.1.2 Community-Level Applications

At the community level, energy storage systems can provide critical support for localized energy resilience and sustainability. One key application is microgrid stabilization, where energy storage enhances the reliability and autonomy of distributed energy systems by balancing supply and demand, mitigating voltage fluctuations, and providing seamless transitions between grid-connected and islanded modes [5]. In remote or off-grid communities, particularly in northern and Indigenous regions of Canada, energy storage is increasingly deployed to reduce reliance on diesel generators, reducing greenhouse gas emissions, lowering fuel costs, and improving air quality. By storing excess RE when supply exceeds demand and discharging it when needed, energy storage reduces reliance on carbon-intensive backup generation (such as oil- or gas-fired plants), directly lowering system-wide emissions. Furthermore, energy storage enhances backup power capabilities for critical infrastructure such as hospitals, emergency shelters, and communication facilities during grid outages, ensuring uninterrupted service during extreme weather events or natural disasters.

1.1.3 Industrial Applications

Energy storage can play as industrial and export-oriented decarbonization strategies. One major application is the production of green hydrogen - a clean fuel for energy-intensive sectors such as mining, marine ports, and heavy transport, as well as a promising export commodity to global hydrogen markets. Large-scale integration of wind power with hydrogen production and storage can help buffer variability, enabling a steady energy supply to support the electrification of heavy industry and reduce dependency on fossil fuels. In high-wind or coastal regions, pairing wind energy with storage systems improves grid stability and optimizes resource utilization, while "hydro-wind synergy", common in provinces like NL, can be enhanced with storage to provide load balancing and dispatchable renewable power. Hydro-wind synergy refers to the complementary relationship between hydropower and wind energy in an integrated energy system. Wind power is variable and weather-dependent, while hydropower is dispatchable and can be ramped up or down on demand. When combined, hydro can act as a natural "battery," compensating for wind variability by storing water during high-wind periods and increasing output during low-wind periods.

Beyond cutting emissions, energy storage offers additional environmental benefits. It helps reduce the need for building new fossil fuel power plants or transmission lines, minimizing land and ecosystem disturbance. Replacing or reducing reliance on diesel generators with RE + storage systems reduce local air pollutants, improving air quality and public health. Moreover, technologies like long-duration storage (e.g., compressed air, hydrogen) can smooth seasonal mismatches between supply and demand, creating a pathway to deeper decarbonization and supporting the province's climate targets.

By enabling greater use of local renewable resources and improving grid efficiency, energy storage can attract new private-sector investments, create skilled jobs, and stimulate the growth of local supply chains in advanced energy technologies. Additionally, as global demand for clean energy solutions rises, jurisdictions with high energy storage potential could position themselves as leaders in energy innovation.

Table 1 Energy Storage Applications

GRID-LEVEL	COMMUNITY	INDUSTRIAL	EXPORT-RELATED
• Energy Arbitrage • Frequency Regulation • Spinning Reserve & Grid Stability • Renewable Energy Integration • Peak Shaving • Microgrid Support/ Islanding • Transmission & Distribution/ Deferral • Black Start Capability • Energy Access & Off-grid Applications	• Resilience & Backup Power • Energy Sharing & Local Microgrids • Load Shifting & Demand Charge Reduction • Electric Vehicle Charging Support • Support for Remote and Islanded Communities • Peak Shaving for Public Buildings • Grid Services Virtual Power Plant Participation	• Peak Shaving & Demand Charge Management • Power Quality & Voltage Support • Backup Power/ Uninterruptible Power Supply • Energy Arbitrage • Process Optimization & Electrification • Renewable Integration for Industrial Sites • Grid Services (Ancillary Revenue Streams)	• Firming Renewable Energy for Export • Wind-to-Hydrogen (Green Hydrogen) • Grid Interconnection Support (Atlantic Loop) • Ancillary Services to External Grid • Hydro-Wind Hybrid + Storage for 24/7 Export • Value-added Clean Energy Products • Off-grid Storage Tech Export

1.1.4 Export-Oriented Applications

Energy storage has the potential to enable electricity exports from NL to other provinces or even U.S. markets. Large-scale, long-duration storage, such as pumped hydro, Compressed Air Energy Storage (CAES), or hydrogen, can help manage variable renewable generation, store excess supply during low-demand periods, and dispatch energy when export markets are most favorable. By smoothing output and enhancing reliability, storage technologies increase the firm capacity available for export through transmission lines like the Labrador-Island Link, Maritime Link, and Atlantic Loop. Over time, strategically deployed storage assets could be positioned not just as infrastructure for local grid support, but as export-enabling services - helping NL become a flexible, responsive energy provider in regional markets. Positioning storage as an export-enabling asset could unlock new revenue streams for the province while supporting regional decarbonization goals. Relevant energy storage applications can be found in Table 1.

2 Energy Storage Technologies

This chapter outlines a few energy storage technology baselines, including global study case examples. Exploring and progressing energy storage concepts now will help to future-proof NL and position the province as a leader in Canada's energy transition.

2.1 Battery Energy Storage Systems (BESS)

BESS (Figure 2) are advanced technologies engineered to store electrical energy in rechargeable batteries for subsequent use. These play a critical role in enhancing the resilience, flexibility, and reliability of modern electricity networks, particularly over short durations. BESS can absorb surplus electricity from the grid or from RE sources such as solar photovoltaic (PV) and wind power, discharging this energy during peak demand periods or instances of grid instability. BESS technologies are typically categorized based on their underlying battery chemistry, including:

- Lithium-ion (Li-ion): The most prevalent, offering high energy density and efficiency.
- Lead-acid: Mature and cost-effective, though with lower energy density and shorter lifespan.
- Sodium-sulfur (NaS): High-T systems with large-capacity potential, primarily for utility-scale applications.
- Flow batteries (e.g., vanadium redox): Well-suited for long-duration applications due to their scalable design and extended cycle life.

Modular BESS configurations enable flexible deployment across a wide range of power capacities, from kilowatt (kW)-scale systems suitable for individual buildings to multi-megawatt (MW)-scale assets for grid-level support. One of the key technical advantages of BESS is their rapid response time, often in the sub-second range, which makes them ideal for grid services such as frequency regulation, spinning reserve, voltage support, and black start capability. Typical BESS durations range from 1 to 6 hours, although ongoing research and development are expanding the capabilities of Long Duration Energy Storage (LDES), which is defined as >8 hours.

Effective management of BESS also involves addressing safety and lifecycle considerations. Li-ion systems require rigorous thermal management and fire safety protocols due to their susceptibility to thermal runaway. All systems incorporate Battery Management Systems (BMS) to monitor key performance metrics, including state-of-charge (SOC) and state-of-health (SOH), which are vital for safe and efficient operation.

Lifecycle considerations for BESS include the environmental and social impacts of critical minerals mining, the manufacturing supply chain, and end-of-life management.

Ontario exemplifies provincial leadership in energy storage innovation, such as their latest BESS operation of 250MW/1000MWh delivered ahead of schedule [6]. In Alberta, a deregulated electricity market has facilitated rapid battery storage deployment, with several hundred megawatts under construction, alongside active hydrogen storage pilot projects. Nova Scotia continues to explore diverse storage solutions to support its energy transition from coal to renewables and has initiated pilot BESS installations backed by regulatory advancements.

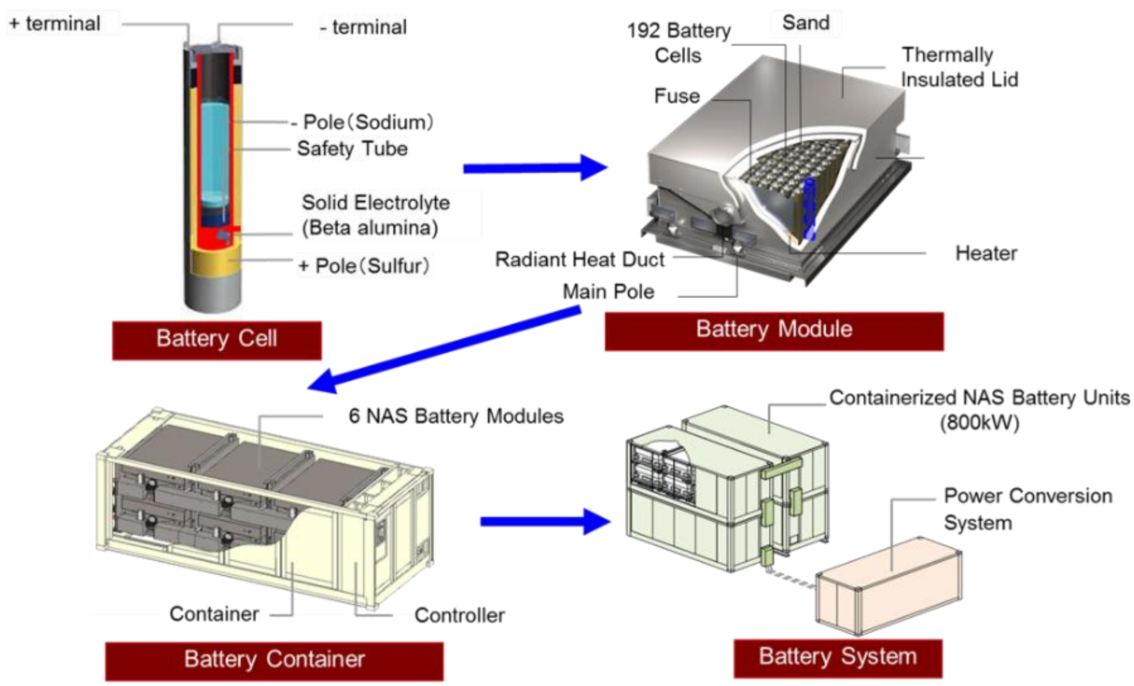

Figure 2 A battery cell is the smallest energy-storing unit, grouped into modules to increase capacity and safety. Multiple modules are placed into a container with a battery management system (BMS), and together with the power conversion system (PCS), they form a complete battery system that can charge from or discharge to the grid (taken from UN Industrial Development Organization).

2.2 Gravity-based Energy Storage (GES)

GES systems harness gravitational potential energy by elevating a mass (typically a solid weight or water) and then releasing it to generate electricity when needed. GES technology has been demonstrated at grid scale in various configurations, including Pumped Storage Hydroelectricity (PSH), abandoned mine shafts, and solid-mass systems.

PSH operates by pumping water from a lower reservoir to an upper reservoir during periods of excess electricity, then releasing it through turbines to generate power during peak demand. Global leaders for installed PSH capacity include China, Japan, and the US, with over 50 GW, 21 GW, and 18 GW installed, respectively [7]. In abandoned mine shafts, energy is stored by raising a mass within the mine shaft during periods of low electricity demand and released to generate power during peak demand. Abandoned mine shafts have also been utilized in PSH configurations globally, with operational projects in Germany, Spain, South Africa and the US. Finally, emerging solid-mass GES systems utilize mechanical cranes or shafts to elevate solid weights like concrete blocks or steel weights. Although commercial-scale implementation is still in its infancy, modeling studies indicate that these systems can achieve round-trip efficiencies ranging from 70% to 90%, influenced by mechanical losses, control systems, and material handling efficiency. In 2023, a 25MW solid-mass GES system was constructed in China by Energy Vault utilizing their EVx technology, as seen in Figure 3 below, which raises large composite blocks to store potential energy [8]. This project was the first of its kind implemented on a commercial scale globally, demonstrating the viability of solid-mass GES systems as an emerging energy storage technology.

Figure 3 Energy Vault EVx GES Technology [8]

2.2.1 Pumped Storage Hydroelectricity (PSH)

PSH is the most established form of grid energy storage, accounting for over 90% of global large-scale energy storage capacity, highlighting its dominance in the sector. PSH offers round-trip efficiencies of 70–85%, rapid response times (< one minute), and exceptional longevity, with lifespans ranging from 40 - 80 years. PSH systems typically have power capacities ranging from 100 MW to several gigawatts, making them well-suited for large-scale applications. They also provide discharge durations of 6–20 hours, ideal for daily load shifting, grid balancing, and frequency regulation.

There are two existing configurations (Figure 4), including Open-loop systems, which are connected to natural bodies of water (rivers, lakes); and Closed-loop systems: isolated reservoirs with minimal environmental disturbance. Recent innovations include underground PSH, modular small-scale PSH, and variable-speed pump-turbines, which improve grid flexibility and efficiency. Despite its proven performance, PSH faces challenges such as long permitting timelines, high upfront capital costs, environmental concerns, and geographic constraints requiring suitable elevation differences and significant water resources.

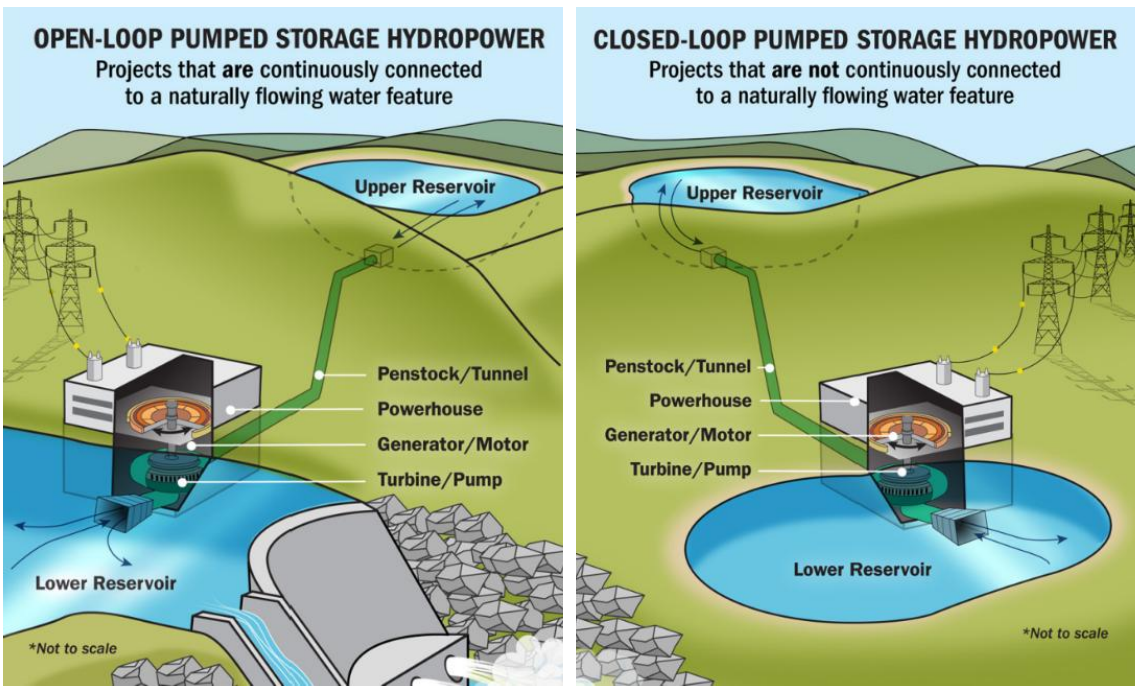

Figure 4 Open vs. Closed Loop PSH (figures taken from U.S. DOE [9])

NL has an abundance of freshwater reservoirs, with 13 hydroelectric facilities currently operating across the province. Of the existing facilities, nine were identified by NL Hydro as being potentially suitable for PSH, and an NL Hydro study conducted in 2023 has concluded that two of the nine facilities are viable options for large scale PSH, with another two facilities being identified as potentially viable [10]. The rugged terrain in NL creates a unique opportunity for the integration of PSH, as these systems rely on the potential energy created due to elevation differences between an upper and lower reservoir to store and dispatch electricity. As such, in addition to the integration of PSH into existing hydroelectric facilities, PSH can also be operated on a closed-loop system, creating opportunity for the development of reservoirs that may have been previously ruled out for the sole purpose of hydroelectric generation.

2.2.2 Abandoned Mine Shafts

Abandoned mines are increasingly being explored as potential sites for innovative forms of GES. These mines offer ready-made vertical infrastructure, reducing the need for extensive excavation and lowering initial capital costs. Depending on the specific technology used, these systems can deliver power capacities ranging from a few megawatts to over 100 MW, with discharge durations typically between 4–12 hours. Round-trip efficiencies vary by technology but generally range from 60–80%, and response times can be within seconds to a few minutes, making them suitable for grid support services like frequency regulation and peak shaving. The lifespan of such systems can exceed 30 years, especially when leveraging the robust structural integrity of existing mining infrastructure.

Newfoundland has a rich mining legacy, with numerous abandoned or inactive mines across the province. Historic sites like Buchans (once a major hub for zinc, copper, lead, and gold) and Bell Island, known for its iron ore deposits vital to North America's steel industry, shaped the region's economy for decades [11]. These legacy mines present potential opportunities for Underground Pumped-Storage Hydroelectricity (UPSH) by repurposing underground shafts as reservoirs. A typical GES system configuration in an abandoned mine can be seen in Figure 5 below.

International projects demonstrate the potential of abandoned mines for PSH. Germany's Prosper-Haniel coal mine was the world's first to host an underground PSH plant, featuring a 25 km horizontal shaft at a depth of 1.2 km and a 1 million m³ water capacity. A planned project in Upper Harz aims to convert an old metal mine at 760 m depth, into a 100 MW underground PSH facility. Spain's Asturian coal mine uses mine water inrush for a semi-underground PSH plant, while South Africa has converted a gold mine into a cascading PSH system. In the U.S., a 1,000 MW semi-underground plant was built in an abandoned New Jersey iron ore mine at 760 m depth. The Eagle Mountain PSH project in California repurposes two mine pits as upper and lower reservoirs, with an installed capacity of 1,300 MW.

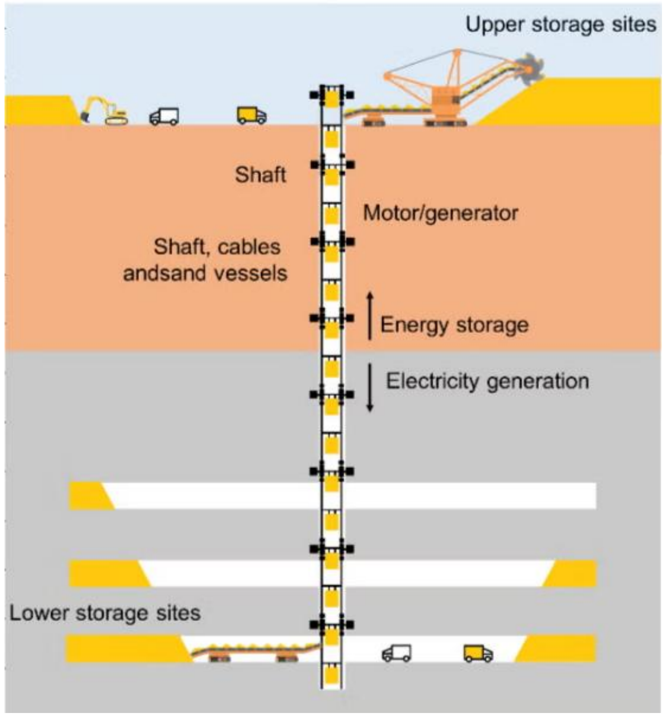

Figure 5 Abandoned Mine GES [12]

2.3 Thermal Energy Storage (TES)

While gravity storage focuses on mechanical potential energy, thermal storage leverages heat management across various temperature ranges and materials. TES systems store excess energy in the form of heat or cold, which can later be retrieved for power generation or direct thermal use. TES is a critical enabler for concentrating solar power (CSP), combined heat and power (CHP) systems, district heating networks, and industrial heat applications. TES technologies are generally classified into three main types:

- Sensible Heat Storage (SHS): Energy is stored by increasing the temperature of a material (typically water, molten salts, or solid materials like concrete or rocks). SHS is widely used in CSP plants, where molten salts operate at temperatures of 290–565°C, achieving energy densities of ~150–300 kWh/m³ and RTE of 75–90%.
- Latent Heat Storage (LHS): Utilizes phase change materials (PCMs) to store energy at constant temperatures during phase transitions (e.g., solid-liquid). LHS offers higher energy densities (200–400 kWh/m³) compared to SHS, but challenges include thermal cycling stability, low thermal conductivity, and material cost. LHS's RTE ranges between 70-85%.

- Thermochemical Storage (TCS): Stores energy through reversible chemical reactions, offering exceptionally high energy densities and long-duration storage with minimal losses over time. Examples include metal oxides, ammonia-based systems, and sorption-based cycles.

2.4 Hydrogen Energy Storage Systems (HESS)

Hydrogen offers a viable pathway to address the intermittency of generation from sources by enabling surplus renewable electricity to be converted into hydrogen through water electrolysis. This hydrogen can then be stored and subsequently utilized e.g. as a fuel in gas turbine during periods of low renewable generation or heightened demand, thus supporting grid flexibility, peak shaving, and long-duration energy storage needs. Even though hydrogen possesses a high gravimetric energy density, making it a lightweight energy carrier, its volumetric energy density is relatively low - about four times smaller than that of natural gas - requiring vast storage volumes. A common method for handling gaseous fuels is compression to high pressures in order to reduce their volume. However, unlike traditional fuels such as natural gas, hydrogen requires significantly more energy for compression due to its lower relative density. Hydrogen's density does not increase linearly with applied pressure due to its molecular properties; achieving a density of 70 kg/m^3, for example, requires pressures exceeding 2000 bar, whereas methane (CH_4) can achieve similar densities at roughly 95 bar under ambient conditions.

For small-scale hydrogen gas storage, pressure vessels are a practical solution and are classified into four types (I–IV) based on their construction materials. Type I vessels are entirely metallic, typically made from carbon or low-alloy steel, and are commonly used in industrial and commercial settings, with capacities up to 50 m^3 at 200 - 300 bar. Type II vessels feature a thick metal liner (steel or aluminum) that ensures gas tightness, with a pressure range of 100 - 500 bar. Type III vessels use a thin metal liner fully wrapped in high-strength fiber resin composite, which bears most of the pressure load, and operates up to 450 bar. Type IV vessels have a polymer liner fully encased in a fiber resin composite, where the polymer provides gas containment; only the vessel boss and liner-junction remain metallic. These vessels support pressures up to 1,000 bar. High-pressure hydrogen gas storage in pressure vessels is employed in fuel cell electric vehicles (FCEVs), with typical operating pressures of 350 bar for buses and trucks and 700 bar for passenger cars, reflecting the differing design requirements and range expectations across vehicle categories.

Underground geological structures e.g. salt caverns, offer a viable option for large-volume storage of hydrogen in gaseous form, such as ACES (Advanced Clean Energy Storage) Delta hub in Utah (Figure 6);

however, the pressure is limited to 200 bar due to the structural constraints of the cavern. Gaseous hydrogen stored in salt caverns can serve as a fuel for gas turbines (combustion), providing a flexible solution to meet grid peaking demands. GE Vernova pioneered aeroderivative turbines (LM6000VELOX) engineered for 100% renewable hydrogen, though the Whyalla project has since been canceled. Mitsubishi is operationalizing hydrogen combustion in utility-scale M501JAC turbines (30% blend now, targeting full hydrogen). Meanwhile, Siemens' HYFLEXPOWER demo confirmed 100% hydrogen capability in its industrial SGT-400 platform. Blending hydrogen into existing natural gas networks is an emerging strategy to decarbonize energy systems by leveraging current infrastructure. This approach involves injecting hydrogen (typically up to 20% by volume) into natural gas pipelines, allowing for a gradual transition toward cleaner fuels without the need for entirely new distribution systems. Eastward Energy, Nova Scotia's natural gas distributor, has been approved to blend up to 5% hydrogen into Halifax's natural gas grid starting as early as 2026.

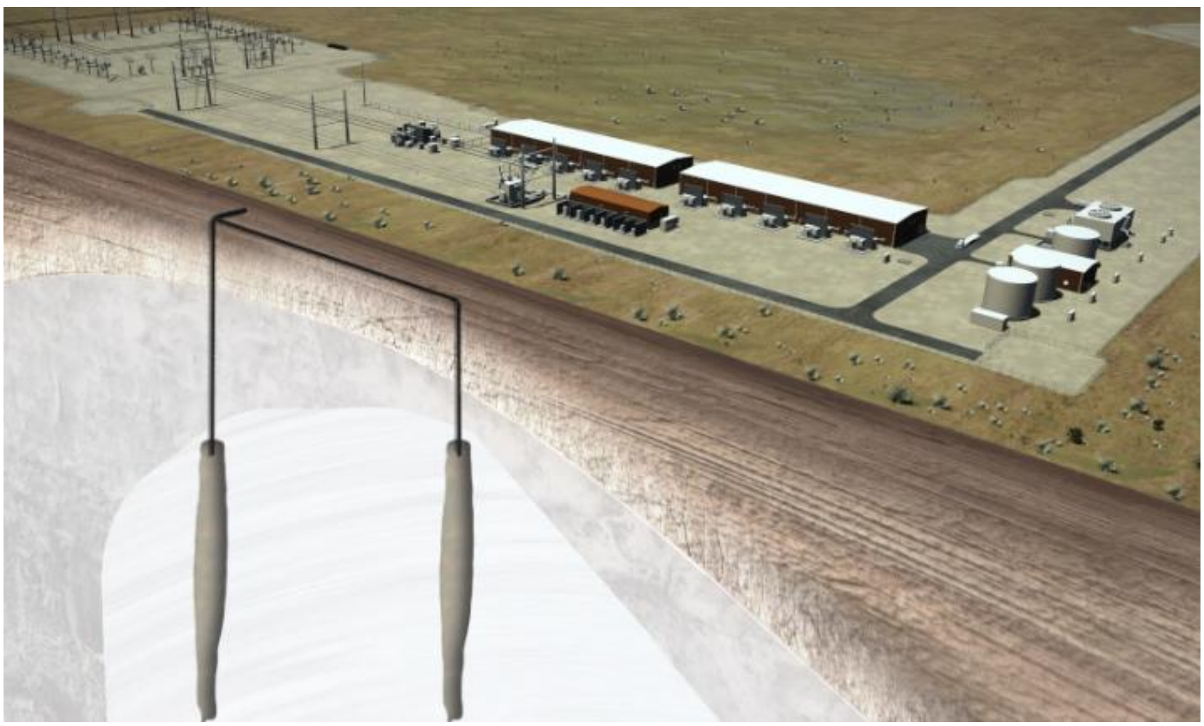

Figure 6 The ACES Delta will initially be designed to convert over 220 MW of renewable energy to 100 metric tonnes per day of green hydrogen, which will then be stored in two massive salt caverns capable upon start up of storing more than 300 GWh of dispatchable energy [13].

Hydrogen's density can be significantly increased by liquefaction, which requires cooling it to temperatures below –253 °C. Despite the use of robust, highly insulated cryogenic storage vessels that meet stringent sealing requirements, evaporation losses, known as boil-off, still occur at roughly 0.520% per day. To mitigate boil-off losses associated with liquefied hydrogen storage, ammonia is considered a promising alternative energy carrier. As a hydrogen-rich compound, ammonia remains liquid under milder conditions (–33 °C at atmospheric pressure), enabling more efficient storage and transport without significant evaporative losses. Ammonia benefits from a well-established global supply chain, with 38 import ports, 88 export ports, and 6 ports serving both functions. The volumetric energy density of liquid ammonia is 3.58 MWh/m3. Currently, approximately 70% of ammonia is utilized in the production of agricultural fertilizers, while the remaining 30% serves as a feedstock for various industrial chemicals, including plastics and explosives.

The Haber–Bosch process, the most technologically mature method (TRL 9), is widely employed to convert hydrogen into ammonia. It has been estimated that 1 kg of hydrogen yields approximately 5.361 kg of liquid ammonia through synthesis. However, to convert liquid ammonia into hydrogen gas requires an ammonia cracking process and it has been established that 1 kg liquid ammonia can produce 0.1416 kg hydrogen gas considering 80% conversion efficiency. Large-scale ammonia crackers are also employed in the production of heavy water, where deuterium - used as a moderator in nuclear reactors - is extracted in the gaseous phase using ammonia as an intermediary.

Liquid Organic Hydrogen Carriers (LOHCs) offer a viable means of hydrogen storage under ambient conditions, enabling reversible hydrogenation and dehydrogenation with minimal loss. LOHCs are liquid compounds that store hydrogen via reversible hydrogenation and release it through dehydrogenation. In this cycle, hydrogen bonds to the carrier and is later released as the sole product, restoring the LOHC to its initial form. Most LOHCs exhibit low melting points and high boiling points, maintaining a stable liquid state at room temperature. This allows them to be handled similarly to petrochemicals, facilitating integration into existing infrastructure within a hydrogen-based economy. Examples of LOHCs include toluene/methylcyclohexane, dibenzyltoluene/perhydrodibenzyltoluene, naphthalene/decalin, N-ethylcarbazole/perhydro-N-ethylcarbazole, and methanol.

Moss Bluff and Clemens, Texas, host two large-scale underground hydrogen storage facilities with capacities of 566,000 m^3 and 580,000 m^3 respectively. Both utilize salt cavern technology, which leverages naturally occurring salt domes to safely store hydrogen under high pressure. These analogous sites demonstrate the scalability and reliability of hydrogen underground storage, supporting grid stability and the integration of renewable energy into the power sector.

The U.S. Department of Energy (DOE) classifies hydrogen storage into several key categories based on physical and material-based storage methods (Figure 7). Compressed Hydrogen Gas and Liquid Hydrogen are categorized in the physical-based storage method. When Hydrogen is stored on the surface of porous materials, like metal-organic frameworks (MOFs) and carbon-based materials, this is called adsorption material-based storage. When hydrogen is stored in chemical compounds like ammonia or liquid organic hydrogen carriers (LOHCs), it is classified as chemical material-based storage [14].

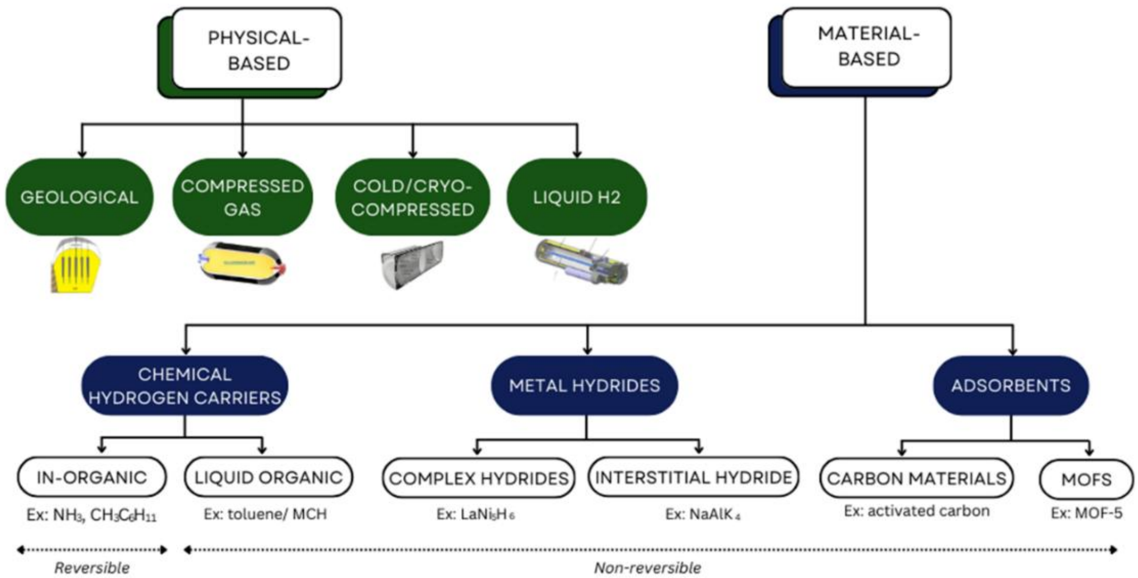

Figure 7 Types of Hydrogen Storage (modified from US Department of Energy [15])

2.5 Underground Caverns

Underground cavern-based systems are mechanical energy storage systems where excess electricity is used to compress fluids and store them in underground geological formations (e.g., salt domes, aquifers, depleted reservoirs, or hard rock caverns). These fluids are then released to drive turbines and generate electricity when needed. Underground cavern-based storage offers grid-scale balancing, renewable integration, and intraday storage potential, contributing significantly to decarbonization goals and grid flexibility.

2.5.1 Salt Caverns

Salt caverns are one of the main underground storage types, besides the well-known depleted gas reservoirs and aquifers (Figure 8) It is the void space created within salt dome structures, both bedded and domal, for storing gas or liquids by solution mining. Salt domes typically appear in regions where large ancient seas once existed, and salt was deposited in layers. Over time, geological forces like tectonics and halokinesis caused the salt layers to shift and fold into dome-like structures, which can trap gases or liquids beneath them. These domes are widely regarded as suitable geological structures, particularly for large-scale CAES, Adiabatic and Diabatic CAES (A/DCAES), and hydrogen storage, which involves the injection of compressed air and hydrogen, respectively, into subsurface salt caverns to be withdrawn when excess power generation is required. Salt caverns are suitable for this type of LDES due to their impermeability, structural integrity, excellent sealing properties, and ability to withstand repeated cycling at high pressures.

Salt cavern solution mining involves the injection of water or undersaturated brine to dissolve underground salt deposits. While effective, the process generates large volumes of concentrated brine that may contain harmful metals like lead, arsenic, and cadmium, along with chemical residues from pretreatment and cleaning. If not properly managed, the disposal of this brine can harm aquatic ecosystems, disrupting marine life and reducing dissolved oxygen levels. The other main risks in underground salt cavern storage stem from cavern stability and well integrity. Repeated pressure and temperature cycling can degrade cavern walls and well materials, especially when storing hydrogen by the weakening and healing plus recrystallization of the halite which in return influences the overall creep behaviour and permeation. To ensure safety and economic viability, storage systems must be carefully designed to minimize these impacts.

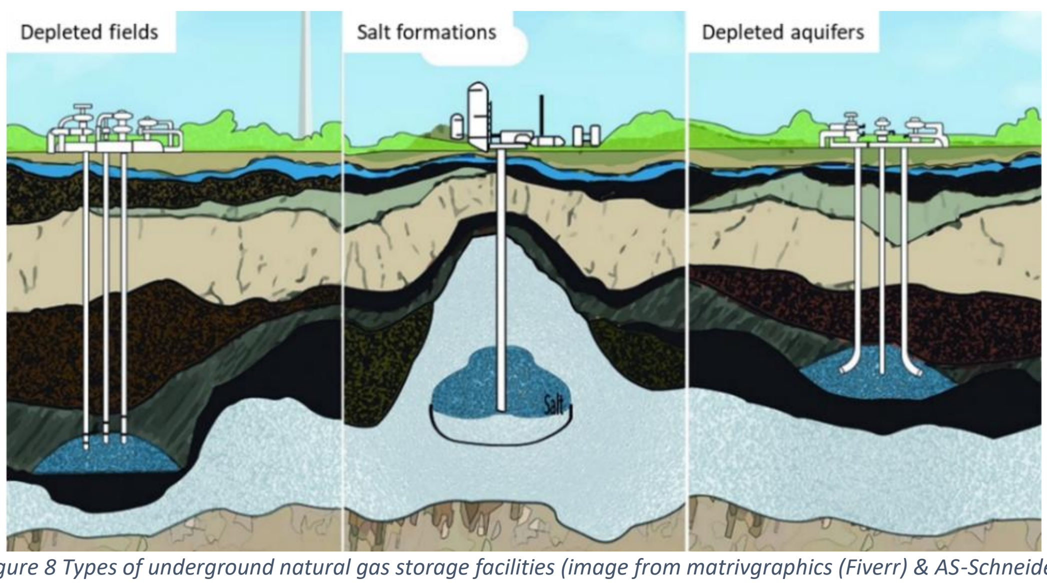

Figure 8 Types of underground natural gas storage facilities (image from matrivgraphics (Fiverr) & AS-Schneider)

Key quantifiable criteria include the lateral extent and depth of the salt structure, with minimum areal dimensions of approximately 1 km² and depths typically ranging between 500 and 2,000 meters, though optimal cavern stability and pressure tolerance are often achieved between 1,000 and 1,500 meters [16]. Salt structures within this depth range benefit from sufficient overburden pressure for cavern integrity, while remaining accessible and economically feasible for solution mining. In terms of cavern design, economically viable volumes typically fall within the range of 100,000 m^3 to 1,000,000 m^3 (1 Mm^3), depending on the energy storage application, operational cycle, and technology used [17].

The design and operational parameters of salt caverns for subsurface energy storage vary significantly depending on whether they are intended for CAES or Hydrogen Energy Storage (H_2ES) applications. H2 storage systems necessitate gas purification units to maintain the required purity levels for downstream use, such as fuel cells or industrial applications. Hydrogen's small molecular size increases the risk of leakage through microfractures or imperfect seals, which makes cavern integrity and monitoring systems critical [18]. H2 presents a higher operational risk profile compared to compressed air due to its wide flammability range, low ignition energy, and potential for explosive behavior under certain conditions. As a result, H_2ES facilities are subject to stricter regulatory oversight, requiring enhanced safety protocols, including advanced ventilation, leak detection, explosion-proof equipment, and robust emergency response systems [19] [9]. By contrast, CAES systems, while also operating under high pressure, generally involve less stringent gas purity and safety requirements. However, they still necessitate careful thermodynamic design to manage the heating and cooling effects during compression and expansion cycles, which impact material selection and cavern thermal performance [20].

2.5.2 Diabatic Compressed Air Energy Storage (DCAES) in Salt Caverns

DCAES refers to traditional CAES systems where the heat generated during air compression into underground caverns is dissipated to the environment, requiring fossil fuel combustion to reheat the air before expansion. While these systems are less efficient (typically 40–55% round-trip efficiency) and have associated emissions, they remain commercially viable and have been successfully deployed at large scale (e.g., the McIntosh in Alabama and the Huntorf plant in Germany). DCAES offers proven reliability for long-duration storage applications and is particularly attractive where natural gas infrastructure is co-located (Figure 9).

2.5.3 Adiabatic Compressed Air Energy Storage (ACAES) in Salt Caverns

ACAES systems improve upon conventional designs (DCAES) by incorporating thermal energy storage, capturing the heat generated during air compression into underground cavern storage and reusing it during the expansion phase. This eliminates the need for external heating fuels, dramatically increasing system round-trip efficiency (often 60–70%) and reducing carbon emissions. A diabatic process involves the gain or loss of heat (and thus a change in entropy) while an adiabatic process occurs without gain or loss of heat (and thus with no change in entropy). ACAES systems can be further broken out into constant volume and constant pressure systems, with the main difference being the presence of a compensation water reservoir for pressure regulation in constant pressure systems. ACAES designs are modular and can be adapted to various geological formations, offering flexible deployment options for supporting RE integration, peak shaving, and ancillary services (Figure 9).

Figure 9 Schematic of Diabatic (left) and Adiabatic (right) CAES [21].

Repurposing a CAES facility for underground hydrogen storage requires thorough geological and engineering assessments. Among various formations, salt caverns stand out as technically viable for long-term hydrogen storage, thanks to their favorable geometry and thermo-hydro-mechanical (THM) stability. However, effectiveness depends on storage capacity, end-use (e.g., power generation or industrial), and hydrogen purity. If salt structures are geochemically complex or biologically active, posing risks like H_2S contamination, CAES may remain the better use [22]. Pressure cycling may create microfractures, especially at halite-anhydrite interfaces, where anhydrite can fuel sulfate-reducing bacteria, leading to H_2S formation. Microbial growth can also occur around wellbore cement and in the sump, a key site for colonization. These processes risk gas contamination, corrosion, and material degradation. Current research supports using clean, homogenous salt caverns with minimal sump interaction to preserve hydrogen purity. One key challenge in repurposing salt caverns or former CAES sites for hydrogen storage is the need for hydrogen- and hydrogen sulfide-resistant materials, particularly in wellbores, seals, and other infrastructure. These materials must withstand hydrogen embrittlement and microbially induced corrosion. Yet, much of this technology remains in early research or pilot stages, with limited commercial application. A phased approach may be viable—

initially deploying CAES, followed by de-brining to restore cavern integrity for hydrogen storage—though this requires careful material selection and design planning.

2.5.4 Aquifers

Aquifers are porous geological formations that contain groundwater within the pore space of the formation rock. Aquifers are classified as either confined, which are those that are overlain with impermeable or very low permeability cap rock, or as unconfined, which are those that are overlain with permeable soil and receive water directly from surface seepage.

Saline aquifers are considered as suitable geological formations for CAES and hydrogen storage due to their large storage capacities, geographical accessibility, and proven historical use for natural gas storage [23]. Saline aquifer storage has a low environmental impact, as it does not require freshwater injection or the disposal of brine, and the risk of hydrogen contamination is relatively low [23]. A fraction of the injected gas is considered as cushion gas, which is unrecoverable and critical for maintaining the formation pressure, while the remaining gas is known as the working gas and is charged and discharged from the formation for energy storage and generation. One key challenge for CAES and hydrogen storage in aquifers is determining the gas trapping capability of the formation, which requires comprehensive geological studies.

2.5.5 Depleted Reservoirs

Similarly, depleted hydrocarbon reservoirs are another viable underground CAES and hydrogen energy storage alternative. Depleted hydrocarbon reservoirs have proven fluid trapping capabilities, as well as existing well infrastructure, however, possible chemical interactions between reservoir hydrocarbons and injected hydrogen need to be studied extensively. The cushion gas requirement for depleted hydrocarbon reservoirs is also lower than that of saline aquifers, due to the presence of remaining native hydrocarbons in the pore space of the formation.

3 Energy Storage in the Newfoundland and Labrador (NL) Context

There is significant opportunity for energy storage applications in NL, and jurisdictional potential depends on several different factors, including: topography, geotechnical properties, resource availability, grid infrastructure, and climate.

3.1 NL Geographic and Resource Suitability Relevant to Storage

NL's energy landscape is characterized by a hydroelectric-dominant system, with over 90% of electricity generated from hydropower sources. Churchill Falls Generating Station alone boasts an installed capacity of 5,428 megawatts (MW) and annual generation of approximately 34,000 gigawatt-hours (GWh). Additionally, there are currently six wind energy to hydrogen projects under development, which would diversify the province's energy portfolio, supply the hydrogen markets in Europe, and present opportunities for energy storage projects due to the intermittency of wind [24] [25]. The province is also home to numerous remote and off-grid communities, particularly across rural coastal regions of Labrador, which often rely on diesel generation for electricity.

There is a current lack of energy storage in the province, with a small-scale BESS project in southern Labrador being the only operational energy storage solution in NL at present time. However, there has been significant opportunity identified for underground storage in the form of salt domes on the west coast of Newfoundland, as well as the integration of PSH into existing hydroelectric facilities in central Newfoundland, with additional opportunities highlighted throughout this discussion paper.

3.1.1 Renewable Energy Resources

NL is home to world class renewable resources, which present significant opportunity for the electrification and diversification of the NL electricity grid but also creates a need for energy storage solutions to combat renewable energy intermittency.

<u>Hydro</u>

The combination of geographic, climatic, and hydrological factors, such as mountainous areas with a dense network of rivers and streams, and steep/ high elevation topography are a key factor for NL's success in hydropower. A key challenge with hydropower is the seasonal variation in water flow, but the constant snowmelt and abundant rainfall in NL help maintain consistent flows year-round, especially in major river systems like the Churchill River in Labrador. Canada's largest hydropower projects, including Muskrat Falls and Churchill Falls, are already well integrated into the energy grid. The hydropower plants could work synergistically with storage technologies like PSH or BESS to balance grid fluctuations caused by the intermittency of other renewable sources.

Wind

In addition to hydro, the west coast of NL, especially near the Gulf of St. Lawrence, is recognized for world-class wind speeds, with some areas reaching class 7 wind speeds (very strong winds, typically 50 – 61 km/hr) that are ideal for large-scale wind farms. The province currently has three utility-scale wind projects located on the south coast of the island. This includes one in St. Lawrence and one in Fermeuse, both are privately-owned 27-megawatt wind farms, on the province's Interconnected Electricity System, and a third project in the isolated diesel-generated electricity system in Ramea, which is now operated by Puffin Wind Inc. The offshore wind potential around NL is also significant, notably also along the Gulf of St. Lawrence areas. NL's long coastline, open, flat terrain with few obstructions, along the Atlantic Ocean, exposes the region to consistent ocean winds, allowing wind to flow unimpeded. Elevated coastal regions also act as natural wind funnels, particularly along exposed ridges and peninsulas. On average, the wind speeds along the NL coast and certain offshore areas are known for wind speeds of 8-10 m/s (29 – 36 km/hr) or higher, which are ideal for large-scale wind turbines (Figure 10)

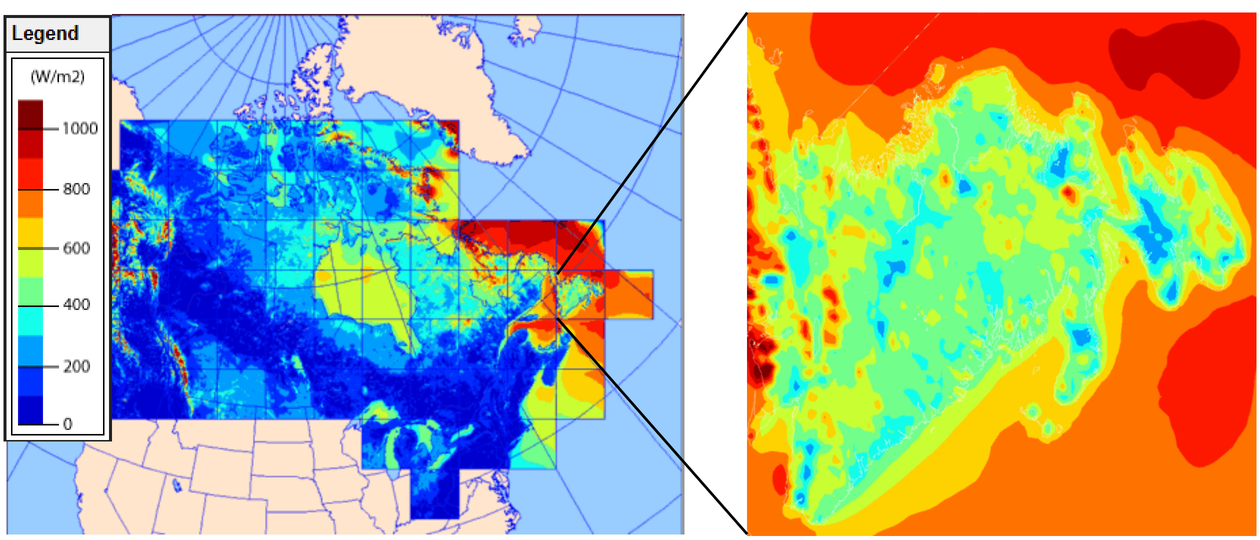

Figure 10 Annual mean wind energy at 50 m height. Base maps generated by Wind Atlas [26]

Solar

NL ranks the lowest for solar production potential out of all Canadian provinces and territories, with the national average solar energy production potential being 1133 kWh/kW/yr and the average in NL being 949 kWh/kW/yr [27]. The region's northern latitude (approximately 47°–60°N) and maritime climate contribute to lower solar insolation, as the sun's rays hit at a more oblique angle than in equatorial areas (Figure 11). In winter, limited daylight hours and extended periods of darkness further reduce solar output. Although solar panels operate efficiently in cold temperatures, heavy snowfall in NL can obstruct panels and reduce performance unless they are properly angled for snow to slide off. Despite these challenges, solar energy, especially when paired with battery storage, can still be a valuable solution for small-scale applications, such as residential solar. The viability of small-scale applications for residential solar in NL is further supported through programs such as the NL Power and NL Hydro Net Metering programs, whereby residential and commercial customers are permitted to generate up to 100 kW of renewable electricity for their own use and supply the provincial electrical system with any surplus for credit.

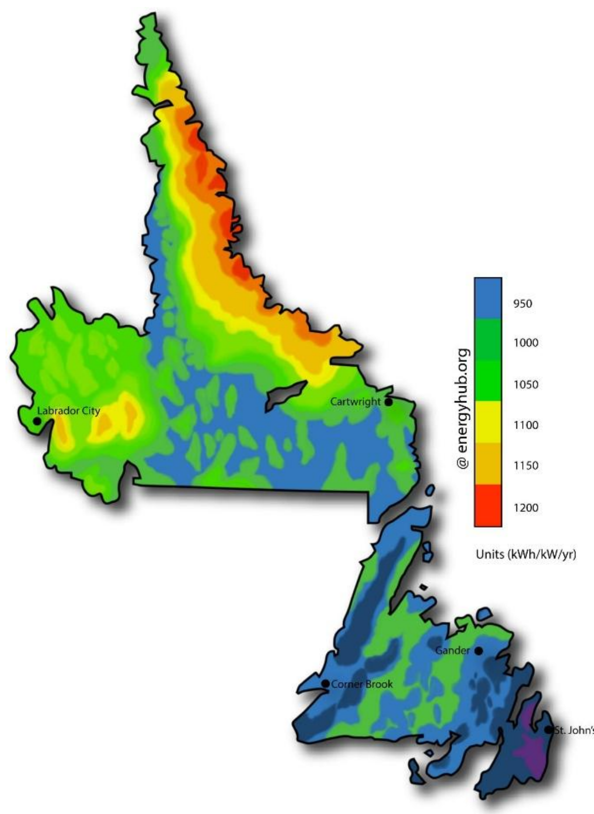

Figure 11 Solar Energy Map of NL shows the amount of energy that a solar photovoltaic system can produce (in units of kWh/kW/yr), based on the intensity of light that reaches the Earth's surface. Figure taken from Energy Hub [27].

Biomass/Biofuel

As with any Canadian jurisdiction, NL inevitably has a variety of organic industrial waste streams, presenting an opportunity for the development of biomass energy and biofuels. NL's industrial organic waste is mainly derived from agriculture, forestry, fishery, aquaculture, clearing and trimming, and wastewater. These sources create opportunity for the development of direct biomass combustion, thermochemical biomass conversion, chemical biomass conversion, and biological biomass conversion for energy generation or the creation of biofuels.

3.1.2 Natural Geological Formations and Geotechnical

Western Newfoundland is not yet as well-known for salt domes as other parts of the world (e.g., Texas or Windsor, Ontario), however, sedimentary basins and potentially favorable conditions for salt deposits exist in this region as seen in Figure 12 below. These salt formations can offer multiple advantages for energy storage, such as compression and containment, since salt domes are impermeable and can hold gases under pressure without leakage. They provide enormous storage capacity in the form of underground caverns that can be scaled up as energy demands grow. Apart from salt formations, NL has large regions of porous bedrock, which could potentially be explored for hydrocarbon-free energy storage systems, such as CAES or geothermal storage, though this would require an in-depth geological assessment. In addition, carbonate rocks such as limestone and dolomite can also have potential for gas storage, particularly in the form of CO_2 sequestration or hydrogen storage.

While not as common for CAES as salt domes, porous carbonate rocks can still serve as effective underground reservoirs. The region is also home to significant amounts of granite and metamorphic rock formations. These are typically much less porous than sedimentary rocks, but they can still serve a purpose in energy storage, particularly if they have fractures or fault lines that could potentially store fluids. These hard rock formations can support certain types of geothermal storage or compressed air storage if certain conditions are met, such as the presence of natural fractures to store pressurized air or water. Some geological survey indicates limited or evaporite sequences identified in parts of offshore basins, but their suitability for energy storage remains uncertain. Factors such as depth, thickness, continuity, and accessibility must be rigorously evaluated to determine whether these formations can support the development of storage caverns.

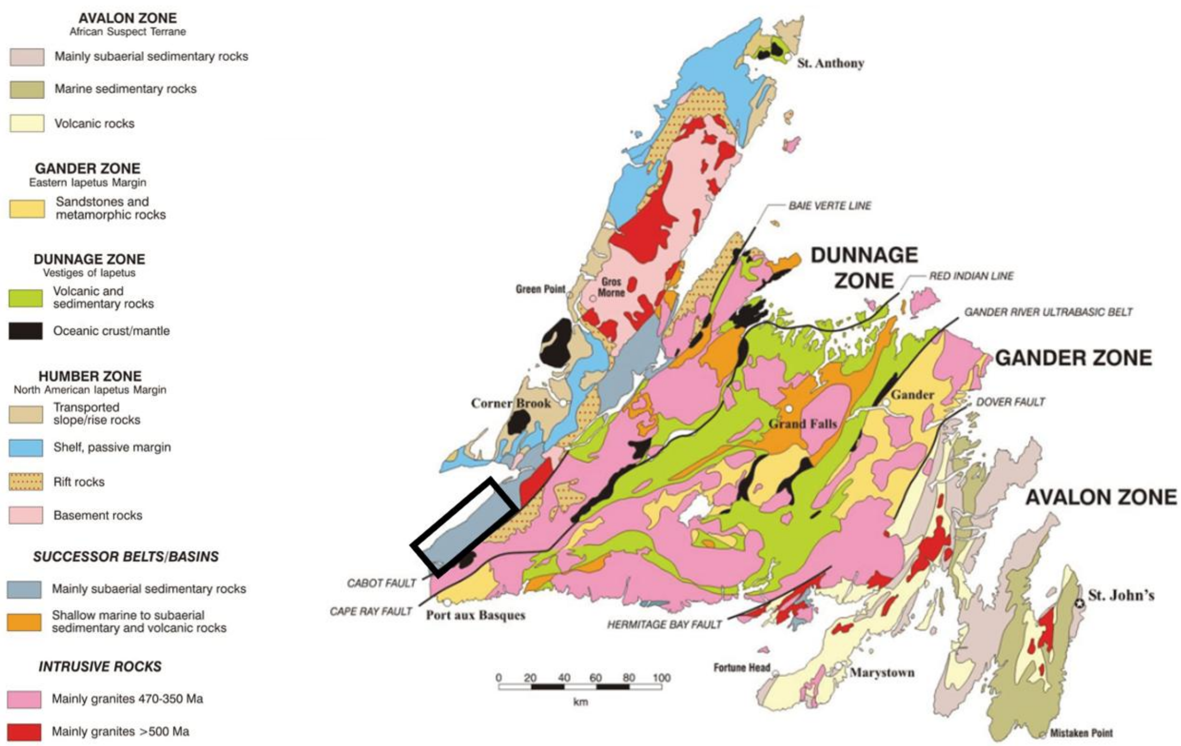

Figure 12 Generalized interpretive map of NL and Appalachians highlighting the zone of two developing underground salt caverns [28].

3.2 NL Energy System Characteristics Relevant to Storage

The energy system in NL presents its own set of unique challenges and opportunities for the integration of additional renewables capacity and energy storage solutions.

3.2.1 Energy Demand and Grid Configuration

NL Hydro generates more than 90% of electricity from renewable resources, and provides energy throughout the island of Newfoundland, and to customers in Labrador. The current demand in NL includes residential, commercial, and industrial customers, which are connected through the electrical transmission system on the island, known as the Island Interconnect System/Grid (Figure 13). The current ~1024 MW Newfoundland demand is an indication of the current customer demand (including system losses) in NL, which is served by:

- Power from NL Hydro generation assets, including:
  - Hydroelectric plants
    - Bay d'Espoir Generation System (Bay d'Espoir, Upper Salmon, Granite Canal)
    - Cat Arm Generating Station
    - Hinds Lake Generating Station

        - Paradise River Generating Station
        - Menihek Generating Station
        - Roddickton Mini Hydro Plant (not currently operating)
    - Holyrood Thermal Generating Station
    - Gas/Combustion Turbines (Happy Valley-Goose Bay, Stephenville, Holyrood, Paradise)
    - 23 Remote Diesel Plants
- Generation from the Churchill Falls and Muskrat Falls Generating Stations that flows across the Labrador Island Link (LIL) to supply customers on the island.
- Generation from the Exploits System (Star Lake, Grand Falls, Bishop's Falls), which NL Hydro operates on behalf of the provincial government.
- Generation from Power Purchase Agreements (PPA) with non-utility generators, including Rattle Brook Hydroelectric Generating Station, Corner Brook Pulp and Paper Cogeneration and Deer Lake Power, Mary's Harbour Mini Hydro, Solar, and BESS, St. David's Biogass, and wind generation from the Ramea, St. Lawrence and Fermeuse wind farms.
- NL Hydro's diesel plants in St. Anthony and Hawkes Bay are available, on standby, if needed.

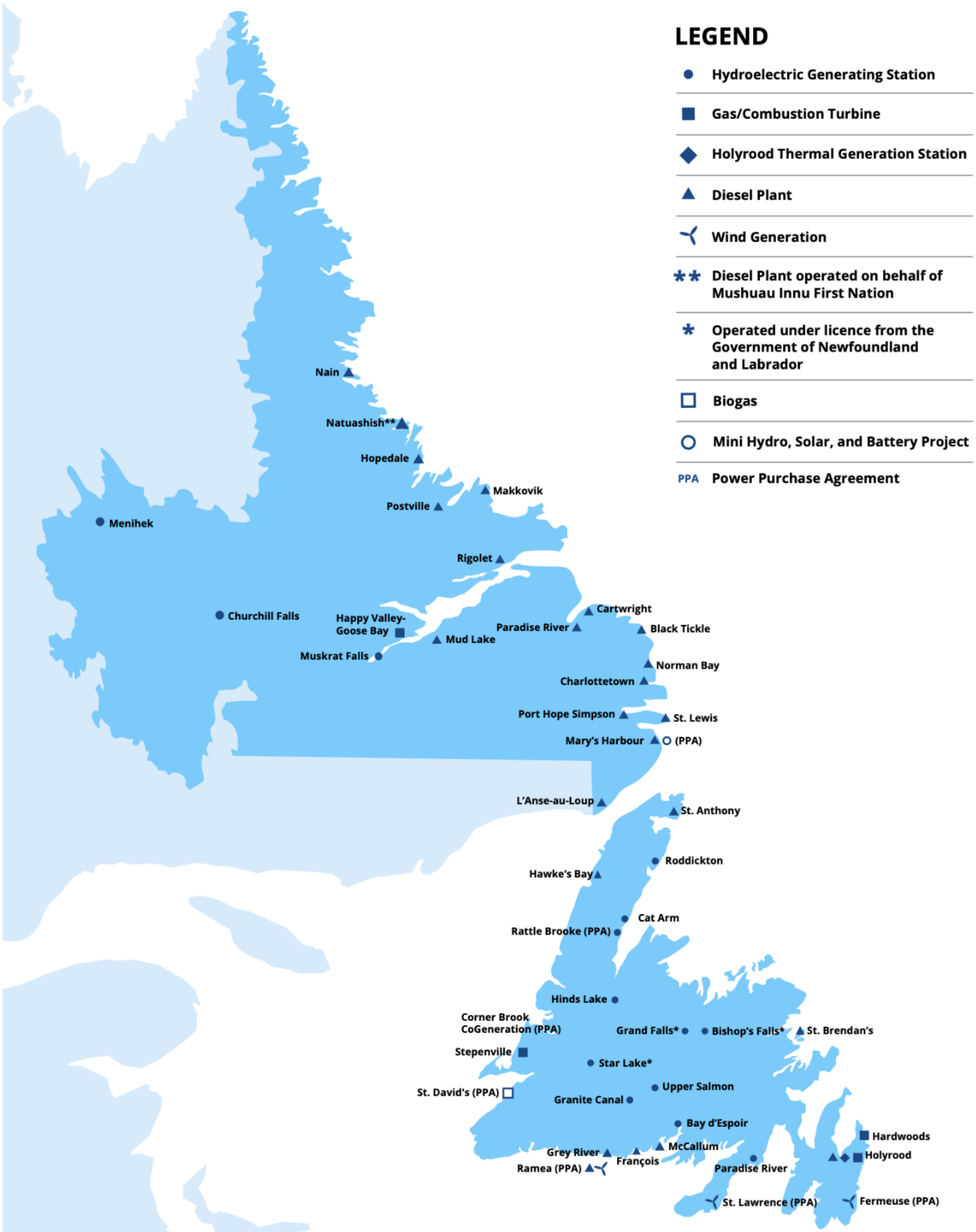

Figure 13 The map of Electricity Generation and Service Areas in NL [29].

3.2.2 Grid Reliability and Existing Transmission Infrastructure

In NL, the transmission[1] system is quite unique because it includes high-voltage AC lines on the island portion, High-voltage DC (HVDC) transmission connecting Labrador to Newfoundland (known as the Labrador-Island Link), HVDC transmission connecting Nova Scotia to Newfoundland (known as the Maritime Link), as well as power interconnections from Labrador to Quebec via the Churchill Falls Generating Station, which supplies power to Hydro-Québec under a long-term contract.

NL Hydro's transmission system includes over 10,000 km of transmission and distribution lines that span through some of the most geographically challenging and isolated areas of the province. This system includes dozens of high-voltage terminal stations and lower-voltage distribution stations, connecting power from Labrador to the island and all the coves, towns and inlets along the way. This system includes Labrador-Island Link (LIL) (900 MW capacity), which is also overhead until it reaches the crossing points, spans approximately 1,100 km, including three 35 km subsea cables (HVDC) beneath the Strait of Belle Isle, connecting Labrador to the island. When it was completed in 2023, this marine cable crossing was the first ever physical connection between Muskrat Falls in Labrador and Soldiers Pond in the island of Newfoundland. Owned by EMERA, the Maritime Link is a subsea HVDC cable spanning the seabed of the Cabot Strait, connecting NL Hydro transmission systems in NL with Nova Scotia. This connection enables the transmission of reliable, renewable electricity from Newfoundland to the neighbors in Nova Scotia, and beyond (Figure 14, Figure 15, Figure 16).

NL Hydro has restricted the total capacity of new interconnections to the Island grid to 155 MW to ensure that the failure of a single interconnection does not violate established system planning criteria for reliability and contingency response. This limitation presents a significant operational constraint on the integration of additional generation capacity, including wind, solar, or BESS, into the provincial grid. Moreover, generation technologies that rely on power electronics, such as inverter-based resources (IBRs), may necessitate additional dynamic support infrastructure, including synchronous condensers, to maintain voltage stability and system inertia. More recent analysis by NL Hydro have identified limits (Maximum IBR in MW) for each Terminal Station across the province for various lengths of transmission connections when connecting IBRs to the power system. An IBR Interconnection Guide has been developed which will serve to provide clarity on interconnection limitations across the Newfoundland transmission system [30].

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[1] *Unlike urban distribution systems, most of NL's transmission lines are overhead towers or poles, traversing the island and Labrador's challenging terrain.*

Figure 14 Detailed view of the transmission and generation assets that make up electricity system in Newfoundland

Figure 15 Detailed view of the transmission and generation assets that make up electricity system in Labrador

The location of new interconnections must also be evaluated through a more detailed System Impact Study (SIS), which assesses the technical implications of integrating new generation or storage resources, including their effects on system stability, power flow, voltage profiles, and fault levels. These studies are conducted in a queue under a first-come, first-served framework, and are essential for identifying potential operational impacts, necessary mitigation strategies, and transmission system upgrade requirements [31].

Interconnection potential with neighboring provinces like Quebec and Nova Scotia could open up cross-border electricity trading opportunities, enhancing the flexibility of energy storage solutions. In December 2024, NL Hydro and Hydro-Québec signed an agreement in principle to advance several major hydroelectric initiatives in Labrador, including a new 2,250 MW generating station at Gull Island, an 1,100 MW expansion of the Churchill Falls facility, and upgrades to existing Churchill Falls turbines to add approximately 550 MW [32]. To transmit this additional power, NL Hydro will construct 340 km of 735 kV AC transmission lines in Labrador, while Hydro-Québec will develop corresponding infrastructure in Quebec. As NL Hydro manages load flows on the Maritime Link, the potential exists to use this infrastructure to actively balance renewables and share energy storage resources with Nova Scotia or other provinces. Such interprovincial cooperation could enhance regional grid flexibility and reliability, especially on the extended Maritimes grid.

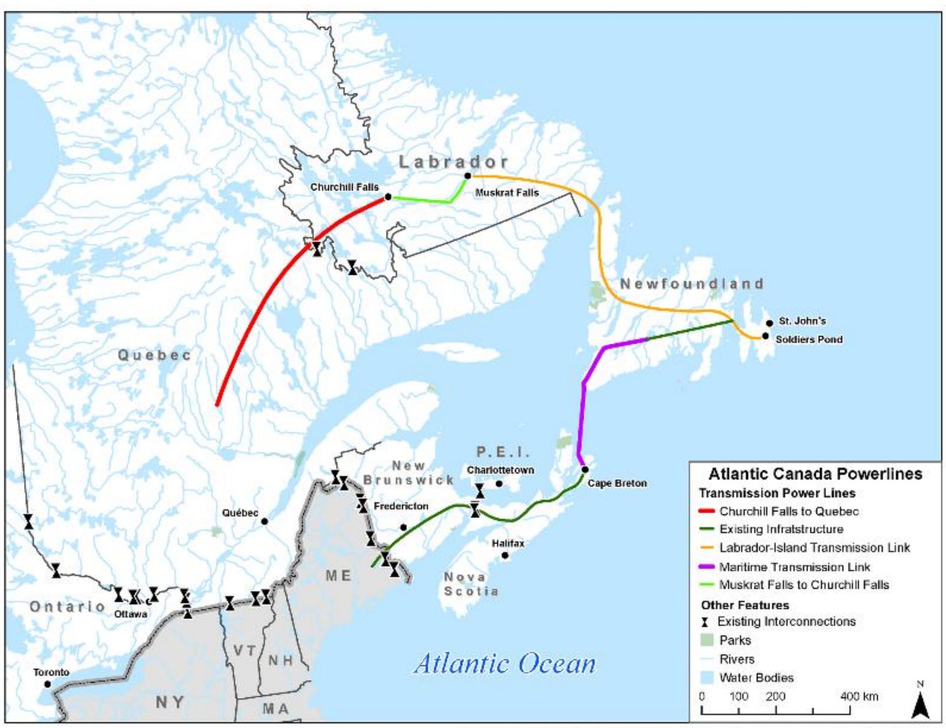

Figure 16 Cross border electricity transmission lines, relevant provincial links, and interconnections between Canada and the U.S.

3.2.3 Remote and Isolated Communities (microgrid)

NL is home to numerous rural and remote communities (Appendix B), each with distinct energy needs, infrastructure, and development contexts. Particularly in remote regions, NL's transmission lines are limited, this could hinder the efficient distribution of power from storage systems. Another challenge is the remote access to certain geographical locations, particularly in Labrador and offshore areas. Energy storage technologies that require large installations, such as PSH or grid-scale BESS, would require substantial infrastructure to connect them to the main grid. In contrast, microgrid systems could help reduce reliance on centralized infrastructure and make it easier to deploy RE with storage in remote or off-grid communities. Given that many of these sites are only accessible seasonally and face logistical constraints, the most viable storage options are typically modular BESS or other compact, dispatchable technologies. However, such deployments must be evaluated on a per-system basis due to high capital costs and unique load characteristics.

A detailed listing of selected rural communities across NL, categorized by community type (Indigenous or non-Indigenous), total installed fossil fuel generation (kW), total RE generation (kW), number of dwellings, and other relevant characteristics – are presented in Appendix B: Rural Community profile in NL. The data provides a snapshot of current energy systems in these communities, highlighting both the challenges and the opportunities for deploying energy storage systems tailored to local needs. It also serves as a foundation for further analysis of where targeted storage interventions can have the most meaningful technical, economic, and social impact.

3.3 Emerging Clean Energy and Storage Industry

Table 2 and Figure 17 below provide a summary of the currently developing Energy Generation for Green Fuels export, Power-to-X, and Energy Storage projects in NL, including key details, and the project status. The snapshot helps illustrate the province’s starting point of discussion on where targeted investments or policy efforts could accelerate energy storage deployment.

Table 2 Installed and planned Energy Generation for Green Fuels export, Power-to-X, and Energy Storage projects in NL

Project Name	Potential Capacity	Developer(s)	Offtake Agreement (Y/N)	Project Status
Robinsons River Salt Project	800,000 Tonnes of H2	Vortex Energy	N	Preliminary Development Phase

Fischells Salt Dome	180,000 Tonnes of H2	Triple Point Resources	N	Preliminary Development Phase
Argentia Renewables (Renewable Energy, Wind-to-Green Fuels, Hydrogen)	300 MW	Pattern Energy	N	Environmental Assessment Registration Document has been submitted
Wind-BESS-Diesel Project (previously Ramea)	900 kW Wind 1000 kW BESS	Puffin Wind Inc.	Y	Undergoing Redevelopment
Project Nujio'qonik (Phase 1,2,3,4)	4000 MW + 280,000 tonnes/yr Green H_2	World Energy GH2	N	Environmental assessment approval
Toqlukuti'k Wind and Hydrogen (Phase 1,2,3)	Phase I: 500 MW Phase II: 1000 MW Phase III: 3300 MW	ABO Energy and Copenhagen Infrastructure Partners (CIP)	N	Permitting process, with environmental baseline studies and community engagement ongoing
Burin Peninsula Green Fuels Project (Phase 1,2,3)	Phase I: 3000 MW Phase II: 5000 MW Phase III: 2000 MW 2500 MW Solar	Everwind Fuels	N	Environmental Assessment Registration Document has been submitted
Exploits Valley Renewable Energy Corporation	3000 MW 180,000 tons of Green H_2 Annually	Exploits Valley Renewable Energy Corporation (EVREC)	N	Environmental Assessment Registration Document has been submitted
North Atlantic Wind to Hydrogen Project (Green Energy Hub)	1100 MW 90,000 tons of Green H_2 Annually	North Atlantic Refining Limited	N	Environmental Assessment Registration Document has been submitted
Project Gwinya	5000 MW	CWP Global	N	(On hold)
Hinds Lake	200MW++ PSH	NL Hydro	Y	Operating (Hydropower 75 MW) PSH (not operating)
Star Lake	200MW++ PSH	Enel Green Power, NL Hydro	Y	Operating (18.4 MW Hydropower) PSH (not operating)
Mary's Harbour Renewables	500-kW Lithium-ion Battery	St. Mary's River Energy LP	Y	Operating

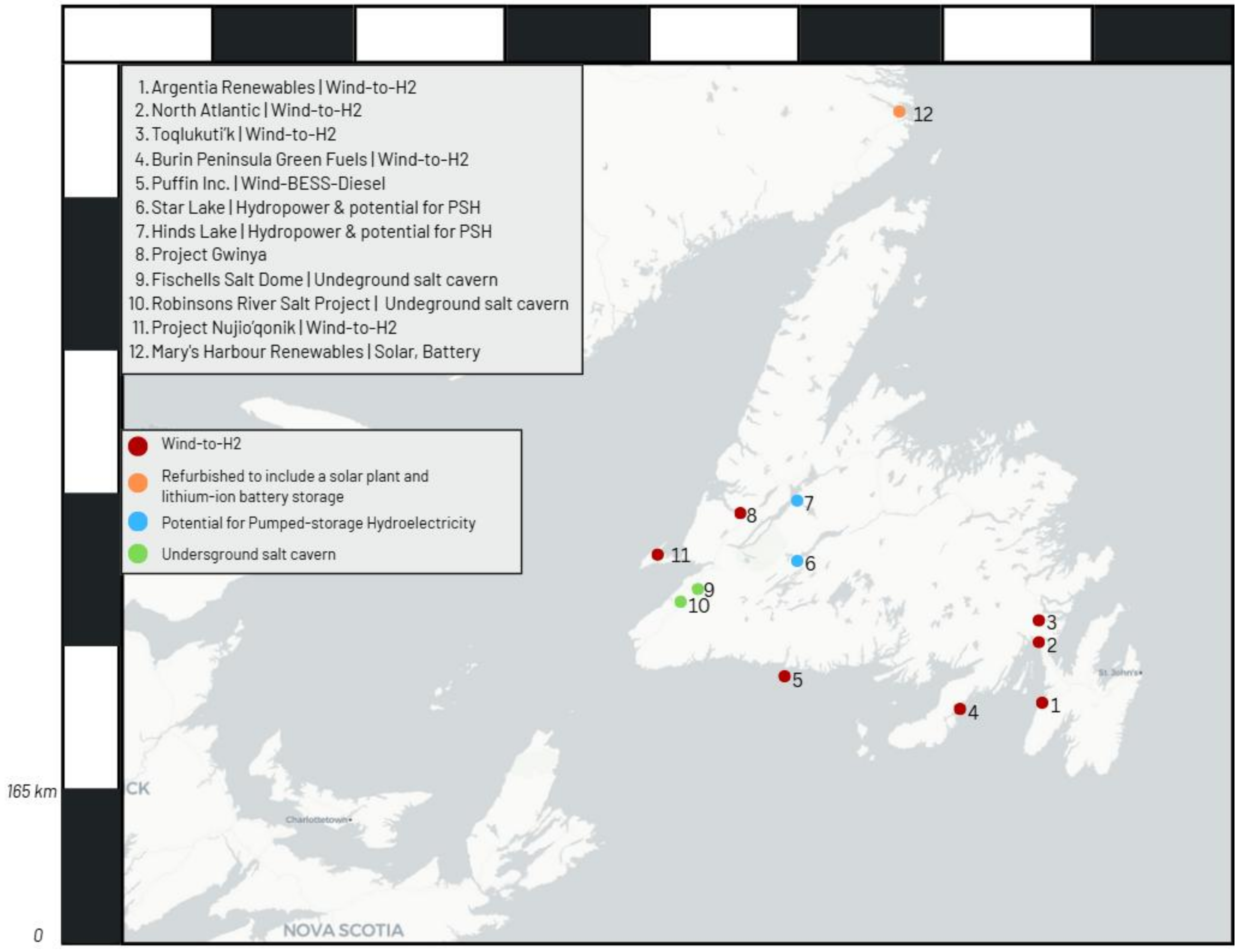

Figure 17 Existing Energy Storage Project Sites Map in NL

3.4 Technical Constraints and Challenges in NL

Technical challenges in the design and operation of energy storage systems in NL are posed by several factors. Firstly, seasonal variability can lead to fluctuating energy demands and supply, especially in colder months, when energy needs for heating soar. Secondly, in cold climates, infrastructure is often under stress due to freezing temperatures, which can disrupt energy generation and transmission, leading to reliability issues. Thirdly, grid topology, or the way the energy grid is structured, can further complicate matters, especially in regions with sprawling, decentralized networks that are difficult to upgrade or optimize for modern needs. Current limitations in technology and resources, such as limited storage capacities or outdated infrastructure, also hinder the ability to effectively manage these challenges.

4 High-Level Discussion on Energy Storage Applications in Newfoundland and Labrador (NL)

In the context of energy storage technologies, the term "application" explores how storage solutions can address NL's unique grid dynamics, geography, and energy needs, with a focus on identifying technologies that are most viable for the province (Table 3). This chapter aims to bridge the gap between the theoretical potential of energy storage, as discussed in the previous chapter, and its practical deployment, considering local energy challenges and the strategic implications for future growth and sustainability.

Table 3 Comparison table of energy storage applications – grid-level, community, industrial, and export-related

	GRID-LEVEL	COMMUNITY	INDUSTRIAL	EXPORT-RELATED
General Purpose	Stabilize the transmission grid, frequency regulation, peak shaving. renewable integration	Local energy independence, reliability, resilience for remote/off-grid areas	Backup power, demand charge management, decarbonizing industrial processes	Store excess renewable energy for sale/export to neighboring regions/countries
Tech Options	Pumped Hydro, BESS (Li-ion, flow), CAES	Li-ion, Flow Batteries, Hybrid Systems	BESS, Thermal Storage, Flywheels	Pumped Hydro, Hydrogen/ammonia + salt domes
Scale	Large (>100 MW)	Medium (100 kW-10 MW)	Medium to Large (1 MW - 50 MW)	Large/Utility-scale (100+ MW, possibly GWh)
NL Use Case	Supplement Hydro (e.g., Churchill Falls); grid balancing via BESS/CAES; defer diesel in isolated grids	Resilience of remote Indigenous/ Labrador coastal communities; reduce diesel reliance	Backup and decarbonize mining/oil industries (e.g., Volsey's Bay, Iron Ore)	Leverage Muskrat Falls _ BESS/H2 for export via Maritime Link & Atlantic Loop
NL-Specific Challenges	Harsh weather, transmission limits to mainland, low demand	Harsh climate, logistics, community acceptance	Harsh winters, legacy systems, cost of retrofitting	Limited export infrastructure, coordination with NS/NB/EU/US market
NL Opportunities	Use hydro+storage for Atlantic Loop balancing	Integrate with diesel reduction programs (e.g., Nain, Hopedale)	Energy-as-a-Service for mining	Position NL as an energy export hub (e.g., green hydrogen, ammonia to EU)

4.1 Grid-Level Applications

Grid-level energy storage refers to large-scale systems connected to transmission or distribution networks, operated by utilities or independent power producers. Its primary role is to stabilize the entire power grid by balancing supply and demand, smoothing out variability from renewable energy sources like wind and solar, and providing ancillary services such as frequency regulation and spinning reserves. These systems are often centralized and strategically placed near substations, renewable energy farms, or load centers to optimize performance and reduce transmission congestion. By doing so, they enhance grid reliability, improve energy efficiency, and reduce the need for peaking power plants or fossil-based backup generation.

Grid-level energy storage in NL offers a vital solution for modernizing and stabilizing the province's unique electricity system. With vast hydroelectric resources such as Muskrat Falls and Churchill Falls, the province already generates abundant clean electricity. However, challenges remain with seasonal variability, transmission bottlenecks, and the need to integrate new variable wind energy from proposed future developments on the island and Labrador. Strategically deployed grid-scale storage, such as BESS, CAES coupled with salt domes, and PSH, can help firm this renewable output, provide real-time grid balancing, and maximize the value of hydro assets by enabling time-shifting and ancillary services.

4.1.1 Potential Technology: Battery Energy Storage Systems (System Reliability)

Since 2020, NL Hydro has assessed system reliability and the potential for BESS integration as part of its Reliability and Resource Adequacy (RRA) Study Review. Driven by rising RE penetration, aging infrastructure, and outage risks (particularly from the Labrador-Island Link (LIL)) the utility has explored both short-duration (4-hour) and long-duration (up to 100-hour) battery storage solutions. The 2023 BESS Study by Wood Canada Ltd. [33] focused on the Avalon Peninsula, evaluating short- and long-duration storage options. The study concluded that short-duration BESS is technically feasible but limited in addressing extended outages. Additionally, lithium-ion systems face performance challenges in cold climates. In Newfoundland, ambient temperatures below 25°C reduce capacity due to increased internal resistance and slower electrochemical reactions, while temperatures above 35°C accelerate battery degradation. These factors highlight the need for robust thermal management and alternative long-duration or hybrid storage solutions to maintain grid reliability [34]. The 2024 Resource Adequacy Plan (RAP) reiterates BESS as a key component in NL Hydro's power planning as more intermittent RE is added to the grid. While it supports 20 MW and 50 MW configurations with 4-hour duration, the RAP also considers 8- and 12-hour extensions for greater flexibility. However, it underscores that short-duration BESS alone is inadequate for addressing long-duration events, such as a prolonged LIL failure. This reinforces the need for hybrid or long-duration storage technologies to ensure energy security during extended disruptions [35]. The island's dependence on hydroelectric power from Labrador via the Labrador-Island Link (LIL) introduces vulnerability during transmission constraints or outages, as experienced during the 2022 LIL maintenance issues. Strategically placed BESS can provide fast-response backup capacity during these events and smooth out the intermittency of wind generation, particularly in the windy yet undersupplied areas of the Avalon Peninsula. A comparable initiative is underway in Nova Scotia, where a 150 MW BESS project is being developed to support local grids, reduce curtailment of wind power, and defer upgrades to aging infrastructure.

As of May 2025, the small-scale BESS in Mary's Harbour, Labrador, is operational and actively supporting the community's renewable energy infrastructure. The system integrates a 190-kW solar PV array with a 335-kW Li-ion battery, which has contributed to reducing diesel fuel consumption by up to 30% annually. This project has benefited from federal funding, including a $2.5 million investment through Natural Resources Canada (NRCan) programs.

4.1.2 Potential Technology: CAES with Salt Domes

Generally, CAES systems have demonstrated a wide range of valuable grid services, including rapid response capabilities, reaching full generation load in under 10 minutes and full compression mode in less than 5 minutes. They offer flexible cycling, same-day discharge, dynamic inertia support (particularly when integrated with optional flywheels in advanced CAES designs), and black start capability, making them highly versatile for modern grid operations. Salt domes provide an ideal storage medium for CAES due to their natural airtightness, durability under frequent pressure changes, and ability to scale to large volumes. Compared to artificial storage solutions or aquifers, salt caverns also offer lower excavation costs and superior thermal insulation, enhancing both performance and economic viability. Advancements in diabatic and adiabatic CAES designs—including novel thermal energy storage and heat-recovery strategies—are boosting round-trip efficiencies from ~42% in legacy systems up to 64–72% in modern implementations. With full-load capacity reached in minutes and potential for multi-hour discharge durations, salt cavern CAES supports grid balancing, peak shaving, and renewable integration at scale.

A leading case study is the Advanced Clean Energy Storage (ACES) project in Delta, Utah, USA, which combines hydrogen and CAES technologies and utilizes salt caverns for high-capacity storage. The project aims to store over 1,000 megawatt-hours (MWh) of energy in repurposed salt domes and provide up to 100 hours of discharge duration, making it one of the largest and most advanced CAES + hydrogen hybrid storage initiatives to date. Several new large-scale salt cavern CAES plants in China have come online between 2022–2025, such as the 400 MWh/100 MW Zhangjiakou facility (70 % efficiency), the 1.4 GWh/350 MW Shandong plant (~64 %), and a Changzhou (60 MW) salt cavern projects—which now provide frequency regulation, load shifting, and peak capacity support to the national grid. Meanwhile in Ontario (Canada), Hydrostor's ACAES facility at Goderich began commercial operation in 2019 (2.2 MW / 10 MWh), offering grid level dispatchable energy storage and fossil plant replacement services. These facilities highlight how ACAES and DCAES at multi-MWh scale are now being deployed as long duration, grid integrated energy storage solutions.

Recently, BaroMar [36] is developing a large-scale, long-duration energy storage that uses underwater compressed air technology. Their system stores energy by using excess electricity to compress air and store it in rigid and static man-made pressure vessels placed deep underwater. When energy is needed, the compressed air is released to drive turbines and generate electricity. BaroMar's approach to leverage the natural pressure of deep water to maintain constant storage pressure enables scalable, minimal land use and reduced infrastructure complexity.

4.1.3 Potential Technology: Pumped-storage Hydroelectricity

In the context of NL, the application of large-scale, conventional PSH systems is constrained by several regional factors. Notably, its relatively flat topography in many areas reduces the urgency and technical feasibility of implementing traditional PSH configurations. Moreover, the existence of abundant run-of-river hydro resources reduces the marginal benefit of developing new storage capacity in many locations across the island. Conversely, Newfoundland already exhibits a high penetration of hydroelectric generation, presenting a unique opportunity for the conversion of existing infrastructure/facilities into pumped storage facilities for peak shaving and seasonal storage.

Despite the identified constraints, localized opportunities do exist. A prime example is the Ramea Wind-Diesel Hybrid System that is newly owned by Puffin Wind Inc. on the island’s south coast, which has demonstrated the potential for small-scale PSH to complement intermittent renewable resources in isolated or off-grid communities [37]. A feasibility study led by Memorial University assessed the integration of a 150-kW pump-turbine system with a ~4,000 m^3 reservoir [37]. The results suggested that such a system could significantly increase the share of RE in Ramea’s energy mix, from below 20% to over 35%, while reducing reliance on diesel [37]. This case illustrates that modular, site-specific solutions tailored to small-scale or remote grid applications may be technically and economically viable in NL.

Additionally, a study was conducted on nine existing hydroelectric generation facilities in Newfoundland to assess their potential for PSH, using both Pugh Analysis and detailed cost evaluation [10]. Of the nine, only two sites were found to be economically viable. Among them, Hinds Lake was identified as the more cost-effective option compared to Star Lake, primarily due to its higher head and shorter penstock, which makes it more efficient in generating equivalent energy. A conceptual design for a new standalone 200 MW pumped storage facility was proposed at each of the two locations. If pursued further, these facilities would require optimization to meet grid demand requirements.

While traditional PSH may face challenges in Newfoundland due to topographical constraints, Labrador presents untapped potential through strategic integration with existing infrastructure and novel site use (e.g., abandoned mines, see section 4.3.2). The region's rugged terrain, coupled with existing hydroelectric infrastructure such as the Churchill Falls Generating Station, offers a potential foundation for innovative PSH configurations. Integrating PSH with large-scale plants like Churchill Falls could also enhance operational flexibility, allowing the facility to respond more dynamically to external electricity markets such as those in Quebec or the northeastern U.S. The 2GW Snowy 2.0 PSH scheme in Australia or the use of mine-based PSH in Germany (e.g., Prosper-Haniel mine) demonstrate how non-traditional topographies and brownfield sites can be adapted for effective energy storage [38] [39]. Moreover, modular and small-scale Omarugawa PSH systems, as explored in Japan, could be tailored to the needs of smaller communities or remote industrial operations in Labrador [40].

4.2 Community Applications

Community energy storage systems are deployed at a neighborhood or village scale to serve the needs of local populations. These systems are typically community-owned or operated through cooperatives or municipalities and are designed to improve energy resilience, reduce electricity costs, and support shared renewable generation such as solar PV. Many rural, coastal, and Indigenous communities face reliability challenges and often rely on diesel generators for backup power, particularly in Labrador and islanded systems. Diesel generators used in remote communities typically operate in islanded mode, requiring consistent oversizing to meet peak demand, often running at partial load, leading to suboptimal fuel efficiency and increased maintenance requirements. In addition, fuel transportation is seasonal and weather-dependent, incurring high logistical costs. Furthermore, emissions per kWh are substantially higher than grid-connected renewable generation and load-following capability is limited, with poor response to variable demand or renewable integration.

By integrating small-scale battery storage with local solar, wind, or even hydrokinetic energy, these communities can enhance energy autonomy, reduce fuel dependence, and lower emissions, all while creating local jobs in installation and maintenance. Given the harsh weather and isolation faced by many residents, energy storage can also strengthen resilience against outages from storms or transmission disruptions.

4.2.1 Potential Technology: Hybrid Systems

When paired with renewable energy sources, BESS can serve as the backbone of hybrid microgrid systems that deliver reliable and cost-stable power to communities, especially for remote northern communities, and those off the main grid. Unlike diesel generators, which must continuously burn fuel and operate at inefficient loads, BESS can respond instantly to fluctuations in demand, store excess renewable energy generated during the day, and discharge when needed, particularly during peak demand periods or in low-generation hours. A typical hybrid system with ~60 % renewable penetration and ~2-hour battery storage can reduce diesel consumption by 70–80%, cut GHG emissions by up to 83%, lower LCOE from ~$0.80–$1.20/kWh (diesel-only) to as low as $0.30–$0.60/kWh in optimized hybrid operation, and deliver a payback period ranging between 0.9 and 6.2 years (e.g. Rwanda case study [41]). In remote Canadian contexts, payback under 5 years is achievable—especially with capital grants, carbon pricing, and high fuel costs driving the economics.

4.2.2 Potential Technology: Off-grid Mining Operations

Off-grid mining operations present a significant opportunity for the deployment of community-scale energy storage solutions, particularly in regions where mines are located far from centralized electricity transmission infrastructure. These sites often rely on costly and carbon-intensive diesel or heavy fuel oil (HFO) generators to power critical operations, which introduces logistical complexities and environmental challenges. Integrating renewable energy technologies, such as wind turbines and photovoltaic (PV) solar arrays with battery energy storage systems (BESS) can dramatically reduce reliance on fossil fuels while ensuring consistent, high-quality power for continuous mining activities.

An off-grid gold mining project in West Africa, developed by the Dornier Group, operates one of the world's largest PV-Battery-HFO hybrid power plants [42]. Located in a remote area where traditional grid access is unfeasible, the system combines a large-scale solar PV field, high-capacity battery storage, and HFO-based generation to create a resilient and cost-effective energy solution. This hybrid configuration not only improves energy efficiency but also reduces operational costs and emissions over the lifetime of the mine. By extending this model to other remote mining contexts, particularly in developing regions with untapped mineral reserves, community-based off-grid systems can serve industrial and local development needs. Energy-intensive remote operations in these cases becomes a key enabler for surrounding communities that may benefit from shared infrastructure such as microgrids or surplus power for water pumping, local businesses, or housing, etc.

4.3 Industrial Applications

Industrial energy storage is privately owned and customized for specific operational needs such as avoiding production downtime, supporting critical loads, or even participating in demand response programs. In industries like mining, steel, and data centers, energy storage boosts process efficiency, supports electrification, and helps meet corporate sustainability goals, without interrupting core industrial activities. In NL, industrial sectors such as mining, aquaculture, oil and gas transition, and marine operations often operate in remote or energy-intensive environments, where stable, affordable power is critical. In mining operations in Labrador or port facilities in St. John's and Corner Brook, storage could enable peak shaving, support electrification of operations, and contributes to GHG reduction targets.

4.3.1 Potential Technology: Thermal Energy Storage (TES)

TES presents a highly practical opportunity for industries in NL that rely on process heat or steam, particularly in sectors such as food processing, aquaculture, forestry, and pulp and paper. TES systems store energy as heat (often using water, molten salts, or ceramic materials) and release it when needed to maintain stable industrial temperatures. In NL's energy landscape, where hydroelectricity is abundant and low-carbon, TES allows industries to shift electricity use to off-peak hours or periods of high renewable generation, storing excess energy as heat to be used later in thermal processes. This not only improves load flexibility and reduces energy costs but also allows partial electrification of industrial heat systems, enabling more stable operation. Given NL's cold climate, TES systems can also be adapted for combined heat and power (CHP) applications, offering both environmental and economic advantages in energy-intensive rural and industrial zones.

4.3.2 Potential Technology: Abandoned Mines and Underground Pumped-Storage Hydroelectricity

In Labrador, the focus for energy storage shifts toward applications that support the mining industry and remote communities. Many of the region's mining operations are located far from the main power grid, making energy storage critical for ensuring a reliable and cost-effective energy supply. Abandoned mines, which are scattered throughout Labrador, offer an opportunity for repurposing these sites into energy storage facilities. The mine shafts could potentially be used to create CAES systems or alternative PSH, taking advantage of the natural topography. The feasibility of using abandoned mines for energy storage varies significantly due to diverse geological conditions and mining methods. These factors lead to inconsistent structural integrity and storage potential. Globally, abandoned mines have been used sparingly for natural gas storage, and no existing infrastructure currently supports CAES (compressed air energy storage) or hydrogen storage in such sites. However, a Swedish consortium completed an underground storage facility in a newly developed mine or so called "lined rock cavern" in 2022 for green hydrogen storage.

Legacy mining sites, such as those near Labrador City or Wabush, may be suitable candidates for abandoned mines for PSH. Using these mines as part of a closed-loop PSH system would mitigate environmental impacts while providing long-duration energy storage, which is increasingly valuable for grids integrating intermittent renewables like wind. “Hydro-wind synergy” synergy is particularly promising in NL. With a strong foundation in flexible hydroelectric generation, such as the Churchill Falls and Muskrat Falls plants, NL is well positioned to integrate more wind energy without compromising grid stability. Hydro assets can effectively buffer the intermittency of wind, making the combined system more resilient and export capable. Unlocking this synergy could enable the province to pursue large-scale wind development (including green hydrogen production) while maintaining reliability, minimizing curtailment, and optimizing the use of existing infrastructure.

4.4 Export-Related Applications

With large-scale wind projects in development, deepwater ports, and abundant hydro resources, NL is positioned to export firm, renewable power to the rest of Atlantic Canada and international markets. First, storage allows the province to firm variable renewable energy like wind and hydro, making it dispatchable and reliable for export through interprovincial connections such as the Atlantic Loop. In tandem, wind-to-hydrogen pathways can convert surplus electricity into green hydrogen or ammonia, creating value-added products for global markets. Storage systems—especially long-duration batteries and hydrogen storage—also provide essential ancillary services (e.g., frequency regulation, spinning reserve), which are critical for cross-border electricity trade. As international buyers increasingly demand 24/7 carbon-free power, energy storage enables green baseload delivery, enhancing the market value of exported electrons. Moreover, by developing and refining advanced storage technologies locally, NL can position itself as an exporter of expertise and systems, particularly to other islanded or remote regions seeking to decarbonize. Storage technologies, particularly grid-scale batteries, CAES, and hydrogen storage, can smooth the intermittency of wind, provide firm delivery for power exports through transmission corridors like the Maritime Link, and support the production of green hydrogen or ammonia for overseas shipment.

4.4.1 Potential Technology: Hydrogen Energy Storage

HES is a critical potential for industrial decarbonization in NL, especially for hard-to-electrify applications that require high-temperature heat or chemical feedstocks. Green hydrogen (produced via electrolysis using excess hydro or wind power) can be stored in compressed or liquefied form and used as a clean-burning fuel in industrial furnaces, turbines, or fuel cells. This is especially relevant for the province's heavy industries, such as mining, metallurgy, offshore supply chains, and future green fuel production facilities. A recent study by econext (KPMG) [43] conducted an Analysis of Opportunities for Domestic Clean Fuels Use in NL which integrated assessment and economic impacts for several sectors, such as marine transportation, port operations, remote communities, electricity grid integration, heavy-duty transportation, public transportation, heavy industry, and aviation. These sectors were identified by econext as NL's hard-to-abate sectors that will rely on the adoption of clean fuels to achieve GHG emissions reduction targets. Hydrogen can replace diesel or natural gas for thermal energy generation in industrial operations that require heat beyond 800°C, where conventional electrification becomes inefficient or cost-prohibitive. Furthermore, hydrogen enables seasonal and long-duration energy storage, addressing intermittency challenges associated with large-scale wind projects currently under development in NL. Stored hydrogen can also be used as a feedstock for ammonia, synthetic fuels, or marine transport applications, opening pathways for industrial diversification and clean energy export.

4.5 Salt Cavern Development in NL

Private developers are exploring the development of subsurface energy storage opportunities in NL, with two of the most prominent being under Triple Point Resources Ltd. and Vortex Energy. The Triple Point Resources Ltd. owned Fischells Salt Dome is a typical salt structure that provides significant potential for subsurface storage. Future plans include subsurface infrastructure (engineered salt caverns), meticulously developed via solution mining, utilizing primarily seawater to minimize freshwater usage and environmental impacts. Seismic and high-resolution ground gravity data have confirmed that the dome's structure distinguishes it from more common bedded salt formations by revealing its bulging, upward-penetrating shape, localized gravity anomaly, and the deformation of overlying strata. These features are absent in simple bedded salt formations. It envisioned that the CAES infrastructure will include surface facilities, such as a compression system, heat capture, storage systems, air expansion systems, turbine generators, substations, and transmission lines, integrating with grid infrastructure at either Bottom Brook or a nearby substation. This is forecasted to address the province's 385 MW capacity shortfall by 2034. A dedicated 37-turbine wind farm (7 MW each) will exclusively power the Adiabatic CAES (ACAES), maintaining emissions-free operations. Each cavern within the dome can store over 8,000 tonnes of green hydrogen, with dimensions of approximately 80 m in diameter at depths of about 1300 m, a volume that exceeds the cumulative energy demand of all currently proposed wind energy projects in NL. The proposed Hydrogen facility involves specialized electrolyzers, hydrogen purification, and compression facilities, storage caverns specifically engineered to address H2 permeability issues, ammonia conversion unit for export market, and pipeline systems connecting storage caverns to export facilities [44].

South of the Fischells site, Vortex Energy is advancing the Robinsons River Salt Dome Project, which includes two potential major salt structures (East and West) identified through gravity and seismic exploration, with significant estimated hydrogen storage capacity. In December 2024, Vortex Energy announced the completion of their core logging and preliminary analysis campaign, stating that the analysis revealed valuable insights into the geological suitability of the formations for hydrogen storage [45]. Core samples displayed no fractures, and the gypsum and mudstone layers overlaying the salt formation exhibit promising sealing capabilities, which is essential for the safe and effective underground storage of hydrogen [45]. "Large-scale H_2-CAES at Robinsons River would require the development of compression stations, underground injection systems, and above-ground pipeline networks to connect with regional transmission infrastructure. Real-time cavern pressure and geomechanical monitoring, microseismic surveillance, and periodic sonar-based cavern mapping would be implemented to ensure long-term integrity [46]." Taken together, these developments underscore NL's strategic advantages in both RE generation and long-duration energy storage (LDES).

<u>Comparison to Other Jurisdictions</u>

Ontario has undertaken pilot projects for CAES, such as the former Goderich initiative with 1.75 MW discharge and 2.2 MW charge capacity, and benefits from a comprehensive regulatory structure managed by the Independent Electricity System Operator (IESO).

In Alberta, the Marguerite Lake CAES project's first phase is on track for commercial operations by Q1 2028, with 125 load and 320 MW of generation [47]. The province has established a Hydrogen Roadmap and is currently updating regulations governing subsurface storage, including hydrogen storage in salt formations, providing Alberta with an early advantage in this domain. The Tent Mountain RE Complex (TM-REX) in Alberta represents a pivotal development in the integration of PSH within the region's energy infrastructure. Conceived as a 320 MW PSH facility, the project aims to improve grid stability and facilitate Alberta's transition toward sustainable energy solutions, reinforcing the province's commitment to RE advancements [48].

Nova Scotia has demonstrated regulatory and technological innovation by enacting the Subsurface Energy Storage Act, enabling CAES development. Hydropower-dominated provinces such as Quebec and British Columbia, comparable to NL in their reliance on legacy hydro infrastructure, have begun integrating battery and hydrogen storage technologies to diversify their energy portfolios. Notably, Hydro-Québec and its subsidiary EVLO commissioned the Parent Energy Storage System (a 4 MW / 20 MWh BESS operational since summer 2024), marking Quebec's largest battery storage project to date. Quebec is also pursuing the development of green hydrogen hubs as part of its long-term energy strategy.

4.6 Hydrogen Developments in NL

Aligned with NL's 2024 Hydrogen Development Action Plan, Canada is advancing toward producing 1.6 million metric tons of green hydrogen. NL's wind, land, marine access, and underground storage position it as a key player, with six proposed wind-to-hydrogen projects in various stages of approvals. These projects also reinforce Canada's commitment to the Canada-Germany Hydrogen Alliance, enabling RE exports to global markets, including Europe, with a focus on Germany in particular [49].

Liquid storage faces several technical challenges, yet it remains crucial for large-scale energy storage and transportation. Issues such as cryogenic temperature requirements, high energy demands for liquefaction, and evaporation losses pose significant hurdles. However, due to its high energy density and effectiveness in fueling various industries, liquid hydrogen continues to be a preferred option for large-volume applications. Converting liquid hydrogen into liquid ammonia presents a viable alternative, addressing many of these storage difficulties [50].

Hydrogen is particularly well-suited for locations near transportation hubs or ports, such as in St. John's or Labrador City, where it can be easily mobilized for industrial or export purposes. Hydrogen's versatility and potential for large-scale storage make it a strategic fit in regions with access to ports, facilitating both local energy needs and export opportunities. In addition, hydrogen production is gaining attention in Labrador, particularly near industrial hubs like the Port of Sept-Îles.

5 Economic and Market Considerations

5.1 Potential Market and Applications

Exporting stored energy from NL represents a strategic energy storage application, not merely a revenue opportunity. Unlike many jurisdictions across North America and the world, NL is uniquely positioned with abundant renewable resources, especially hydro and wind, and a growing capacity to store this energy reliably. For other provinces, states, and international partners lacking firm, clean energy resources, access to on-demand stored energy could be crucial for achieving decarbonization goals while maintaining grid stability. Energy storage in NL can enable the export of firmed renewable electricity via existing infrastructure like the Maritime Link or through proposed expansions such as the Atlantic Loop and potential new subsea transmission lines to key demand centers. Additionally, converting stored electricity into hydrogen or ammonia enables energy to be exported as a transportable zero-carbon fuel, supporting international markets that require clean inputs for industry and transportation. In this way, NL's energy storage assets are not only supporting its own grid but also becoming part of a broader decarbonization toolkit, such as de-risking transitions in energy-poor jurisdictions by supplying firm capacity, grid services, and low-carbon fuels when and where they're most needed.

Another major driver of clean energy demand is the rapid expansion of data centers, many of which are actively seeking to power their operations with RE. To meet sustainability goals and ensure reliability, data centers are contracting significant amounts of clean power. As of 2024, U.S. data centers had secured 34 GW of wind and solar capacity, a figure expected to grow to 40 GW by 2030. This surge in demand for renewable power is also accelerating the need for energy storage solutions, particularly in industrial applications, to ensure round-the-clock reliability. As energy storage becomes a critical part of powering these digital infrastructures, it creates direct demand for advanced storage systems and opens opportunities for NL to export RE in a stored and dispatchable form.

Europe

The European hydrogen market is projected to grow significantly, with low-carbon hydrogen production expected to reach 20 million metric tons (Mt) by 2030. By 2050, hydrogen is projected to supply as much as 24% of the EU's total energy demand, equating to approximately 2,250 TWh of energy [51]. NL's vast RE resources, including wind power, offer an ideal foundation for large-scale green hydrogen production.

Additionally, NL's proximity to Europe enhances its competitive advantage by reducing transportation costs compared to other global suppliers. On Jun 3, 2025, in Saskatoon, NL Premier Hogan joined other provincial leaders and Prime Minister Mark Carney to discuss building a stronger, more resilient Canadian economy. He reaffirmed NL's commitment to key projects like the Churchill Falls expansion, new hydro capacity at Gull Island, and the Bay du Nord oil and gas project. These investment-ready initiatives align with federal priority project criteria and promise long-term benefits for the province. A major outcome of the meeting was the recognition of the Eastern Energy Partnership as a nation-building initiative. This plan will connect clean energy, mainly hydro and wind, from Atlantic Canada and Quebec to markets in Western Canada and the northeastern U.S., supporting energy security and Canada's clean growth goals [52].

Analysis indicates that the EU could remain dependent on energy imports in the medium term [53], which represents a great market void that could be filled by energy from NL. By 2045, Germany's need for hydrogen storage is expected to grow dramatically, from just 4 TWh in 2030 to approximately 58.5 TWh, and eliminate all fossil fuels from the energy sector. Across the European Union, hydrogen demand is forecasted to exceed 140 TWh, with Germany potentially responsible for housing up to one-third of that capacity. Positioned at the heart of Europe, Germany can become a key hydrogen storage hub, facilitating cross-border energy flows, reducing market volatility, and supporting a more integrated and resilient European energy system [54].

As of May 2025, Canada has not yet commenced exporting clean hydrogen to Germany, despite the 2022 trade agreement [55] aiming for initial shipments by 2025. While both nations have reaffirmed their commitment, backed by a joint $600 million investment to support hydrogen trade infrastructure, several hurdles remain. As of May 19th, 2025, the Honourable John Hogan, KC, Premier of Newfoundland & Labrador, has signed a memorandum of understanding (MOU) with the Port of Amsterdam, Netherlands [56] with specific objectives of cooperation highlighted: assess the potential to establish international supply chains between NL and the Port of Amsterdam for green hydrogen and derivatives, with a view to supplying parties in the Netherlands and the wider northwestern European area. Additionally, in Zuidwending (northern Netherlands), Gasunie is preparing four salt caverns for hydrogen storage over the next few years, with a total capacity of 20,000 tonnes of hydrogen [57].

USA

At the same time, the need for resilient energy infrastructure is becoming more urgent in the face of increasingly frequent and severe climate-related events. According to the National Oceanic and Atmospheric

Administration (NOAA), the U.S. East Coast experiences flooding on average once every 0.8 days from March to October. Canada faces similar risks. In these situations, especially in remote or vulnerable communities, access to reliable power becomes critical. Severe weather events often disrupt power systems, and restoration can take days or even weeks. During such outages, stored RE, whether through community-based battery systems or utility-scale storage, can provide critical backup, supporting emergency services, communications, heating or cooling, and economic continuity [58].

According to a 2022 study from the United States (US), the residential sector accounted for 38.4% of total electricity consumption, around 1.51 trillion kWh. Moreover, the nationwide forecast of electricity demand shot up from 2.8% to 8.2% growth over the next five years, with an additional 61 GW of growth in recent updates, the demand is set to increase by 15.8% by 2029. Energy storage can help bridge this gap, storing excess RE when supply is high and discharging it during peak residential demand for heating and cooling [59]. For NL, this presents a compelling opportunity to export clean, stored energy, particularly from hydro and potential long-duration storage, to help meet growing needs across North America.

5.2 Financing and Investment Challenges

There are existing business models in RE and grid connection that help companies minimize their electricity costs by partnering up with renewable systems and either installing them under their projects or by buying from existing energy farms, e.g. In P2P sharing, a prosumer (producer and consumer) can share electricity with other prosumers in a local electricity market [60]. Another widely adopted model is the feed-in tariff (FIT), a policy mechanism that supports RE development by guaranteeing above-market prices for electricity fed into the grid. FITs typically involve long-term contracts (15–20 years) and are prevalent in countries such as Germany, Japan, and parts of the U.S. Additionally, net metering allows companies to offset their energy usage by exporting surplus power to the grid, receiving credits or payments based on the difference between power consumed and generated. Power Purchase Agreements (PPAs) function similarly but involve selling electricity at a predetermined fixed rate. There are also large-scale renewable farms that generate electricity for lease to various companies. These setups are often operated by Independent Power Producers (IPPs), which commercialize RE generation and storage projects to serve multiple clients efficiently.

Despite these challenges, various initiatives, outlined in the previous section, aim to address these uncertainties and encourage both investment and development. Governments worldwide are increasingly prioritizing renewable energy storage and implementing measures to overcome such barriers and stimulate market growth.

5.3 Salt Domes and NL's Incredible Global Opportunity

The salt domes in NL possess a tremendous capacity for renewable energy storage systems, with minimal emissions, a result of renewable energy technologies. This capacity presents an opportunity, which, if utilised properly, can help Canada become an energy superpower with NL at its forefront. NL would be able to support provincial projects and still have enough energy to be a major stakeholder as an exporter. Salt domes enable the creation of engineered underground caverns that can store massive quantities of energy-dense materials, including compressed air, hydrogen, synthetic fuels, or natural gas substitutes. This storage can serve not only as backup for intermittent renewables but also as the firm capacity backbone required for 24/7 carbon-free electricity, decarbonized industrial heat, and clean fuels trade.

From an economic standpoint, developing salt dome storage infrastructure in NL could catalyze an entire cleantech industrial cluster, attracting investments in hydrogen production, offshore wind integration, low-carbon manufacturing, and next-generation storage technologies. At a national level, these domes represent a strategic advantage that should be integrated into Canada's energy security and climate planning. At the provincial level, they can help NL leverage its renewable resources not just for export, but for long-term economic diversification and energy sovereignty.

6 Policy and Regulatory

Canada has established comprehensive policies to promote RE at both the federal and provincial levels, aiming to transition towards a sustainable, low-carbon future. However, challenges remain, including infrastructure development and clear definitions. Initiatives are underway to integrate new RE sources and evaluate long-term options for energy generation. This section synthesizes current federal and provincial regulatory support, barriers, and recommendations to catalyze the development and integration of energy storage within the Canadian electricity landscape. Relative to provinces such as Ontario, Alberta, and Nova Scotia, NL trails in both the regulatory advancement of diversified and emerging storage systems (Appendix A: Comparison to Other Canadian Jurisdictions.

6.1 Overview of Current Regulatory Framework

Below outlines the various policies and initiatives laid out both federally and provincially in support of renewable energy developments (Table 4). Clearly defined national objectives offer guidance to utilities, investors, and provinces, while facilitating alignment with net-zero electricity aspirations.

Table 4 Current Federal and Provincial Regulatory Framework

FEDERAL	
Clean Electricity Regulations (CER)	Published under the Canadian Environmental Protection Act, 1999 (CEPA), finalized in December 2024 Commits to a net-zero electricity grid by 2050, extending the previous target of 2035 Does not specifically mention energy storage
Amendments to the Atlantic Accord Acts	Expanded the mandates of the C-NLOER (Canada-Newfoundland and Labrador Offshore Energy Regulator) and CNSOER (Canada-Nova Scotia Offshore Energy Regulator) to include the regulation of offshore RE projects Enacted under the Canadian Energy Regulator Act (CER Act), the ORER establishes safety, security, and environmental protection requirements for offshore RE projects [61]
Investment Tax Credits (ITCs)	Offers up to 30% of the capital cost for clean electricity generation systems, including wind generation Clean Hydrogen ITC provides up to 40% of capital costs for projects producing hydrogen with a carbon intensity below 0.75 kg CO_2/kg H_2.
Canada and EU Agreements	Joint declaration of intent between the Government of Canada and the Government of the Federal Republic of Germany on establishing a Canada-Germany Hydrogen Alliance MoU between the Government of Canada and the Government of the Netherlands on cooperation in the field of hydrogen energy
PROVINCIAL	
Renewable Energy Plan	Released in December 2021, outlines the province's vision to reduce fossil fuel usage and deliver affordable, reliable RE Emphasizes environmental protection, meaningful Indigenous engagement, job creation, and industry growth

Wind Energy Initiatives	In April 2022, the province lifted a 15-year moratorium on onshore wind farms In February 2023, NL introduced a Wind-Hydrogen Fiscal Framework to provide a predictable and transparent fiscal system
Regional Energy and Resource Table	In March 2024, a collaboration framework was released to achieve net-zero emissions Focuses on maximizing the use of surplus RE, accelerating the adoption of electric vehicles, converting heating systems to high-efficiency electric options, and advancing electrification in various sectors
Hydrogen Development Action Plan	Launched in May 2024, this plan details strategies to develop green hydrogen for domestic use and export Includes 31 action items to be accomplished over three years

6.2 Policy/Regulatory Barriers and Recommendations

To enable the widespread deployment of energy storage technologies, NL will need to address policy and regulatory gaps and/or barriers that can impact the scale, efficiency, and integration of energy storage projects in the province. In the development of this discussion paper, a number of policy and regulatory gaps and/or barriers were identified.

6.2.1 Grid Integration and Regulatory Framework for Storage

There is currently a lack of storage-specific regulatory frameworks for integrating energy storage technologies into the grid. The *Electrical Power Control Act (EPCA), 1994 (SNL 1994, c E-5.1)* outlines the regulatory framework for power generation, transmission, and distribution assets within NL and governs how electrical power is produced and delivered across the province. The *Public Utilities Act (RSNL 1990, c. P-47)* outlines the obligations and standards that public utilities in NL must follow. While the Act does not explicitly address electricity storage or the reinjection of stored power into the grid, it is reasonable to assume that existing regulations for power generation and interconnection would apply in the absence of specific provisions.

NL Hydro holds exclusive rights to generate power in the province. However, *Section 14(7) of the EPCA* allows the NL Board of Commissioners of Public Utilities (PUB) to issue exemptions for other entities to generate power. If such an exemption is granted, the company may then be classified as a public utility and would fall under the regulatory scope of the Public Utilities Act. To prevent this classification (and the accompanying regulatory obligations) a separate exemption may also be required. With the growing number of industrial power generation projects in NL, there is increasing pressure to streamline these processes.

Grid operators may face challenges incorporating these systems into daily operations and balancing supply and demand effectively. Additionally, the regulatory framework for energy markets in NL may not fully account for the value that storage technologies bring to grid stability, such as frequency regulation, voltage support, or load leveling. There is also a need for updated or new interconnection standards for various types of energy storage systems.

6.2.2 Compressed Air Energy Storage (CAES)

With regards to the caverns required for CAES, the *Environmental Protection Act (EPA), SNL 2002, c E-14.2, Section 83* sets out requirements for obtaining approvals for industrial facilities in NL. Additionally, the *Environmental Assessment Regulations (EA Regs), 2003, NLR 54/03 and the federal Impact Assessment Act (IAA), SC 2019, c 28, s 1* outline processes for assessing environmental, stakeholder, and socioeconomic impacts, as well as for conducting public and Indigenous consultations to authorize project development. However, NL currently lacks specific legislation or regulations that govern the approval, design, construction, or operation of underground storage facilities and related surface infrastructure, such as CAES projects. This highlights a need for new or updated laws, regulations, or guidance to fill the gap. Other provinces have models that could provide useful frameworks to address regulatory gaps in NL.

The *Canadian Standards Association (CSA) standard CAN/CSA Z341-98* includes requirements for the design, construction, and operation of hydrocarbon storage in underground formations, which can be adopted. Although its application to CAES is currently limited, the development of the Code of Practice is considered. *API RP 1170 and API RP 1171* offers guidance for the design/operation of solution-mined salt cavern used for natural gas storage and ensures the functional integrity of natural gas storage in depleted hydrocarbon reservoirs and aquifer reservoirs. Nova Scotia's *Subsurface Energy Storage Act, SNS 2001, c 37*. Ontario's *Oil, Gas and Salt Resources Act, RSO 1990, c P.12*, along with the Provincial Standards for Compressed Air Energy Storage in Salt Caverns: Applications and Operations. The Saskatchewan's Ministry of Energy and Resources has granted authorization of an application that includes storage or disposal in underground salt caverns form.

The lack of clear regulations and targeted incentives for deploying CAES systems may limit the ability to scale such projects in NL. While federal incentives such as the Clean Technology Investment Tax Credit (ITC), Clean Hydrogen ITC, and the Atlantic Investment Tax Credit may support clean energy infrastructure, it remains unclear whether key components of salt dome storage projects, such as drilling, cavern development, and associated energy conversion systems, are explicitly eligible. Given the capital-intensive nature of CAES, it is crucial to provide clarity on eligibility and consider expanding these credits to explicitly include CAES and hydrogen-to-power systems. In addition, tailored regulatory incentives at the provincial level would help promote the development of these emerging technologies, particularly in jurisdictions like NL where such systems are not yet established. A detailed assessment of CAES component eligibility under current ITC frameworks could help identify gaps and opportunities for policy alignment.

6.2.3 Hydrogen-Specific Regulations

Building on the renewable growth momentum, Canada has taken significant strides with its Clean Hydrogen Strategy, first released in 2020. According to the May 2024 progress report, the country has introduced a range of policy instruments to support clean energy innovation, including investment tax credits for hydrogen production, clean technologies, and carbon capture, utilization, and storage (CCUS). To date, over 80 low-carbon projects are in development, representing more than CAN$100 billion in potential investment, including 13 low-carbon hydrogen production facilities [55].

Although hydrogen is seen as a critical element of NL's future energy strategy, policy and regulatory gaps remain. Given hydrogen's high flammability, establishing robust regulatory frameworks for the safe storage, transport, and handling of hydrogen (especially at large scales) is essential. For example, *CSA Z341 Series* covers standards for the storage of hydrocarbons in underground formations, including salt caverns, which can be applicable to hydrogen storage [62]. *Canadian Hydrogen Installation Code* sets installation requirements for hydrogen-generating equipment for non-process end use, ensuring safe and standardized deployment.

Learning from other jurisdictions, Alberta has taken initial steps by releasing a hydrogen roadmap to address hydrogen production, transport, and storage requirements [63]. Historically, Alberta has stored hydrocarbons in salt caverns, but no dedicated hydrogen storage regulations have yet been developed. Preliminary decisions have designated the Alberta Energy Regulator to oversee subsurface hydrogen storage. Similarly, as with CAES, the *Canadian Standards Association's CAN/CSA Z341-98* standard for storing hydrocarbons in underground formations, including salt caverns, could be considered for hydrogen storage applications [64].

6.2.4 Environmental Assessment and Permitting Processes

The permitting process for energy storage technologies can be complex and challenging, particularly for large-scale systems like CAES and hydrogen facilities. Projects often face lengthy approval periods due to requirements for detailed environmental assessments or encounter opposition from local communities or environmental groups, which can extend timelines and increase costs.

To address these concerns, the *Provincial Environmental Protection Act (SNL 2002, c E-14.2), the Environmental Assessment Regulations (2003, NLR 54/03)*, and the *Federal Impact Assessment Act (SC 2019, c 28, s 1)* provide a comprehensive framework. These regulations outline requirements for evaluating environmental, stakeholder, and socioeconomic impacts; mandate consultation with the public, Indigenous communities, and other affected stakeholders; and establish the processes for granting project approvals. Although this framework promotes comprehensive oversight, it is essential to adapt it specifically for salt cavern development to simplify the permitting and environmental assessment processes. For example, a key regulatory gap for CAES development in NL is the lack of clear guidance on brine management. While the Water Resources Act governs water use and removal, it does not address the specific challenges of brine disposal associated with salt cavern storage. This creates uncertainty for developers regarding permitting, environmental compliance, and project design. Learning from the McIntosh CAES facility (USA) and Huntorf CAES facility (Germany), they adhere to stringent environmental and safety standards, including regular monitoring of brine disposal and cavern integrity; evaluate potential impacts on local ecosystems, and engage with community to address concerns.

6.2.5 Land-use and Land Access

Land access for surface facilities is granted through various Provincial Acts, such as the *Mining Act (SNL 1999, c M-15.1)*, *Mineral Act (RSNL 1990, c M-12)*, *Lands Act (1991, c. 36)*, and the Crown Land Nomination Process for Wind Energy Projects. While these existing frameworks do permit access to surface lands for underground storage projects, the permitting process remains inefficient and fragmented. Developers must often submit separate applications to the Department of Fisheries, Forestry and Agriculture (for surface land use), the Department of Industry, Energy and Technology (for subsurface rights), and the Department of Environment and Climate Change (for environmental approvals), resulting in delays and regulatory uncertainty. To streamline and clarify the process, the application and approval procedures for accessing surface land related to underground storage should be integrated into any new legislation developed to govern such projects.

Numerous acts already govern land clearing and development, both at the provincial and federal levels. Under the *Canadian Environmental Assessment Act (CEAA)*, projects like CAES or PSH that involve significant changes to land use, water diversion, or energy generation typically require a federal environmental assessment. Furthermore, in Ontario, the *Oil, Gas and Salt Resources Act* governs the use of underground spaces for energy storage, including CAES. Similarly, Alberta's regulatory framework addresses the repurposing of mine sites for energy storage, provided that safety and environmental standards are met. Many provinces have land reclamation policies that encourage the rehabilitation of abandoned mine sites. These laws ensure that a range of environmental, ecological, and land use considerations are addressed.

6.2.6 Inter-jurisdictional Coordination

NL's participation in an interconnected grid with other provinces presents regulatory challenges for the development of CAES and other long-duration energy storage technologies, particularly around grid connection, market participation, and data reporting. While federal laws such as the *Canadian Energy Regulator Act (SC 2019, c. 28, s. 10)* and the *Inter-Provincial and International Power Lines Act (RSC, 1985, c. I-20)* provide a legal framework for cross-border transmission infrastructure, they do not directly address coordination of storage-related permitting, performance standards, or market rules. To support CAES development, there is a need for targeted interprovincial collaboration focused on harmonizing definitions, operational standards, and data reporting requirements. This could be facilitated through bilateral agreements between provinces with salt formations or through federal coordination mechanisms, modeled on efforts like the Atlantic Loop. Specific outputs could include a shared registry of eligible storage assets, unified emissions accounting methodologies, and common interconnection guidelines to streamline cross-border participation.

One of the key challenges in advancing energy storage lies in the mutual hesitation between customers and infrastructure operators. Potential customers may be reluctant to invest without assurance that the necessary storage infrastructure will be in place, while operators are hesitant to proceed with planning and construction without confirmed demand and adequate investment. This interdependence creates a negative feedback loop, potentially leading to stalled development or even market failure. Compounding this issue is the difficulty of generating accurate demand forecasts in the early stages of the market, as predictions often carry significant uncertainty and variability [54].

7 Suggested Next Steps

To support NL's transition toward a net-zero future, energy storage will be a critical component in decarbonizing energy infrastructure. As such, key recommendations to support the development of energy storage initiatives in the province include:

Develop a Phased Energy Storage Deployment Plan

1. Integrate technology, regulation, and local needs.
2. Establish a provincial energy storage roadmap with short-, medium-, and long-term targets.
3. Identify high impact use cases aligned with decarbonization and RE trends.
4. Set Strategic Priorities, which include improve grid reliability, diversify energy sources, support integration of wind and other renewables, reduce diesel reliance in isolated communities.

Launch Targeted Pilot Projects

1. Demonstrate value of storage technologies in various applications.
2. Priority regions include industrial load centers that could benefit from greater flexibility, areas experiencing wind curtailment, and NL's isolated grids.
3. Explore use cases like behind-the-meter storage for commercial customers, community-scale microgrids, and hybrid wind-storage systems.
4. Ensure deep collaboration with Indigenous governments and local communities.

Evolve Regulatory and Policy Framework

1. Define clear ownership models (e.g., utility-owned, third-party, community-operated).
2. Enable mechanisms such as:
    a. *Time-of-use electricity pricing.*
    b. *Performance-based incentives.*
    c. *Capacity market participation.*
3. Align with provincial and federal regulators to support deployment.

Leverage Funding and Strategic Partnerships

1. Utilize existing federal funding programs.

a. Collaborate with national and international partners for technical expertise, project financing, and adoption of global best practices.

Invest in Local Innovation and Research

1. Foster partnerships among government, academia, and industry.
2. Support real-world testing of storage technologies (TRL 6–9), including:
   a. *Wind-storage hybrids.*
   b. *Hydrogen integration.*
   c. *Long-duration storage solutions.*
3. Promote applied research to de-risk investment and build local expertise and leadership.

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Appendix A: Comparison to Other Canadian Jurisdictions

Category	NL Performance	Other Provinces
PSH	Very strong (natural reservoir storage)	Quebec & BC also strong
BESS	Minimal deployment	Ontario, Alberta, NS moving fast
CAES	Early exploration, no major deployment yet	NS & Ontario have clearer pathways
HESS	Early-stage discussions, no pilots yet	Alberta & Quebec advancing pilots
Regulatory readiness	Lacking specific storage regulations	NS, Ontario, Alberta more advanced
Market integration	Limited (mostly utility-scale hydro)	Ontario, Alberta: storage in markets

Appendix B: Rural Community profile in NL

Note that (I, Indigenous; NI, non-indigenous)

Community Name	Community Type	Population	Total Fossil Fuel Generating Capacity (kW)	Annual Fossil Fuel Generation (MWh/yr)	Total Renewable Energy Generation (kW)	Usual Residents/ Dwellings	Main Power Source	Annual Energy Demand (from 2011)
L'Anse-au-Clair	NI	216	-	-	0	98/111	Hydro	
Forteau	NI	409	-	-	0	161/181	Hydro	
L'Anse-au-Loup	NI	558	7,150	-	24,579	302/322	Diesel	
West St. Modeste	NI	111	1,108	-	0	51/62	Hydro	
Pinware	NI	88	-	-	0	28/31	Hydro	
Red Bay	NI	169	-	-	0	62/69	Hydro	
Lodge Bay	NI	65	-	-	0	31/37	Diesel	465
Mary's Harbour	I	341	2,635	4,561	0	121/147	Diesel	3,110
St. Lewis	I	194	1,020	1,604	0	72/93	Diesel	1,923
Port Hope Simpson	I	412	1,965	3,504	0	159/186	Diesel	2,187
Charlottetown	I	290	3,160	5,631	0	113/140	Diesel	1,496
Norman's Bay	I	25	160	211	0	5/15	Diesel	
Black Tickle	I	150	1005	1163	0	33/72	Diesel	1080
Cartwright	I	427	2220	4477	0	204/243	Diesel	3933
Paradise River	I	10	150	210	0	-	Diesel	186

Rigolet	I	305	1320	3049	0	125/134	Diesel	2064
Makkovik	I	377	1700	4520	0	142/154	Diesel	2422
Postville	I	177	890	2032	0	75/83	Diesel	1293
Hopedale	I	574	2500	5203	0	193/208	Diesel	2673
Natuashish	I	936	3273	9420	0	196/239	Diesel	
Nain	I	1125	3755	9377	0	245/266	Diesel	5142
St. Brendan's	NI	145	712	1051	0	69/122	Diesel	1208
McCallum	NI	73	446	501	0	21/44	Diesel	545
Francois	NI	89	635	660	0	28/47	Diesel	751
Grey River	NI	104	522	583	0	41/50	Diesel	715
Ramea	NI	447	2775	3853	588	206/207	Diesel	6686

Appendix C: Comparison of Energy Storage Opportunities per Region

Region	Energy Profile	Storage Opportunity	Recommended Technology
Island Grid (Avalon Peninsula, Central, Western NL)	Hydro-dominant, grid-connected	Peak shaving, grid support, wind integration, load management, wind balancing	CAES, Lithium-ion batteries
Labrador (Upper Churchill, mining zones)	Hydro surplus, industrial loads	Bulk storage, hydrogen for industry/export	CAES, Pumped-storage hydro
Remote/Isolated Coastal Communities (e.g., Northern Peninsula, South Coast)	Diesel-reliant, off-grid	Diesel offset/replacement, microgrid resilience	Lithium-ion batteries, hydrogen fuel cells
St. John's Metro/ Urban Area	Urban hub, high energy demand	Backup for critical infrastructure, health/transport, EVdemand management	Lithium-ion, flywheels
Port and Industrial Zones (e.g., Argentia, Stephenville, Goose Bay)	Industrial growth, potential hydrogen hubs	Powering green hydrogen, storage for export readiness, industrial resilience	Hydrogen storage, CAES

Appendix D: Deployment Status and Commercial Readiness by Technology

Technology	Deployment in NL (2025)	Readiness Level	Key NL Use Cases	Action Needed
BESS	Small pilots active	Proven globally Early planning and feasibility assessment stage	Microgrids (low capacity), short-duration backup	Regulatory clarity, ownership policy, financial incentive design
PSH	None		Bulk storage, grid balancing	Feasibility studies, infrastructure support
Under-ground H2ES	None	Emerging globally Geological assets and strategic plans position it well for future development.	High capacity, long-duration, green H2 hubs	Geology mapping, safety regulations
Under-ground CAES	None		High capacity, long-duration, wind integration	Site exploration, pilot funding

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