

July 15, 2022



Barriers and Opportunities to Offshore Renewable Energy Electrification

A STRATEGIC RISK-BASED APPROACH



Letter of Introduction

On behalf of Growler Energy, I am pleased to provide our Barriers and Opportunities to Offshore Renewable Energy Electrification – A Strategic Risk-Based Approach report to Energy Research & Innovation Newfoundland & Labrador.

This project was executed with funding from Natural Resources Canada’s Emissions Reduction Fund, Offshore RD&D program, which was managed and administered by Energy Research & Innovation Newfoundland & Labrador.

The overall objective of the ERF fund was to:

- 1. Accelerate the adoption and deployment of clean technology and solutions to reduce GHG emissions, and
- 2. Drive innovation in Canada’s natural resources sectors by supporting research, development and demonstration

This program has demonstrated that solutions do exist and can be developed right here in Newfoundland and Labrador. The success of this project was built on developing a core team of local companies and subject matter experts. Key team members included Angler Solutions, Cabletricity, Canadian Projects Limited, C-CORE, Frobisher Energy Services, LeDrew Environmental Services, Robot Interactive + Marketing, and SEM.

Operator engagement is critical to support these types of projects and initiatives, and Chevron Canada played an integral role in the development of the study objectives and overall execution. Chevron Canada provided insight and availability of key subject matter experts in North America to help guide the work.

We are proud to be part of such an important and successful program, and provide possible solutions that can support GHG emissions in Newfoundland and Labrador. Thank you to Chad Butler (Growler Energy Project Manager), Kim Coady (ERI Program Coordinator), Lee O’Brien (Chevron Canada Facilities Engineer), and all other companies and team members that contributed to the success of this important project.

We look forward to the future of both the Renewable Energy and Oil and Gas industries and how they can work together to provide significant future benefits for the people of Newfoundland & Labrador.

Yours truly,



Robert Woolgar, P.Eng., FEC
President and CEO

Executive Summary

This project was generated with funding from Natural Resources Canada's Emissions Reduction Fund (ERF), Offshore Research, Development & Demonstration (RD&D) program, which was managed and administered by Energy Research & Innovation Newfoundland & Labrador.

The overall objective of the ERF fund was to:

1. Accelerate the adoption and deployment of clean technology and solutions to reduce greenhouse gas (GHG) emissions, and
2. Drive innovation in Canada's natural resources sectors by supporting research, development and demonstration activities to reduce GHG emissions in Canada's offshore oil and gas sector.

A component of this Emissions Reduction Fund included an Offshore RD&D Program supporting research, development and demonstration projects to advance solutions to reduce GHG emissions from Newfoundland and Labrador's offshore industry. Growler Energy's Barriers and Opportunities to Offshore Renewable Energy Electrification – A Strategic Risk Based Approach report was one of the projects selected to support this initiative.

Both the Renewable Energy and Oil and Gas industries have the potential to provide significant future benefits for the people of Newfoundland & Labrador (NL). There exists a significant opportunity to link the converging industries in supporting the development of the emerging renewable energy industry and the continued success of the Offshore Oil and Gas industry.

The Offshore Oil and Gas industry in Newfoundland & Labrador also represents a significant source of GHG emissions for the province of Newfoundland & Labrador. In other jurisdictions, notably the North Sea, these emissions are being reduced through the electrification of offshore oil and gas assets using renewable energy from shore. Newfoundland and Labrador has the advantage of having a plethora of renewable energy development potential, namely in wind and hydro, similar to progressive jurisdictions in the North Sea.

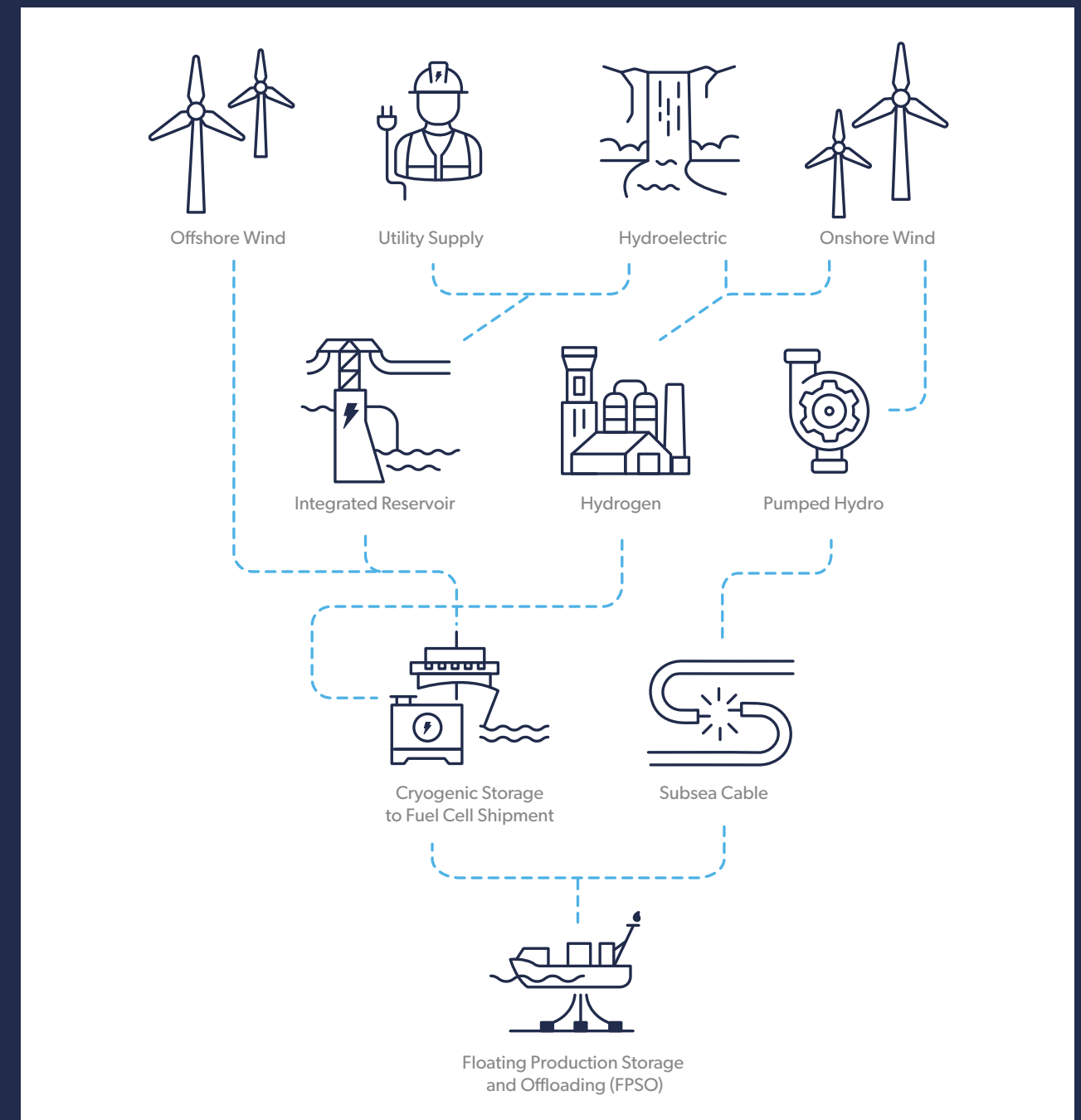
For the province of Newfoundland & Labrador, electrification of the Offshore Oil and Gas industry represents an opportunity to maintain continued macroeconomic and microeconomic benefits received from the offshore oil and gas industry in the form of jobs, royalties, taxes, and other spin-offs such as sub-contracted works. It also represents an opportunity to position the province as a global leader at the forefront of the energy transition.

For Offshore Oil and Gas operators, electrification of existing and new offshore assets represents an opportunity to maintain a social license to operate and improve brand image through the ownership of cleaner, more modern assets. Additionally, with the recent announcement of a federal emissions cap on the Oil and Gas industry, it is becoming increasingly important for operators to minimize GHG emissions in the quest for continued growth and development.

Exploring the electrification of offshore Newfoundland & Labrador is a positive step towards energy security and a low carbon future. It was the hypothesis of this report that electrification of new "green field" oil and gas developments in Newfoundland and Labrador's offshore is feasible using renewable energy.

This project took a risk based approach, to identify barriers and opportunities associated with using renewable energy in new "green field" developments offshore Newfoundland and Labrador.

This approach included determining the generating, transmission, and storage technologies that were most applicable.



Below is a list of some of the key barriers and opportunities to electrifying offshore oil and gas Newfoundland & Labrador with renewable energy:

Barriers:

- Technical challenges for all of the evaluated technologies. Hydrogen and cable technologies might be promising solutions, but will require further engineering.
- Regulatory environment does not yet allow for these types of developments, although policy makers are moving in this direction.
- Economics is one of the the largest barriers to these types of developments.

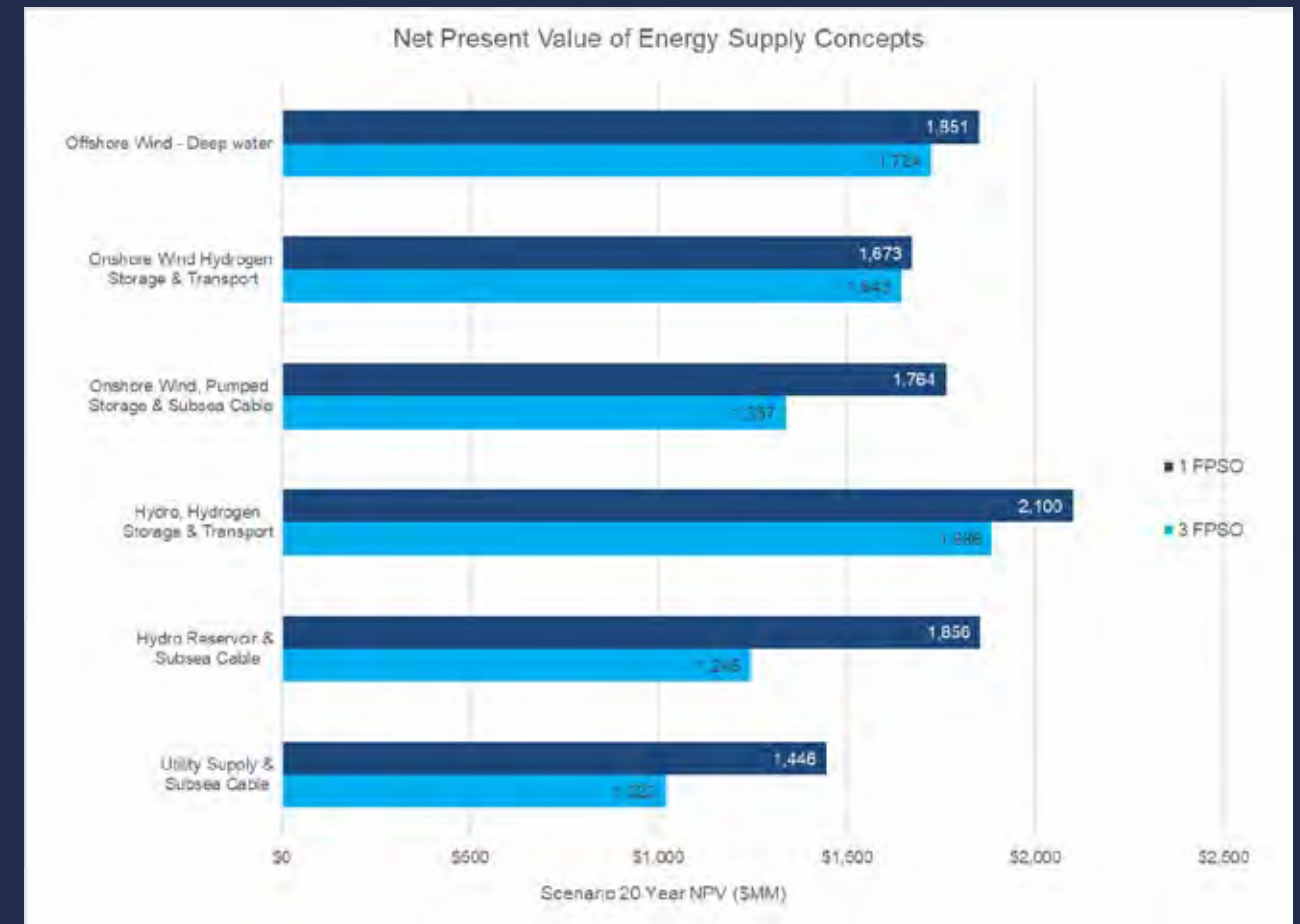
Opportunities:

- 120,000 - 250,000 Tonnes carbon dioxide equivalent (CO₂e) / year GHG emission reduction / platform
- Potential surplus utility energy (availability still unclear)
- Many potential locations for grid interconnection
- Many potential cable landfall locations
- Onshore wind and hydro meets the energy requirement many times over, the surplus of which could be utilized on the grid
- Cables have proven to be more robust than anticipated in an iceberg impact, which could translate to cost savings on ice protection.
- Green hydrogen industry is developing in parallel, oil and gas industry has potential to be off-taker

There is a continued need for this type of study work for all new developments regardless of sector. Even since completing of this 1-year long study there have been significant advancements in the technology and policy that could affect overall feasibility of an offshore oil and gas electrification project.

From a technology perspective the best solution will depend on a variety of factors. Project cost is one of the key drivers in selection of a preferred solution. The following chart illustrates the Net present value (NPV) for the technical solutions that were considered as part of this project. It is important to note that many of the solutions that were considered involved the implementation of privately developed power generation and transmission, as this project has shown that utility purchased power is not necessarily the best solution.

Offshore Newfoundland and Labrador is not the North Sea. Therefore the solution for Newfoundland and Labrador will likely look different. This may include utilizing technologies such as green hydrogen to transmit the clean energy instead of power cables, or the development of new cable technologies. Technology is advancing at an incredible pace for sustainable energy technologies and each technology has its own advantages and drawbacks. There are also new industries emerging that could be symbiotic with oil and gas such as green hydrogen (H₂), for example, if green H₂ production and export already exists then oil and gas facilities could buy this clean fuel in lieu of traditional hydrocarbon based fuels.



Policy is changing in real time. Since this report was started the provincial government has announced a removal of the onshore wind ban and has rolled out a renewable energy plan. The federal government is also implementing policy change, such as a tax on carbon emissions, that will have a material impact on the economics of renewable energy electrification projects. What doesn't make sense today might make sense tomorrow and tomorrow is fast approaching

Newfoundland & Labrador has a sustainable development advantage due to the abundance of undeveloped, cost effective renewable energy resources. Large scale energy developers have shown interest in developing these resources for export via green hydrogen and others are eyeing the opportunity to set up domestic sustainable industries such as mining operations in Newfoundland and Labrador. This type of development will only serve to increase the value of the oil and gas resource by ensuring GHG emissions are limited.

The local technical expertise is there to continue with this work and ensure that Newfoundland and Labrador continues to be a leader in the global energy transition.

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1. Introduction

1.1 Contributors



- **Growler Energy:** Lead proponent, including project coordination, shore / landfall approach assessment and overall project management
- **Chevron:** Provided guidance from subsea cable and offshore subject matter experts throughout the project
- **Angler:** Project economic considerations assessment and management of characterization studies
- **Canadian Projects Limited:** Renewable energy resource assessment & concept evaluation support
- **C-Core:** Ice risk assessment
- **Cabletricity:** Power cable submarine alternatives assessment
- **Frobisher Energy Services:** Grid interconnection assessment
- **SEM:** Environmental and regulatory risk identification and GHG emissions opportunity assessment
- **LeDrew Environmental Services:** Senior project advisor
- **Robot Interactive + Marketing:** Communications consultation

1.2 Fund Overview

This project was supported with funding from Natural Resources Canada's Emissions Reduction Fund, Offshore RD&D Program, which is managed and administered by Energy Research & Innovation Newfoundland & Labrador.



1.3 Background

The Province of Newfoundland and Labrador (NL) has an abundance of developed and undeveloped onshore and offshore renewable energy. Combined with this wealth of renewable energy resources, the Province has vast potential with undeveloped oil and gas resources.

Other jurisdictions globally are taking advantage of this combination to electrify offshore oil and gas developments thereby reducing the GHG emitted as a result of the oil and gas developments. It has not been done in Newfoundland and Labrador to date.

1.4 Vision

There is a long history in offshore oil and gas development, with the potential for continued success in the future, while providing significant benefits for Newfoundland & Labrador. A key element in this continued success is reducing the greenhouse gas emissions from the offshore oil and gas industry. An important step to achieving this goal is integrating the energy industry in Newfoundland and Labrador for the greater success of the Province – in particular, continued success relies on integrating the renewable energy industry with the offshore oil and gas industry. This project is the first step to aligning both industries and providing the base work to understand the risks and opportunities to electrifying offshore Newfoundland and Labrador.

1.5 Hypothesis

“Electrification of new oil and gas developments in Newfoundland and Labrador’s offshore is feasible using renewable energy.”

1.6 Approach

This project took a risk-based approach, as illustrated in the following pages, to identify barriers and opportunities associated with using renewable energy in new developments offshore NL.

TASK 1: The frame / scope of the study was defined. It was agreed at this time to focus on “greenfield” developments in higher probability areas.

TASK 2: Energy generation, transmission, and storage technologies were evaluated independently to produce a short list of higher probability technologies that could be deployed for the application of electrifying new offshore oil and gas developments. These technologies were then combined to look at some specific combinations of these technologies that would provide a full solution.

TASK 3: A strengths, weaknesses, opportunities, and threats (SWOT) analysis was performed to identify risks and opportunities for the short listed generation, transmission, and storage technologies.

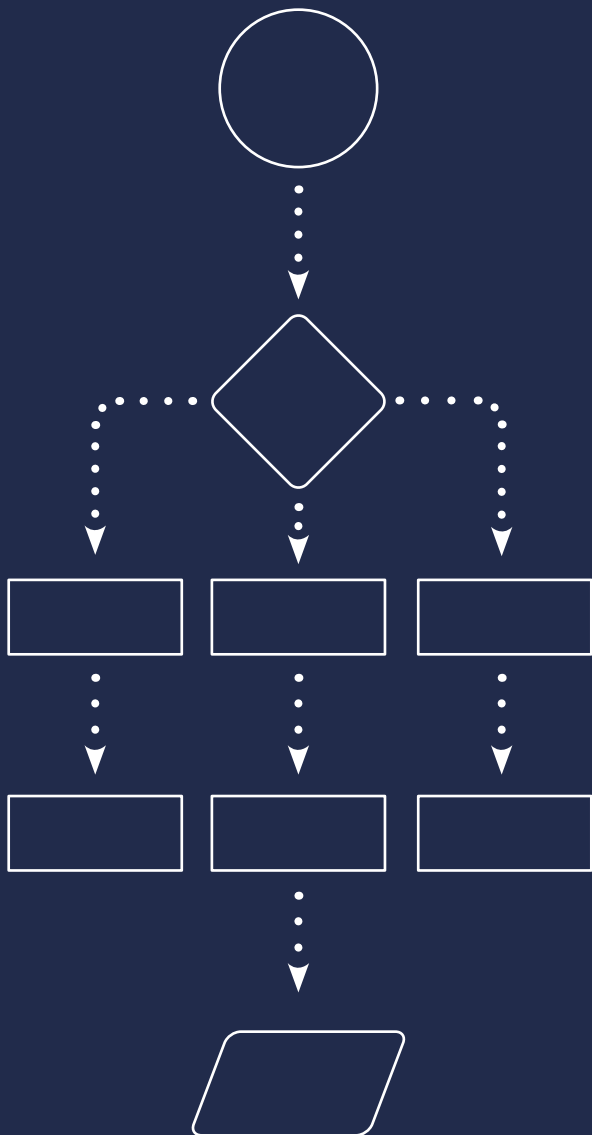
TASK 4: Several key risks and opportunities were identified through other work and industry knowledge. These were all studied independently.

TASK 5: Final report and roadmap development to illustrate pathways to electrify NL’s offshore oil and gas industry.



2. Project Framing

Project framing is the foundation for the successful completion of projects.



Appropriately framed projects have the right people to solve the right problems from the right perspectives. Likewise, appropriately defined projects allow the project team to maximize the value of the opportunity.

Poorly framed projects can overwhelm teams with non-essential information, lead to misidentification of key issues, provide sub-optimal solutions, or provide the right solutions to the wrong problems.

This section explores the objectives, success vision, value drivers, and project boundaries of the Barriers to Offshore Electrification: A Risk Based Approach study.

2.1 Key Project Objectives

Project objectives are statements of desired achievements for the Project. The primary objectives of the project are:

- 1. Close the knowledge gap to the barriers that currently exist in renewable energy electrification of the offshore industry by taking a strategic risk-based approach.
- 2. Identify and address risks, opportunities, and knowledge gaps that exist for three development scenarios: Orphan Basin (North), Orphan Basin (South), and Labrador South Region. Refer to the map below for the location of these offshore sites.

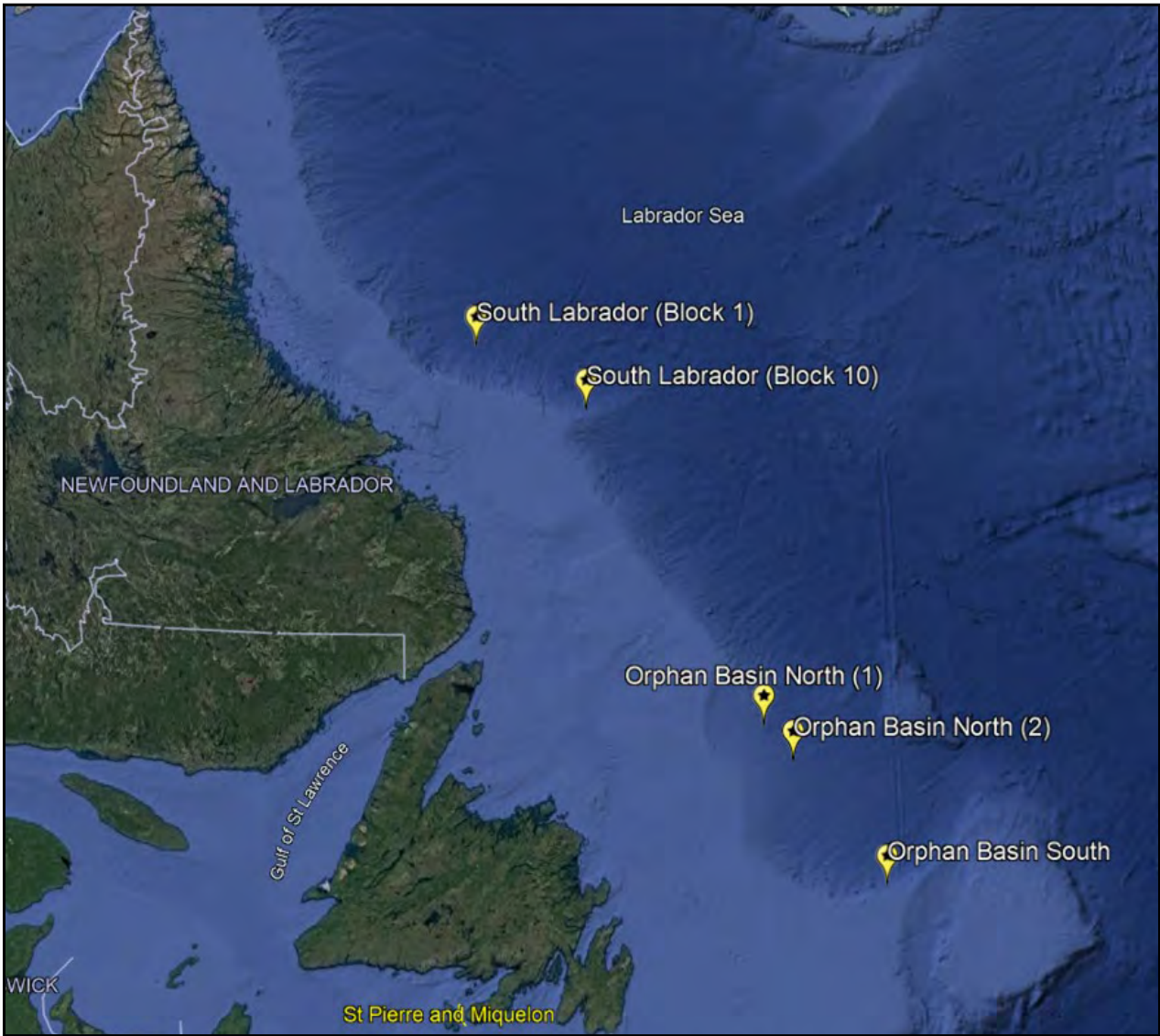
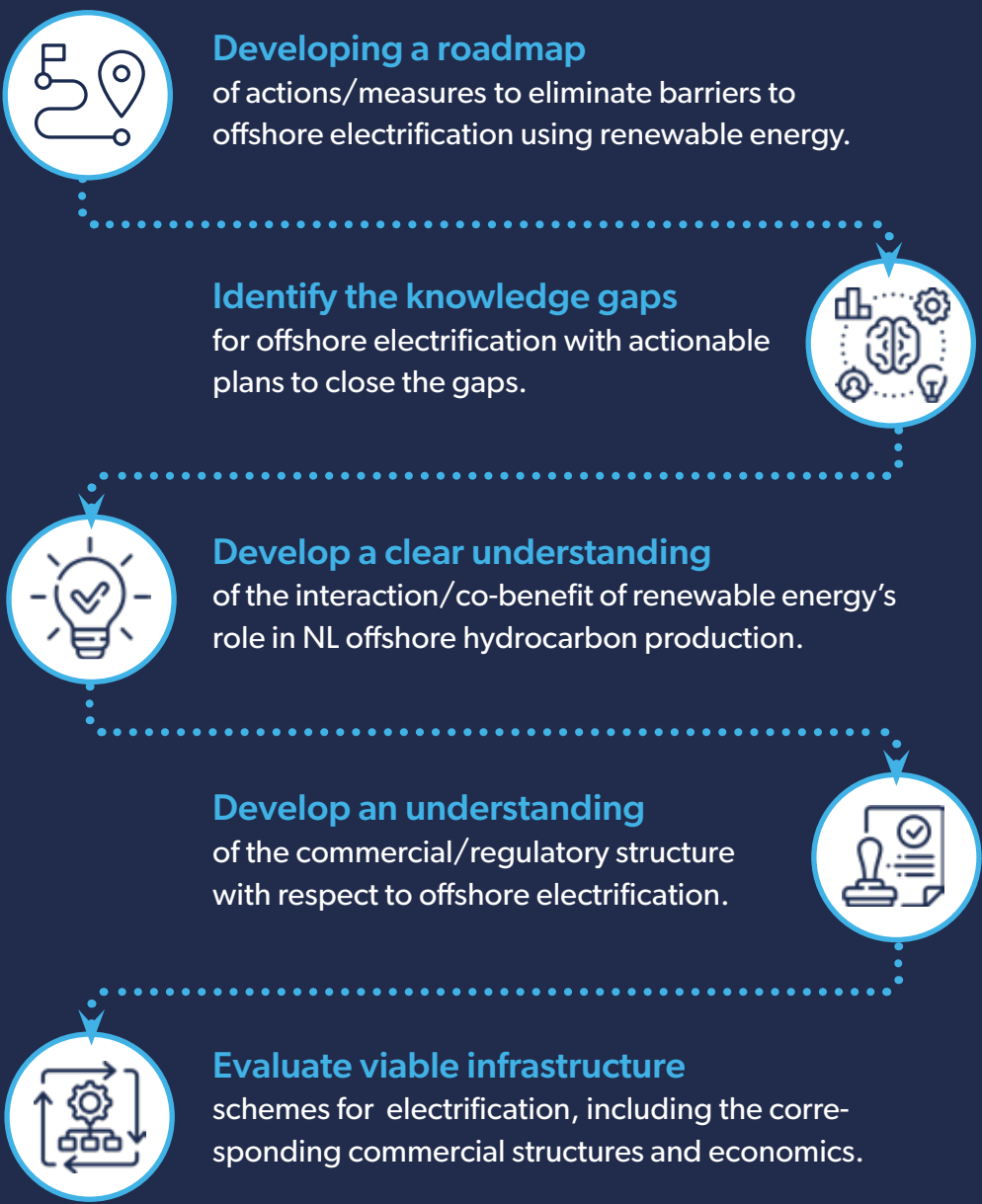


Figure 1. Location of potential oil and gas developments offshore Newfoundland and Labrador

2.2 Success Vision

Success for this project will help identify the actions required to position NL’s offshore industry for continued success in a low carbon future. The vision of success for this project includes:



2.3 Value Drivers

Value drivers are the factors that most influence the value of an opportunity. Value drivers can include uncertainties as well as other factors and they can be anything that allow decision makers to objectively evaluate one alternative against another. Value drivers should be objective measures that are important to the decision maker and relevant to the opportunity.

The value drivers identified for the Barriers and Opportunities to Offshore Electrification study are:



- 1. Emissions Reduction**
Reduce CO₂ equivalent emissions, measured in kg/bbl.



- 2. Renewable Energy Deployment**
Increased renewable energy use at offshore facilities, measured in MW.



- 3. Renewable Energy Nodes**
Creation and access to new renewable energy nodes, either through transmission or generation infrastructure.



- 4. Platform CAPEX**
Potential to optimize platform size, measured in \$CAD.



- 5. Platform OPEX**
Potential to reduce OPEX by reducing onboard equipment, measured in \$CAD/yr.



- 6. Economics**
Reduced exposure to carbon tax, better access to investment associated with sustainability initiatives, and a basin-wide analysis can examine commercial structures to maximize economic recovery per development.



- 7. Socio-political**
Achieve company sustainability targets, developments can provide positive outcomes for regulators, and improved timelines for regulatory approval.

2.4 Project Boundaries

Project boundaries define the scope of work for the project team and document items that are excluded from consideration. Known information, asset limitations, external constraints (regulatory, environmental, logistical, and physical), and contractual terms assist in establishing the project boundaries.

Clearly defined boundaries reduce redundancy and rework by preventing the team from working on areas/topics addressed by others or pursuing alternatives that are not realistic. The project frame effectively bounds the scope of the overall project and focuses the project team on the key scope requirements.

Items can move inside, onto, or outside the frame throughout project execution, but should be clearly identified as inside or outside the frame (with rationale) at the end of the project. This section captures the project boundaries as they were defined at project completion.

(See following tables)

Technical – Platform Loads (Load Nodes)

Project Boundaries	In Bounds	Out of Bounds	Rationale
Production Load Profiles - Typical	•		A typical load profile (24hr) for a platform in a +500mmbbl recoverable field to be used as benchmark for the study.
Field Development Schemes - Locations	•		Development scenario locations will make the gaps identified in the study more relevant to future development scenarios. Does not need to be precise for this level.
Platform Interconnections (i.e. field microgrid)		•	This is more efficient than electrification, would need to be coupled with other solutions and should therefore be out of scope.
Platform Options (FPSOs, Spars, Tension leg platforms (TLP), etc)		•	Platform types should have little effect on understanding the load requirements for a typical deep-water development
Drilling Operations and Associated loads		•	Marine vessel electrification considered a separate R&D scope.
Subsea Installation & Workover Loads		•	Marine vessel electrification considered a separate R&D scope.
Supply Vessel or Other Logistics Vehicles		•	Marine vessel electrification considered a separate R&D scope.
Combined Cycle Turbines or Other Generation Efficiencies		•	While this may ‘optimize’ the eventual preferred development scheme, it is not a ‘barrier’ to electrification
Flaring or Other Operational Efficiencies		•	This is the subject of other emissions reduction initiatives and does not fit this scope.
Carbon Sequestration		•	While this may ‘optimize’ the eventual preferred development scheme, it is not a ‘barrier’ to electrification.
Brownfield Tie-ins		•	Time horizons are too long to practically consider the integration of existing operations.
Future Expansion		•	The study explored the potential implications of additional future demand and/or cost savings that can be realized through economies of scale.
Operations & Maintenance		•	O&M could significantly affect economics due to reduction in platform resourcing. This was ruled outside the boundary. Platform design implications and therefore operations and maintenance implications were beyond the scope of this study.

Technical – Generation Nodes

Project Boundaries	In Bounds	Out of Bounds	Rationale
Met-Ocean Data Analysis (Wind, Wave, Solar)	•		Existing met-ocean data from the Nalcor NESS system is ideal for this application and should be used in study for the energy resource assessment. Only used for energy assessment, not design loads.
Met-Ocean Data Analysis (Pack Ice, Icebergs)	•		Only used in assessing risks/opportunities of alternatives.
Offshore Wind Energy	•		Floating offshore wind feasibility to be assessed using existing data; energy supply profiles to be completed.
Onshore Wind Energy	•		Onshore wind generation will be assessed.
Solar Energy	•		Offshore solar technology to be assessed during concept evaluation, energy supply profiles to be completed.
Hydroelectricity Expansion	•		For the ‘near term’ opportunity, it is assumed that no major change in hydroelectricity availability. This will change in the ‘long term’ analysis. Expansion is the operative term.
Wave Energy	•		Offshore wave technology to be assessed during concept evaluation. Energy supply profiles to be completed.
Geothermal Energy	•		Like hydroelectricity, there’s no identified opportunity in the near term.
Battery Storage	•		Battery storage to be considered as a part of the study in terms of capacity and capital cost.
Green Hydrogen - Storage	•		Hydrogen paired with energy generation facilities is a consideration.
Hydrokinetic	•		Currently not deployed in water depths greater than 45m.
Green Hydrogen – Transshipment	•		Hydrokinetic to be assessed during concept evaluation
Blue Hydrogen – Production & Storage		•	Not considered a renewable technology but might be considered an emissions reduction measure.

Technical – Transmission & Utility Grid Modeling

Project Boundaries	In Bounds	Out of Bounds	Rationale
Met-Ocean Data Analysis (Pack Ice, Icebergs)	•		Iceberg contact rates and return periods assessed over cable route. Physical impact testing also conducted.
Submarine Cable (Transmission) - Technology Assessment	•		This will include high/med/low voltage alternating current (AC) and direct current (DC) technologies. It will also consider previous work completed for comparative analysis. Study to include ‘State of the Art’ Analysis for this scenario/region.
Submarine Cable (Transmission) - Specifications		•	This study is to identify barriers and opportunities in electrifying offshore NL; too early to specify technologies since the study may point to other preferred methods.
Submarine Power Facilities - Technology Assessment	•		Offshore converters, subsea transformers, reactors, and substations to be considered in this study. A focus on High Voltage Direct Current (HVDC) will help bound this activity.
Submarine Power Facilities - Specifications		•	This study is to identify barriers and opportunities in electrifying offshore NL; too early to specify technologies since the study may point to other preferred methods.
Connection Types and Details		•	Too early for this level of detail. Included in the roadmap with recommendations for further action.
Dynamic Cables	•		Dynamic cable applications briefly discussed. A technical note was prepared as part of the study.
Grid Interconnection Points	•		Interconnection points to be modeled including a conceptual single line diagram.
Protection & Controls Philosophy	•		Qualitative commentary in system studies. It is too early to begin work on protection and controls.
Load Flow and Stability Analysis - Power from Shore	•		This will include consideration of large motor start ups, cable faults, etc.
Power Quality Harmonics Analysis - Power from Shore	•		This is essential for understanding any constraints or complexities associated with interconnecting to the grid.
Submarine Cable Installation Methods		•	Considered too early in the process for this level of detail.
Submarine Cable Repair Methods		•	Considered too early in the process for this level of detail.

Regulatory, Economics, and Commercial Considerations

Project Boundaries	In Bounds	Out of Bounds	Rationale
Cost Estimates – Level 4/5 AACE	•		Cost is a key metric in comparison of different development options.
Cost Forecasting — 10-To-20-Year Technology Pricing Outlook		•	As with most developing technology, pricing will change as the technology commercializes and proliferates. It is too speculative to forecast commodity and technology pricing.
Schedule Development & Analysis		•	Construction schedules and timelines are not in the current scope; not perceived to be a barrier in the prescribed time horizon.
Energy + Economics Model	•		System too complex to consider cost on its own. Must be viewed along with multiple economics inputs to understand the full picture.
GHG Emissions Calculations and Carbon Tax Analysis	•		This is a core consideration for economics modelling and sustainability planning.
Regulatory Gap Analysis - Provincial & Federal	•		This is a clear gap discovered in the review of existing local studies.
United Nations Convention on the Law of the Sea (UNCLOS) Boundary - Implications		•	Assumed to be outside the boundary of the electrification scope. This would likely have broader economics implications that are not directly associated with electrification, but rather, the overall project economics.
Commercial Structure - Analogous Regions	•		Identified as a gap discovered during the jurisdictional review. Understanding commercial structure of analogous regions can shed light on how electrification is viable in other regions.
Power Purchase Agreements/Electricity Pricing		•	The current study assumed current industrial rates. LCOE was estimated for in-situ generation for the purpose of comparison.



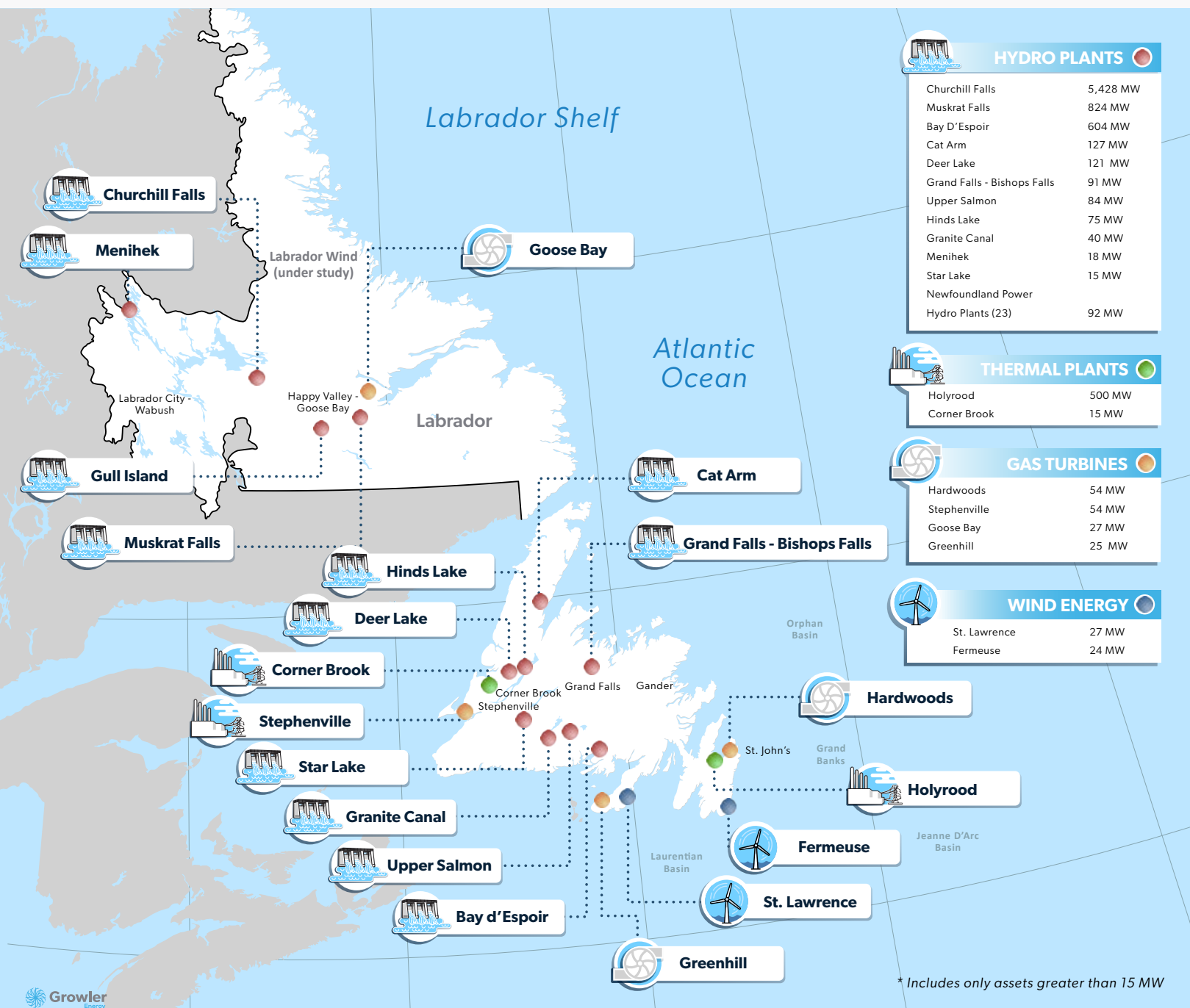
Renewable Energy Supply Assessment

As outlined in the project methodology, this project executed a number of pre-identified characterization studies, including the following assessment of Newfoundland and Labrador's renewable energy supply.



2.5 Existing Generation and Infrastructure

- Total installed generating capacity in the province is about 7,700 MW with an average annual energy production capability of about 47,000 GWh.
- Most of the generation in the province is owned by the province and to a lesser degree, Newfoundland Power. There are a few Independent Power Producers (IPPs) or Non-Utility Generators (NUGs) including the two 27 MW wind farms and Algonquin Power's 4 MW Rattle Brook small hydro station.



- The 5,428 MW Churchill Falls generating station is the third largest hydro-electric generating station in North America which is jointly owned by Newfoundland and Labrador and Québec through CF(L) Co.
- The Churchill River in Labrador has significant hydropower potential of about 8,500 MW at three sites: Churchill Falls, Gull Island, and Muskrat Falls
- The agreements negotiated for its development in the 1960s intended that most of the generation, about 34,000 GWh annually, is sold to Hydro Québec under the contract which expires in 2041, at a low fixed price of \$2 / MWh

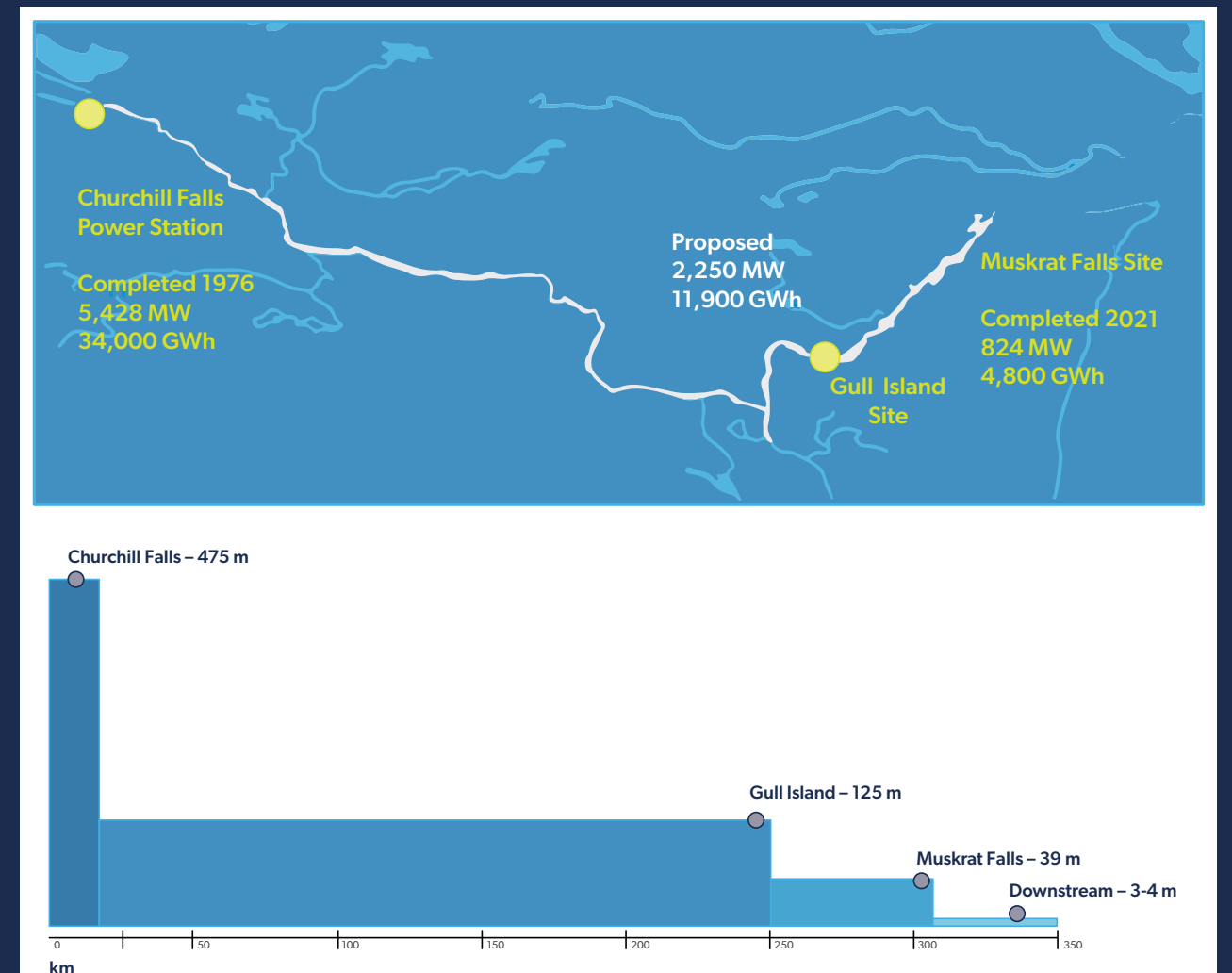


Figure 2. Churchill River Hydro Power Developments (Marshall, 2018)

Newfoundland and Labrador Interconnected System

- 900 MW HVDC Labrador-Island Link (LIL) from Labrador to Newfoundland and 500 MW HVDC Maritime Link from the island of Newfoundland to Nova Scotia.
- An important aspect of the 900 MW capacity LIL system is that it can operate at a reduced 675 MW capacity in the event of a failure on one of the two poles (mono pole operation).
- The availability of surplus energy and capacity from Labrador must consider the reliability of the LIL for both the availability of the energy and reserve capacity.



Figure 3. Renewable Energy Atlantic Loop Concept (with Possible Offshore Exports Areas) (Hydro, 2018)

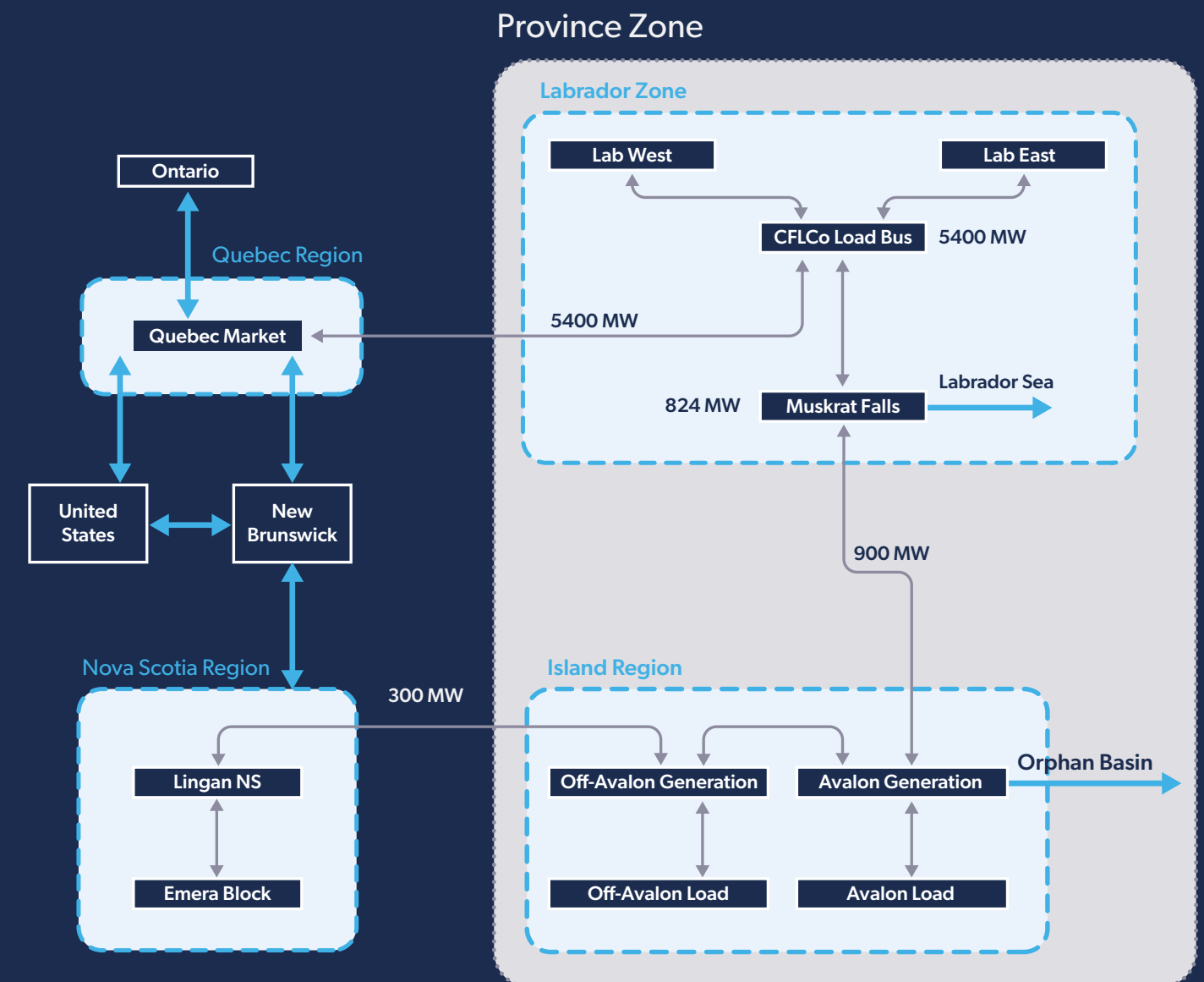


Figure 4. Newfoundland and Labrador Interconnected Transmission Systems (Hydro, 2018)

2.6 Power & Energy Demand/Forecast - NLH

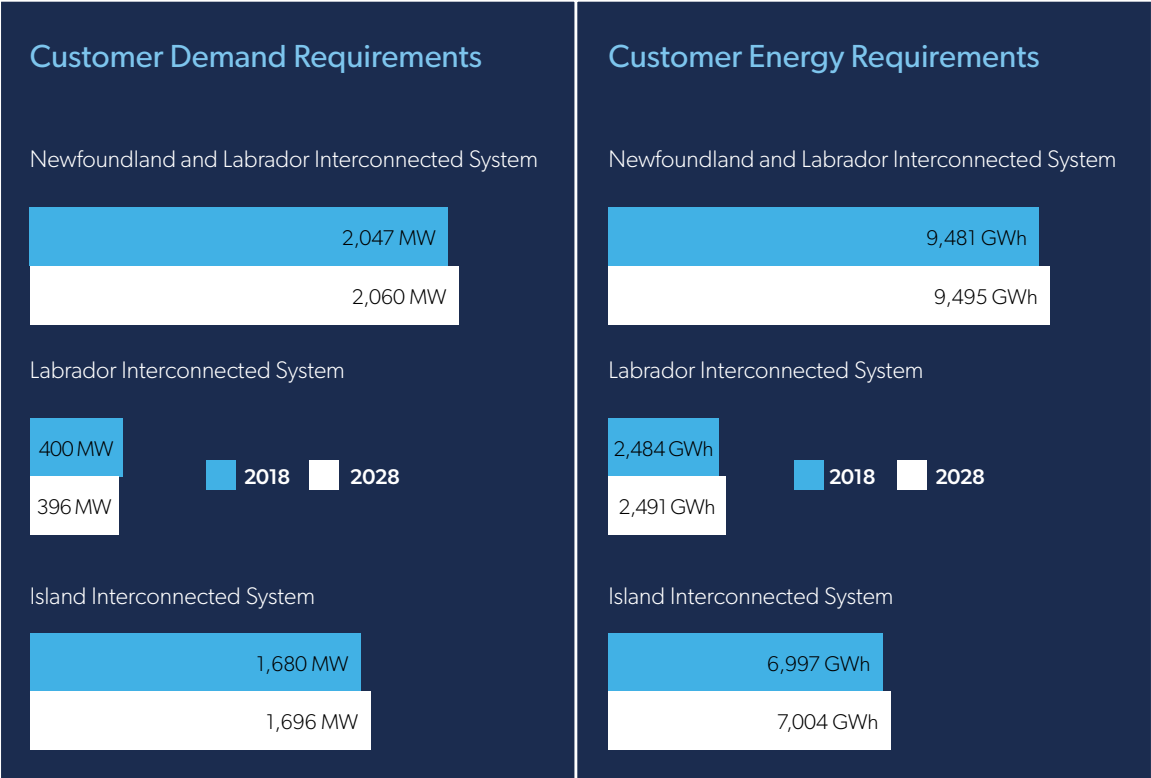


Figure 5. Newfoundland and Labrador Customer Power and Energy Requirements (Hydro, 2018)

- The total customer demand and energy requirements as reported by Newfoundland and Labrador Hydro is about 2,000 MW and 10,000 GWh per year.
- Base case planning scenario indicates that no electric load growth is expected to 2028.
- Significant prospects for increased demand in addition to the offshore complexes are the refining processes of Western Labrador mining operations and the transition to electric vehicles.

- Net increase in generation associated with the completion of Muskrat Falls, the retirement of the Holyrood thermal generating station, and the upcoming expiry of the Churchill Falls energy contract with Hydro Québec, there stands to be a surplus of renewable energy, potentially subject to transmission constraints and other matters

Generation / Demand (MW)	2027		2041	
	Average	Firm	Average	Firm
Churchill Falls Generation				
Recapture Energy	300	300	0	0
Twin Co Block	225	225	0	0
Balance of Generation	3470	2870	3995	3395
Muskrat Falls Generation	560	515	560	515
Labrador Interconnected System Demand	(285)	(285)	(285)	(285)
Hydro-Québec Contract Requirements	(3470)	(2870)	0	0
Labrador Surplus (Deficit)	800	755	4270	3625
Labrador Export Transmission Capacity	5300	5300	5300	5300
LIL Capacity Limited Island Transfer	800	755	900	900
Island Hydro Generation	615	525	615	525
Island Wind Generation	25	20	25	20
Island Cogeneration	10	10	10	10
Island Interconnected System Demand	(800)	(800)	(800)	(800)
Nova Scotia Block	(110)	(110)	(110)	(110)
Newfoundland Surplus (Deficit)	540	400	640	545
Island Export Transmission Capacity	300	300	300	300

Table 1. Near and Long-Term Surplus Energy Estimates from Existing Provincial Sources

2.7 Energy Regulation

Provincial Energy Legislation

- In 2012, the Province amended the Electrical Power Control Act through Bill 61 which gives Newfoundland and Labrador Hydro the exclusive right to supply, distribute, and sell electrical power or energy on the island portion of the province.
- The Electrical Power Control Act precludes an industrial customer from generating power for its own consumption, except for facilities operating before 2012 and in emergency circumstances. There is, however, a provision for the government to grant an exemption to industrial customers.
- To ensure hydroelectric facilities operating on the same river work together to optimize the value of the resource to the Province and power generators, the Provincial Government has taken steps to regulate the coordination of water management and power production on provincial rivers.
- Under current regulations, power to supply the offshore FPSO's would have to be purchased from Newfoundland and Labrador Hydro (NLH) at the price set according to the NLH Schedule of Rates, Rules, and Regulations (Newfoundland and Labrador Hydro, 2021)

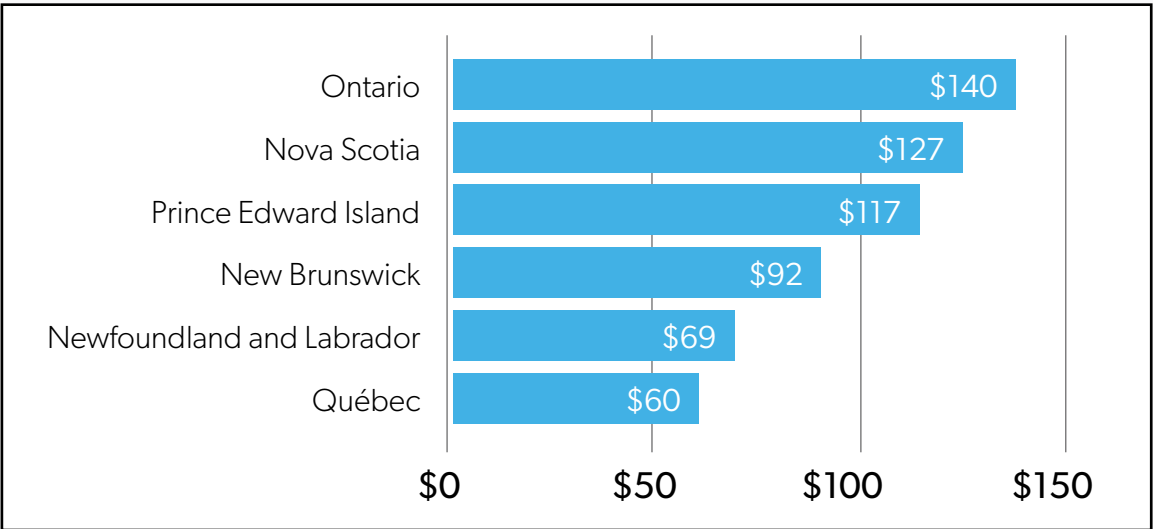


Figure 6. Effective Average Cost of Industrial Electricity Supply in Eastern Canada (\$ / MWh)

NL Government lifts 15-year ban on onshore wind farms

April 2022, the Provincial Government announced “lifting the ban on wind development in Newfoundland and Labrador to allow companies to generate and export onshore wind energy.” The associated timelines and details of the specific regulatory changes relating to the announcement were not provided.

Notwithstanding the current legislation and energy pricing, the following circumstances should be considered in speculation of possible future energy pricing available to supply the offshore:

- Surplus energy from Muskrat Falls and the high development cost of Muskrat Falls;
- The new ability to import and export power to the island via Nova Scotia via the Maritime Link;
- The interconnection of the island and Labrador transmission systems;
- The potential construction of the 2,250 MW Gull Island hydro station in Labrador;
- The looming expiry of the Churchill Falls contract with Hydro Québec in 2041;
- Critical variable for the electricity rate is the rate impact associated with the relatively high cost of the Muskrat Falls project. The hydro facility generation represents about 50% of the provincial demand and will replace relatively cheap thermal generation;
- Various project-based economic analyses for Muskrat Falls yields an energy value of about \$250 / MWh, there is a risk that energy prices will increase significantly, however the Province is actively pursuing “rate mitigation” strategies with the Federal Government;

- The geography of Newfoundland and Labrador features mountain ranges, including the Long Range (an extension of the Appalachian) in Newfoundland, and the Torngat range in Labrador. It also features numerous lakes and rivers which make for an excellent and well-developed hydroelectric potential. Bays and fjords along the coastline, coupled with strong coastal winds, suggest more untapped energy potential;
- In 2007, the province inventoried more than 6 GW of undeveloped hydropower, and 5 GW of undeveloped wind power, while projecting significant renewable energy generation growth potential as illustrated.

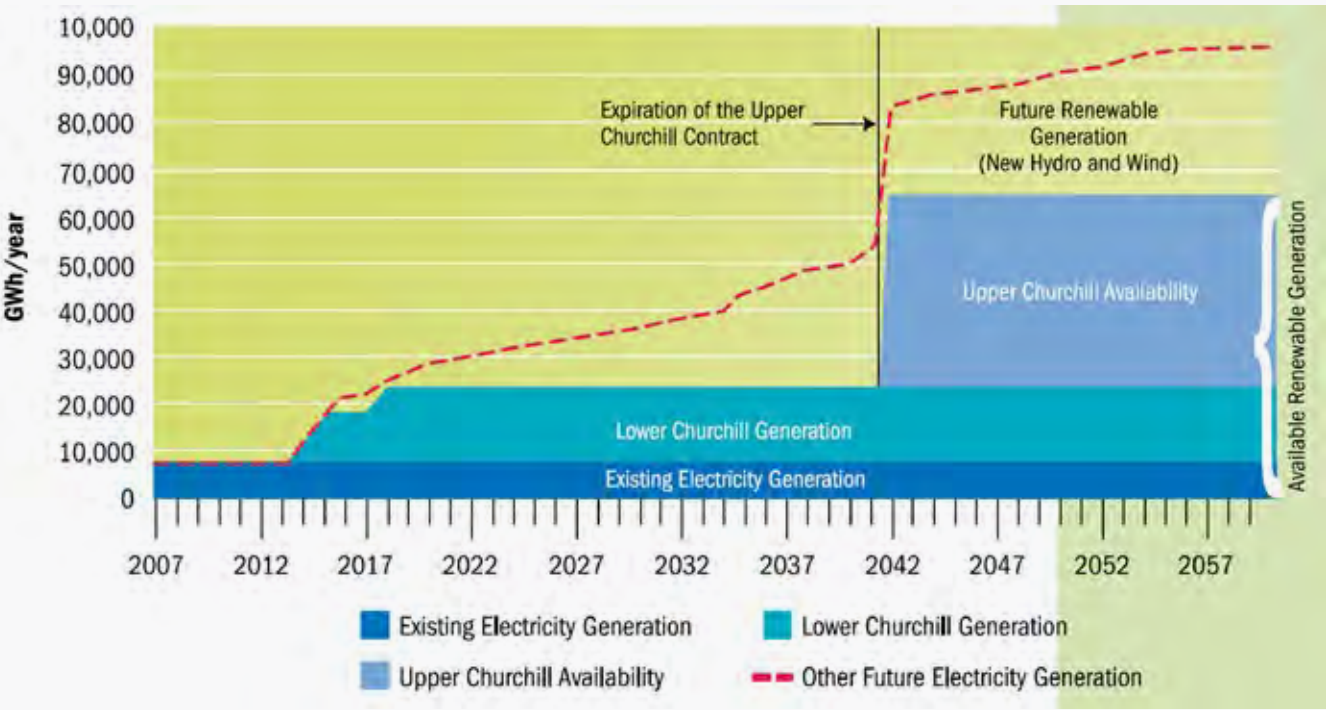


Figure 7. Newfoundland and Labrador Renewable Energy Development Projections (Newfoundland and Labrador 2007)

The Big Reset (May 2021)

“The Big Reset” report prepared by the Premier’s Economic Recovery Team, in 2021 included the following comments on renewable energy:

Significant other climate-friendly opportunities include green mineral development, green manufacturing such as green steel (steel produced without fossil fuels), and a transformation of the transportation sector.

The world is moving to renewable energy in many forms including hydroelectricity, wind, solar, and hydrogen, and this province can be part of the solution. Hydrogen can be produced by hydro or other renewable electricity or natural gas using carbon capture. The province has an ample supply of both, and this opportunity must be explored now.

Provincial Energy Plan (December 2021)

On the heels of the Big Reset, a new Provincial Renewable Energy Plan was released in December 2021 with the following actions:

- Inventory undeveloped renewable energy resources, including hydro, wind, biomass, and solar.
- Inventory of the province’s features that enables renewable energy development (deep marine ports, surplus energy, available crown land, relevant legislation/policies, contacts, current schedule of rates, etc.).
- Support opportunities to improve the efficiency of the province’s electricity system.
- Support transitioning fossil fuel powered operations to renewable energy, including fossil fuel-generated electricity.
- Assist navigating the provincial processes regarding development of renewable energy projects.
- Support the research and development of renewable energy and clean technology
- Attract new industry to the province to use renewable electricity from the interconnected grid.
- Support the transition to electrification and renewable energy supply for vehicles, large industry, oil fueled buildings, ports, ships, public transit, transport trucks, and new offshore oil and gas platforms.
- Pursue export opportunities including renewable energy supply to other provinces.
- Explore opportunities to generate and export new green products such as green hydrogen, green ammonia, or biofuel.
- Work with Newfoundland and Labrador Hydro, to examine financial models for any new renewable energy project, to ensure maximum value for, and protection of, electricity ratepayers and taxpayers.
- Examine financing options to support potential new renewable energy projects.
- Explore opportunities to leverage federal investment to enhance the province’s transmission system, build a more flexible and modern electrical grid, to maximize the efficient use of, and value from, the province’s developed renewable energy resources.

2.8 Offshore Demand Opportunities

- Orphan Basin development scenarios are projected as areas of interest for exploration and potential future development. Due to the deep water located in the Orphan Basin, FPSO is the leading concept to develop this region. For this study, two potential FPSO locations in the North of the basin, named Ephesus 1 and 2, and one potential FPSO location in the South, named Capelin were considered.
- Due to its proximity to a renewable power source and the potential of interest in the region, Labrador South is also included in this study. To cover the region outlined by the Canada-Newfoundland and Labrador Offshore Petroleum Board (CNLOPB) as blocks of interest, two potential FPSO sites were analysed.

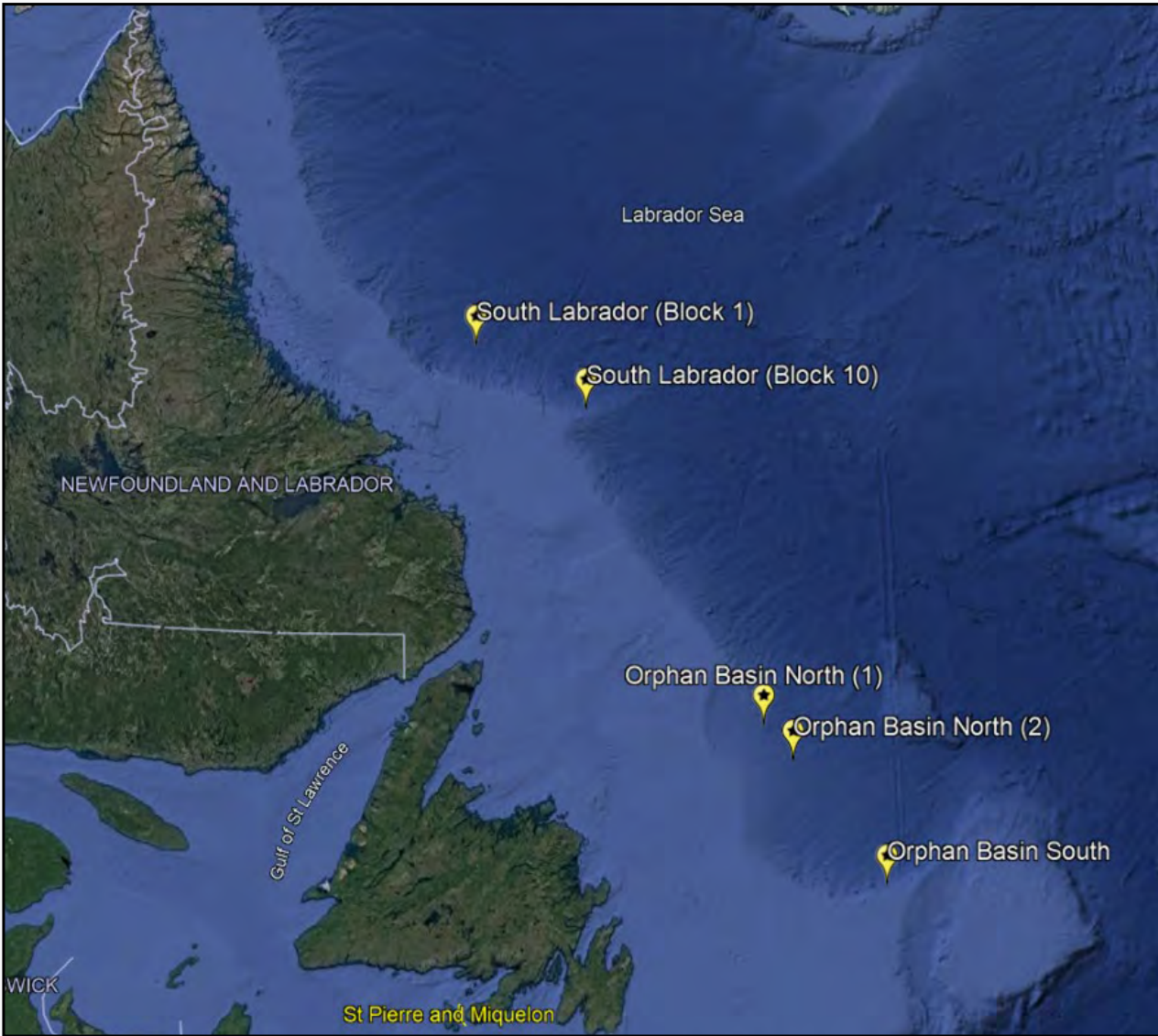


Figure 8. Offshore Facility Sites

Power and Energy Requirements

Characteristic	Displacement Scenario	Replacement
On Board Generator Capacity	70 MW Peak	5 MW (Emergency power only)
Fossil Fuel Offset	50 to 70%	100%
Target Renewable Supply	Intermittent Sources w/o Storage (Wind, Wave, Solar)	Hydropower with Storage Intermittent Sources Coupled with Storage
Forced Production Outage Risk	No Change	1 to 5 Days per Year

Table 2. Offshore Renewable Energy Electrification Scenarios

Two emission reduction scenarios were considered for the FPSOs. A replacement scenario that provides the FPSO with 100% of the energy from renewable energy sources.

The second is a displacement scenario which provides the FPSO with approximately 50% to 70% of the energy demand from renewable energy sources. The displacement scenario would require the full complement (70 MW) of onboard generators when the renewable energy supply is low.



Figure 9. Terra Nova FPSO

These power and energy requirements estimated from typical offshore operations were used for reference and assessments.

Peak Power 70 MW	Average Power 50 MW	Average Annual Energy 438,000 MWh
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Energy Costs

Item	Rate	Quantity	Annual Cost
Demand Charge	\$10.73/kW per month of billing demand (\$128.76/kW per year)	70,000 kW	\$9,013,000
Firm Energy Charge	\$0.04041/kWh	440,000,000 kWh	\$17,780,000
Wheeling Charge	\$0.00831/kWh	440,000,000 kWh	\$3,656,000
Total / Effective	\$0.06920/kWh	440,000,000 kWh	\$30,449,000

Table 3. Average Energy Cost Estimate based on NLH Schedule of Rates for an Industrial Customer

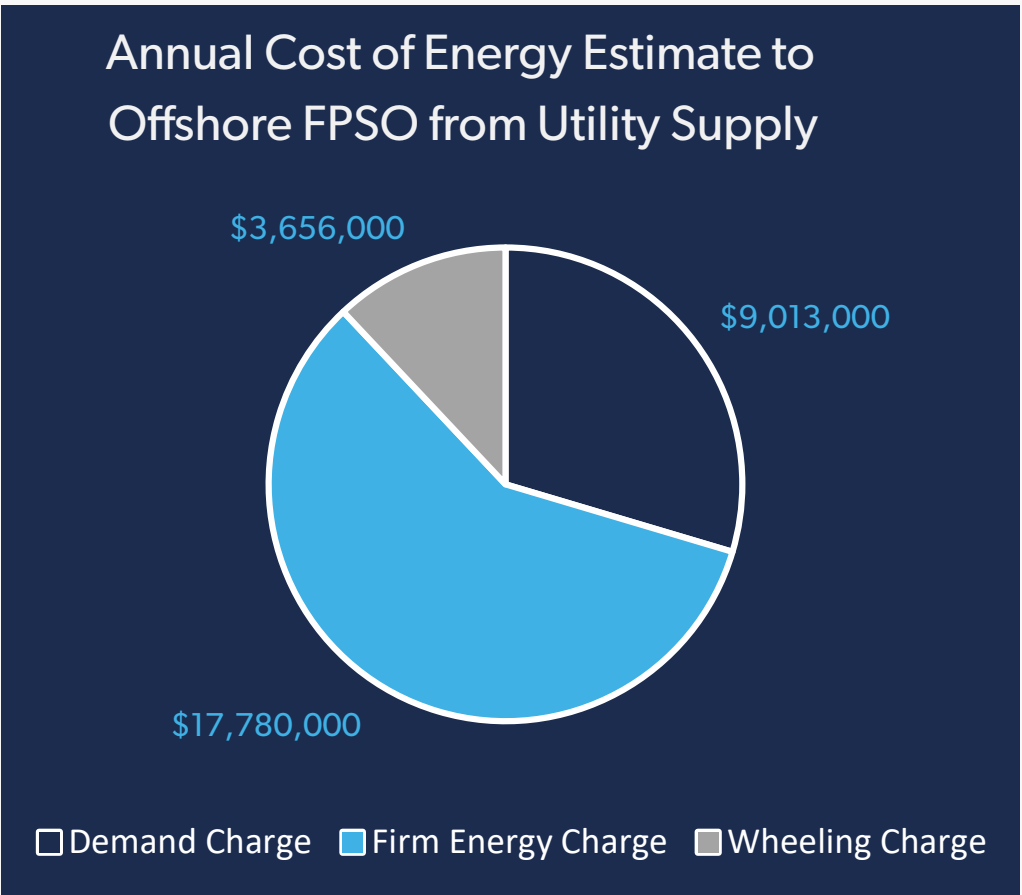


Figure 10. Annual Cost of Energy Estimate to Offshore FPSO from Utility Supply

3. Technology Screening

This section explores the viability of various energy generation, storage, and transmission technologies that are being considered.



3.1 Technology

Identify technologies to support the utilization of renewable energy at the offshore FPSOs. Assess Energy Generation, Energy Storage Systems, or Energy Transmission for viability and benefits in deploying for FPSO utilization.

Generation		Storage	Transmission
Utility Supply	Ocean Current (Hydrokinetic)	Pumped Hydro	Subsea Cable
Wind (Onshore & Offshore)	Ocean Wave	Batteries	Hydrogen
Solar	Biomass	Hydrogen	
Hydro	Geothermal	Compressed Air	
Ocean Tidal		Buoyant Energy	

Technologies were assessed and then compared using a traffic-light screening process against a comprehensive list of criteria which included technical, environmental, regulatory, and socio-economic factors.

Screening Criteria		
Resource Power Capacity	Levelized Cost of Energy	Health and Safety
Average Annual Energy	Net Present Value	Biophysical Environment
Firm Power Capacity	Power and Energy Management	Local Infrastructure
Firm Energy	Technology Readiness Level	Local Benefits
Energy Storage Power Capacity	Technical Risks	Stakeholder Public Support
Storage Energy Density	Schedule	Resource Use
Storage Round-Trip Efficiency	Constructability	Protected Areas
Capital Development Cost	Strategic	Regulatory
Operating Cost	Flexibility	

Criteria	Applicability			Description
	G ¹	S ²	T ³	
Resource Power Capacity	•	•	•	Total available resource capacity within the region, discharge rating of pure storage systems, or power carrying capability of transmission systems (MW).
Average Annual Energy	•			The average annual resource energy output at potential installed capacity (TWh).
Firm Power Capacity	•			The portion of potential installed capacity which can deliver firm power (MW).
Firm Energy	•			The portion of available energy which is on-demand firm energy (TWh).
Storage Power Capacity		•		Amount of power the storage device is capable of supplying (MW).
Storage Energy Density		•		Physical properties of energy storage devices. Generally, physical limitations in the deployment of storage solutions with low energy densities, and capital limitations in the deployment of storage solutions with high energy densities.
Storage Round-Trip Efficiency		•		Accounting for the losses associated with the charging and discharging of the energy storage system.
Capital Development Cost	•	•	•	Initial development / capital expenditures. Energy and power components are separated for storage technologies.
Operating Cost	•	•	•	Operating and maintenance costs including sustaining CAPEX to reach the 20-year target life. Energy and power components are separated for storage technologies.
Levelized Cost of Energy	•			Experience and literature-based estimates of Levelized Cost of Energy of project costs on a per kWh or MWh basis considering development costs, CAPEX, and OPEX (\$ / MWh).
Net Present Value		•	•	The net present value over a 20-year period at 5% discount rate included development costs, OPEX, revenue, and residual value (\$million (MM)). NPV of energy storage systems determined by applying the OPEX and CAPEX rates for 70 MW peak power demand and 2,400 MWh energy supply scenario. For storage technologies, the round-trip efficiency is applied to the calculation for comparison purposes.
Power and Energy Management	•	•		General applications for energy storage and the associated ramp up and duration: Bulk Energy Services: Energy arbitrage and time-shifting of energy (days-months). Bridging Power and System Services: including regulation reserves, load following, emergency backup, ramping, and black starts (minutes-hours). Power Quality and Regulation: including frequency regulation, voltage support, and transient stability (seconds-minutes).

Criteria	Applicability			Description
	G ¹	S ²	T ³	
Technology Readiness Level	•	•	•	Stage of technology development based on Natural Resources Canada Levels.
Technical Risks	•	•	•	Technical risks aside from Technology readiness level (TRL). Includes ice, resource definition, outages, failures, and associated fallout.
Schedule	•	•	•	Relative timeline to operation. Equipment supply, scope of the projects, regulatory approvals. Approximate development years to operation.
Constructability	•	•	•	Complexity, availability of specialized equipment, reliance on weather windows, level of interfacing required, experience.
Strategic	•	•	•	Degree to which the technology or system contributes to emissions reductions and Canada’s target of net-zero emissions by 2050 or public / stakeholder perception of the same. Emissions reduction or offset potential.
Flexibility	•	•	•	Ability to accommodate expansion, modularization, incorporate component changes and upgrades.
Health and Safety	•	•	•	Perceived or actual risk to project personnel and the public. Where Risk Assessment Ranking = Probability of Failure X Consequence of Failure.
Biophysical Environment	•	•	•	Interactions with the biophysical environment including fish, wildlife, and avian species. Adverse effects on Species at Risk (SAR), contaminants and pollutants, mortalities and injury, habitat disturbance and destruction. Significance of residual effects on SAR and valued components.
Local Infrastructure	•	•	•	Degree to which new local infrastructure is required to support the development including electrical grid upgrades, substations, roads, fabrication facilities.
Local Benefits	•	•	•	Contribution to local economy or other indirect benefits through project lifecycle.
Stakeholder Support	•	•	•	Perceived or actual support (or opposition), Indigenous group engagement, social license, number of intervenors.
Resource Use	•	•	•	Impacts to terrestrial or marine resource use, harvesting patterns, marine navigation.
Protected Areas	•	•	•	Parks or wildlife, ecological, conservation reserves affected by the technology or the development of the infrastructure associated with the technology.
Regulatory	•	•	•	Perceived or actual level of effort, risks, issues with lack of framework or possible changes, ‘novelty’ factor, number of required permits and approvals.

← Continued from previous page G¹ - Generation S² - Storage T³ - Transmission

Technology Screening - Methodology

- **GREEN** - Value is likely to be within the target or acceptable range. No issues or concerns identified or expected.
- **YELLOW** - Value is possibly not within the target or acceptable range. Some issues or concerns identified or likely and are expected to be manageable with reasonable effort.
- **RED** - Value is not likely to be within the target or acceptable range. Showstopper or issues of significant concern identified which are possibly insurmountable.

Criteria	Red	Yellow	Green
Resource Power Capacity	<200 MW	200 – 600 MW	>600 MW
Average Annual Energy	<1 TWh	1 – 5 TWh	>5 TWh
Firm Capacity	0 MW	0 - 50 MW	>50 MW
Firm Energy	0 TWh	0 – 1 TWh	>1 TWh
Storage Power Capacity	< 1 MW	10-100 MW	>100 MW
Storage Energy Density	<10 kWh/kg	10-20 kWh/kg	>20 kWh/kg
Storage Round-Trip Efficiency	0-35%	35-70%	>70%
Levelized Cost of Energy	>\$250 + / MWh	\$100 - \$250 / MWh	<\$100 / MWh
Net Present Value	>\$3,000 MM	\$1,000 - \$3,000 MM	<\$1000 MM
Power and Energy Management	Short (Seconds-Minutes)	Medium (Minutes-Hours)	Long (Days-Months)
Technology Readiness Level	0 – 5	6 – 7	8 +
Technical Risks	High	Medium	Low
Schedule	>7 years	4 -6 years	0 – 3 years
Constructability	Significant Challenges	Minor Challenges	Normal
Strategic	Less than 50% Offset	Less than 100% Offset	100% Offset
Flexibility	Low	Moderate	High
Health and Safety	High	Moderate	Low
Biophysical Environment	>2 SAR Significant and Adverse Impacts	1 SAR Adverse Impacts	Limited SAR Low or No Impacts
Local Infrastructure	High	Medium	Low
Local Benefits	None	Moderate	High
Stakeholder Support	General Opposition / Limited Support	Neutral	Limited Opposition / General Support
Resource Use	Several	Limited	None
Protected Areas	3 +	1 – 2	None
Regulatory	High	Significant	Low / Normal

3.2 Energy Generation Technologies

Generation Technology - Hydroelectric



Figure 11. Muskrat Falls Power Station and Associated Infrastructure

- Hydroelectric power is a prevalent and well-proven technology in the province.
- With the commissioning of the Muskrat Falls project, over 90% of the provincial demand will be supplied by hydropower.
- The majority of the existing and undeveloped potential is in Labrador, however, some opportunities remain on the island.

Site	Capacity (MW)	Average Energy (GWh)	Firm Energy (GWh)	Location
Island Pond	36	186	175	Island Interior
Portland Creek	23	142	125	Island West Coast
Round Pond	18	139	129	Island Interior
Red Indian Falls	42	268	228	Island Central
Badger Chute	24	154	131	Island Central
Star Lake Unit 2	30	100	50	Island Interior
Cat Arm Unit 3	68	0	0	Island West Coast
Bay D’Espoir Unit 8	154	0	0	Island South Coast
Gull Island	2200	11,900	10,900	Labrador
Dominion – Minipi	425	3,600	3,600	Labrador
Lobstick Control Structure	171	1,000	900	Labrador
Fig	146	1,200	1,100	Labrador
Other Labrador	200+			Labrador

Table 4. Known Hydro Development Sites in Newfoundland and Labrador

Generation Technology – Onshore Wind

- Newfoundland and Labrador has incredible onshore wind energy resources.
- The province has the highest wind energy potential of all the provinces and territories, with the majority of the province experiencing a mean wind speed of over 8 m/s at an 80 m elevation.
- The landscape on the island of Newfoundland is well suited for wind turbines with expansive rock plateaus and barren treeless expanses.

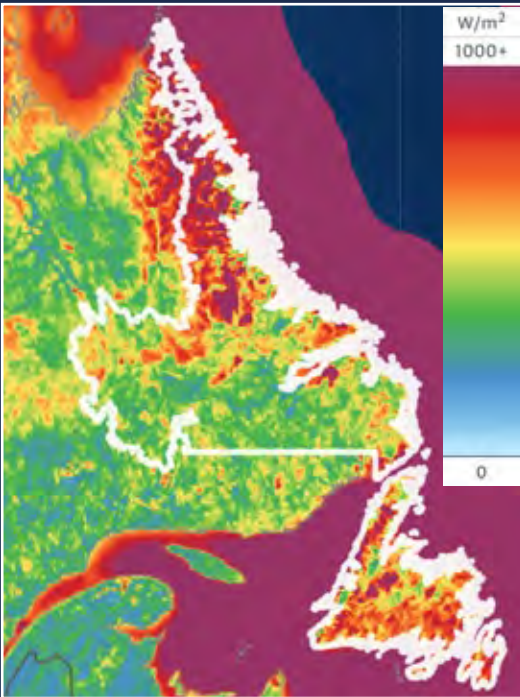


Figure 12. Annual Average Mean Wind Density at 100m – Newfoundland and Labrador (Global Wind Atlas, 2021)

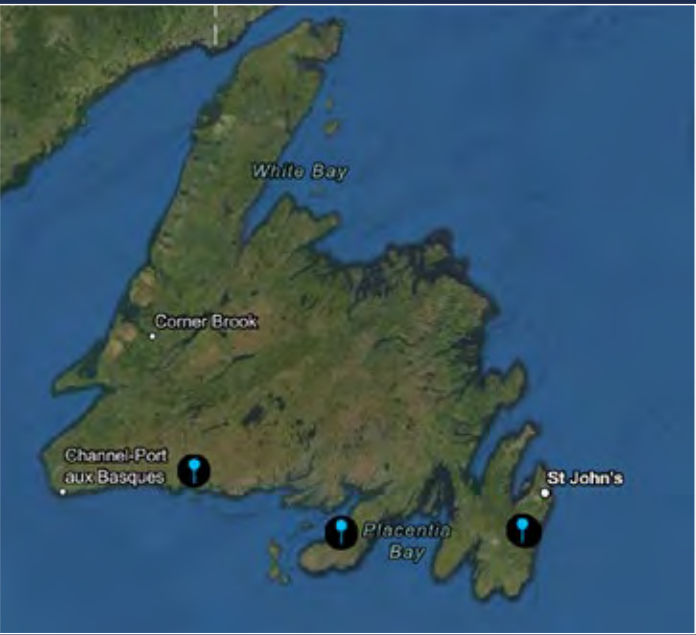


Figure 13. Location of Wind Farm Developments on Newfoundland. Data from (Government of Canada, 2020).

Global Wind Atlas (2021).
Government of Canada (2020). [Canadian Wind Turbine Database](#).

- Three operational onshore wind farms in Newfoundland.
 - Fermeuse (27 MW)
 - St. Lawrence (27 MW)
 - Ramea (0.69 MW)

Screening Criteria	Onshore Wind
Potential Capacity	60,000 MW
Average Annual Energy	263 TWh
Firm Capacity	0 MW
Firm Energy	131 TWh
Capital Development Cost	\$1,500 / kW
Estimated LCOE	\$45 / MWh
Technology Readiness Level	9

Table 5. Resource Assessment Results

Period	Mean Wind Speed (m/s)	Weibull Shape (k)	Weibull scale (A) [m/s]
Annual	9.9	2.36	11.17
Winter	11.07	2.41	12.48
Spring	9.6	2.29	10.84
Summer	9.06	2.56	10.21
Fall	10.12	2.48	11.41

Table 6. Resource Assessment Results

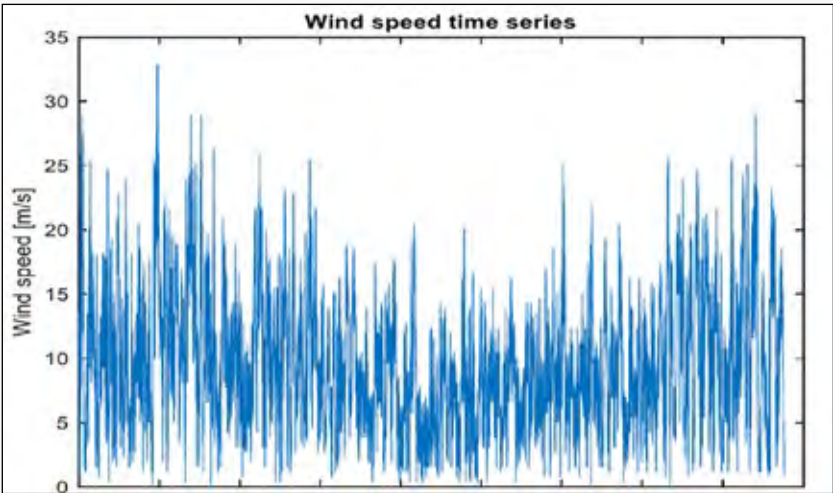


Figure 14. Typical Hourly Wind Speed Series St. Johns International Airport



Figure 15. Typical Wind Turbine Array

Onshore Wind
Firm Capacity = 0 MW
Firm Energy = 131 TWh

Canadian Wind Atlas for Blow Me Down Mountains
Numerical Values at 80 m
Latitude 50.047
Longitude -57.513
Zone 21

Generation Technology – Offshore Wind

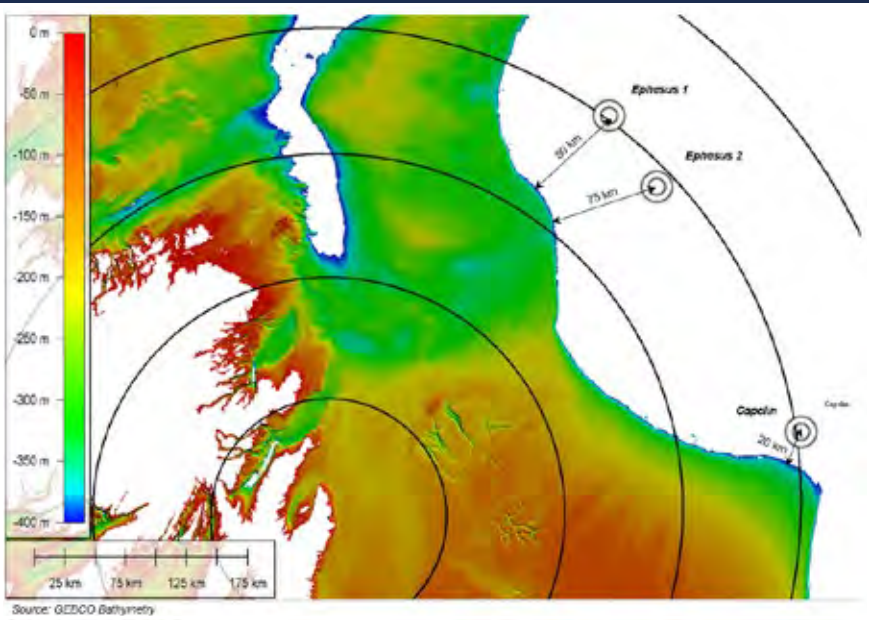


Figure 16. Bathymetry at FPSO Sites - Distance to 400 m Depth

- Newfoundland and Labrador has incredible offshore wind energy resources.
- The landscape offshore is challenging for wind turbines with ocean depths that are 300 m or greater within a 75 km radius of all offshore development sites.
- In addition to the ocean depths, icebergs are frequent in the waters of Atlantic Canada.

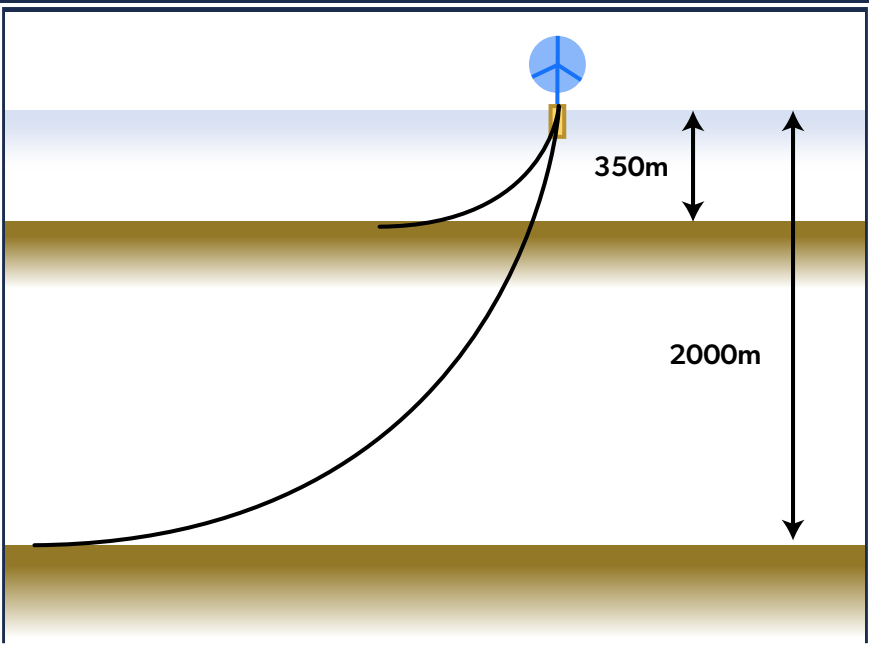


Figure 17. Comparative Floating Wind Turbine Anchoring Cable at 350 m and 2,000 m

- At the FPSO development sites themselves, ocean depths range from 1,800 to 2,000 m. Significant technical and capital cost challenges are associated with anchoring at such significant depths.
- There are no operational offshore wind developments off the coast of Newfoundland and Labrador.

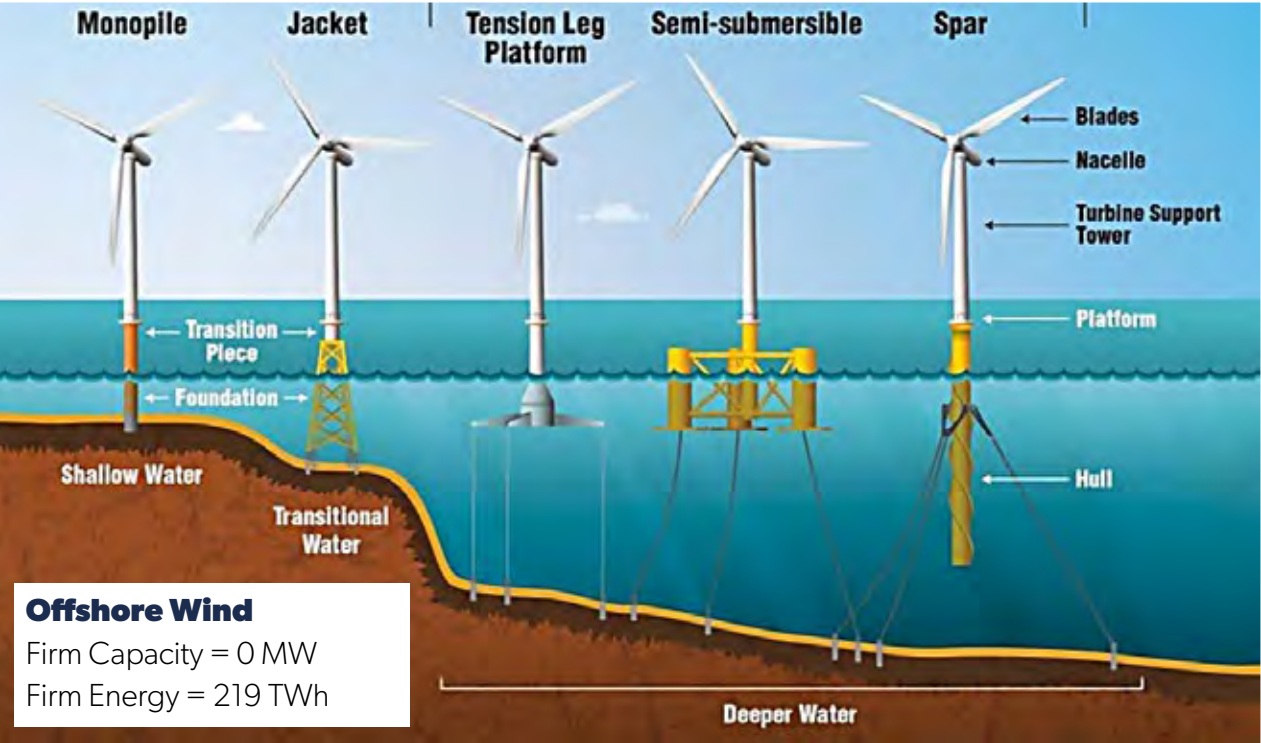


Figure 18. Types of Offshore Wind Turbines (Speht, 2021)

- Offshore wind development risk mitigation to site the offshore wind array apart from the FPSO sites and on the oceanic shelf, where water depths are around 300 m.
- Deployment of floating wind turbine design system similar to North Sea developments in water <300 m depth.

Canadian Wind Atlas for Ephesus I

Numerical Values at 80 m				
Latitude = 50.497, Longitude = -49.528 Zone 22				
Period	Mean Wind Speed (m/s)	Mean Wind Energy (W/m²)	Weibull Shape Parameter (k)	Weibull Scale Parameter (A)
Annual	11.11	1,279.38	2.05	12.54
Winter (DJF)	13.66	2,079.25	2.39	15.41
Spring (MAM)	11.52	1,328.62	2.21	13.00
Summer (JJA)	9.77	805.5	2.23	11.03
Fall (SON)	11.69	1,385.25	2.22	13.20

Table 7. Resource Assessment Results

Screening Criteria	Nearshore Wind (Fixed Bottom)	Nearshore Wind (Floating)	Offshore Wind (Floating)
Potential Capacity	100,000 MW	100,000 MW	100,000 MW
Average Annual Energy	440 TWh	440 TWh	440 TWh
Firm Capacity	0 MW	0 MW	0 MW
Firm Energy*	219 TWh	219 TWh	219 TWh
Capital Development Cost	\$4,077 / kW	\$5,328 / kW	\$6,466 / kW
Estimated LCOE	\$90 / MWh	\$100 – 140 / MWh	\$200-300 / MWh
Technology Readiness Level	9	8	8

Table 8. Resource Assessment Results

* Under the assumption there is significant widespread built capacity to permit Firm Energy production
 Equinor (2022). Hywind Scotland.
 Speht (2021). Ready-to-float: A permanent cost reduction for offshore wind. Retrieved from Wind Power Engineering & Development

Generation Technology - Solar

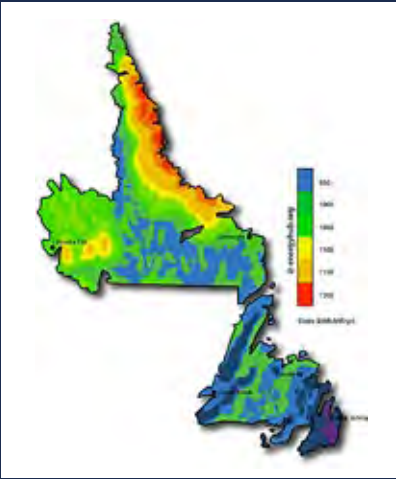


Figure 19. Newfoundland and Labrador Solar Energy Potential

- Newfoundland and Labrador has low onshore solar energy resource potential.
- Newfoundland and Labrador has the lowest average solar energy potential of all the provinces and territories.
- Along the Labrador coastline, the average solar energy potential is in line with national average of ~1,133 kWh/kW/yr
- Offshore solar, while having higher average solar potential is challenged by ocean conditions. There are several demonstration floating solar energy projects in various stages globally, typically located on a reservoir or a lake.

Screening Criteria	Onshore Solar	Nearshore Solar	Offshore Solar
Potential Capacity	94,970 MW	1,332 MW	1,000 MW
Average Energy	83.2 TWh	1.17 TWh	0.87 TWh
Firm Capacity	0 MW	0 MW	0 MW
Firm Energy*	41.6 TWh	0 TWh	0 TWh
Capital Development Cost	\$1,930 / kW	\$4,000 / kW	N/A
Estimated LCOE	\$96 / MWh	\$354 / MWh	N/A
Technology Readiness Level	9	7	5

Table 9. Resource Assessment Results

* Under the assumption there is significant widespread built capacity to permit Firm Energy production

Generation Technology - Ocean Wave

- Conversion of the kinetic and potential energy associated with a moving ocean wave into useful mechanical or electrical energy.
- Potential wave power is measured per unit length of wave crest (as kW / m), and is a function of the average wave height and wave period.
- Newfoundland and Labrador have strong ocean wave energy resources.
- The landscape offshore is challenging for ocean wave energy converters with deep water and frequent icebergs in the waters of Atlantic Canada.

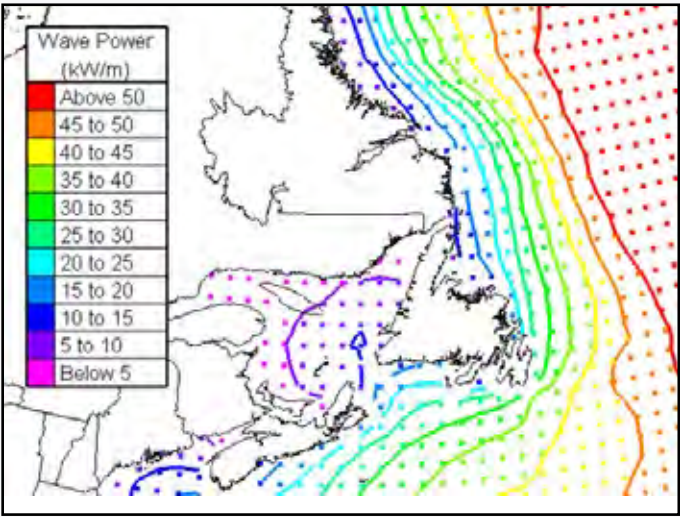


Figure 20. Wave Power Potential off the Newfoundland and Labrador Coast (Cornett, 2006)

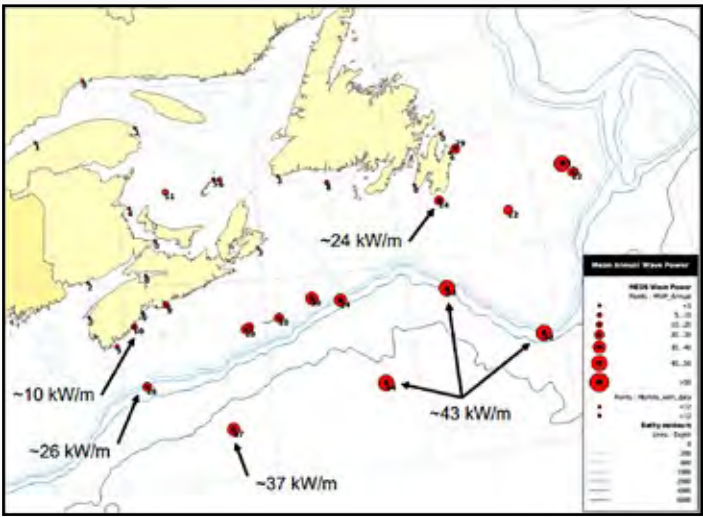


Figure 21. Annual Mean Wave Power for NW Atlantic Sites (Cornett, 2006)

Screening Criteria	Wave
Potential Capacity	340 MW
Average Annual Energy	0.88 TWh
Firm Capacity	0 MW
Firm Energy	0.70 TWh
Capital Development Cost	Limited Commercial Data Available
Estimated LCOE	\$300 – 500 / MWh
Technology Readiness Level	7

Table 10. Resource Assessment Results

Ocean Wave
Firm Capacity = 0 MW
Firm Energy = 0.7 TWh

Generation Technology - Ocean Tidal & Current

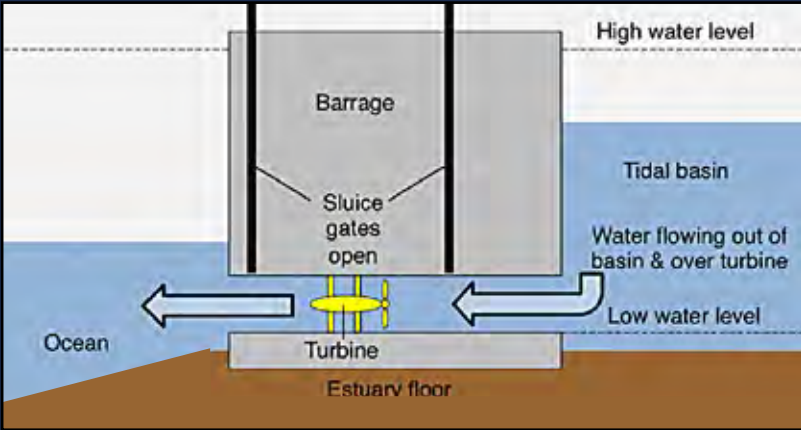


Figure 22. Operation of a Tidal Barrage System

- Potential energy associated with tides can be harnessed by building barrages or other forms of construction across an estuary.
- The Annapolis Royale in Nova Scotia had a capacity of 20MW before being decommissioned in 2019.

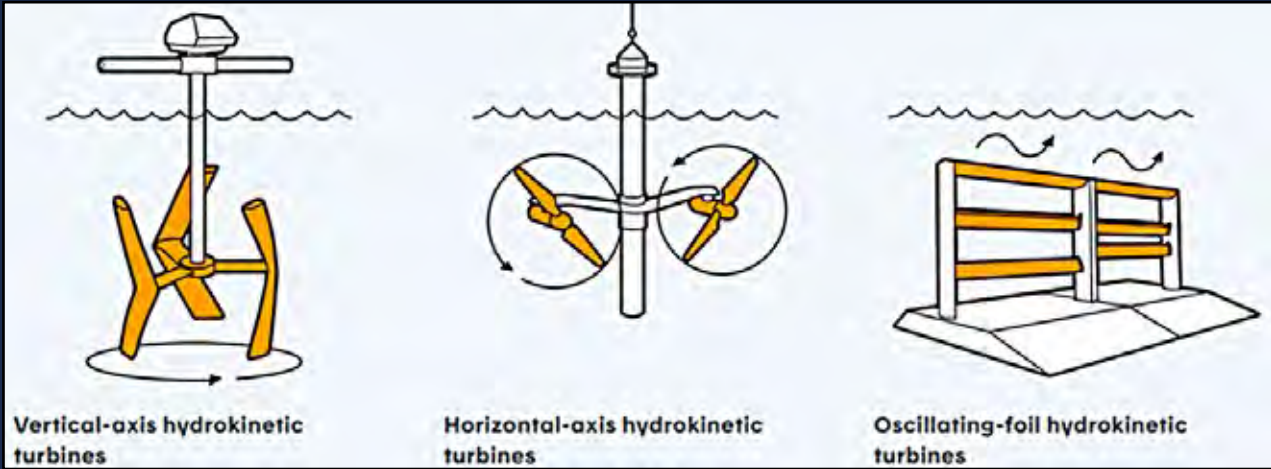


Figure 23. Types of Hydrokinetic Turbines

- Ocean current (hydrokinetic) energy associated with tidal currents can be harnessed using modular hydrokinetic systems.
- Several hydrokinetic demonstration tidal energy projects are in various stages of development globally.

Screening Criteria	Tidal	Hydrokinetic
Potential Capacity	360 MW	544 MW
Average Annual Energy	0.88 TWh	3.34 TWh
Firm Capacity	0 MW	0 MW
Firm Energy	0.70 TWh	2.67 TWh
Capital Development Cost	(High) Site Specific	\$4,400 / kW
Estimated LCOE	\$300 - 500 / MWh	\$150 - 250 / MWh
Technology Readiness Level	8	7

Table 11. Resource Assessment Results

Generation Technology - Geothermal

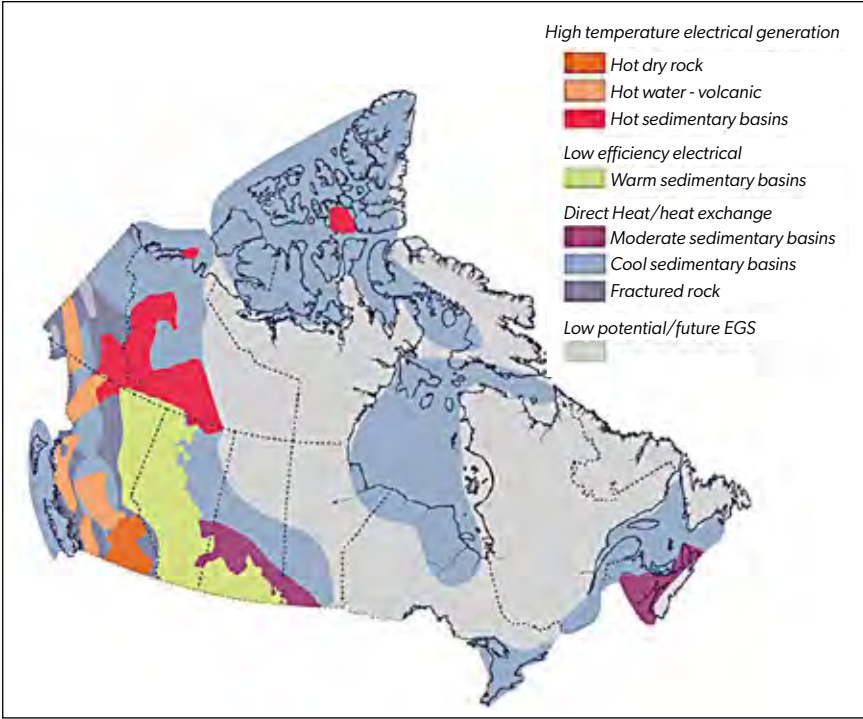


Figure 24. Regional Distribution of Geothermal Energy Potential in Canada (Grasby et al., 2012)

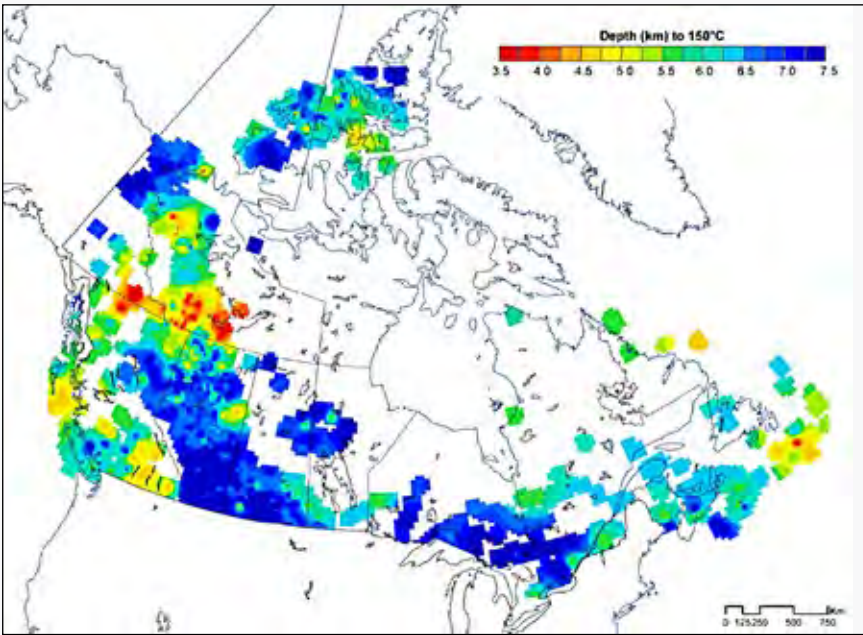


Figure 25. Estimated Depth to 150°C Temperature in Canada (Grasby et al., 2012)

- High and medium temperature resources are used globally for stable base-load electrical generation.
- Medium to low temperature resources are primarily used for direct space heating of residences and commercial buildings, or other similar applications.
- Newfoundland and Labrador has low onshore geothermal resource potential.

- Offshore geothermal potential located at the southern tip of the Grand Banks at a depth of less than 4 km.
- While having higher average geothermal potential offshore, development is challenged by ocean conditions.
- No known offshore geothermal demonstration facilities exist today.

Screening Criteria	Onshore Geothermal	Offshore Geothermal
Potential Capacity	Limited	140 MW
Average Annual Energy	Limited	1.22 TWh
Firm Capacity	0 MW	140 MW
Firm Energy	0 TWh	1.22 TWh
Capital Development Cost	\$12,000 – 26,000 / kW	\$65,000 / kW
Estimated LCOE	N/A	\$400 / MWh
Technology Readiness Level	9	5

Table 12. Resource Assessment Results

3.3 Energy Storage Technologies

Applications for Energy Storage Devices

- Energy storage systems are a flexible and responsive resource that enables both system operators and consumers to effectively manage variability in energy generation and load.
- Energy storage is the preservation of energy for future use.
- Includes short duration power quality management, medium duration bridging power, and long duration energy management.
- Target attributes for the FPSO is a combination of both large-scale storage (power) and long-duration storage (energy), thus within the Energy Management category.

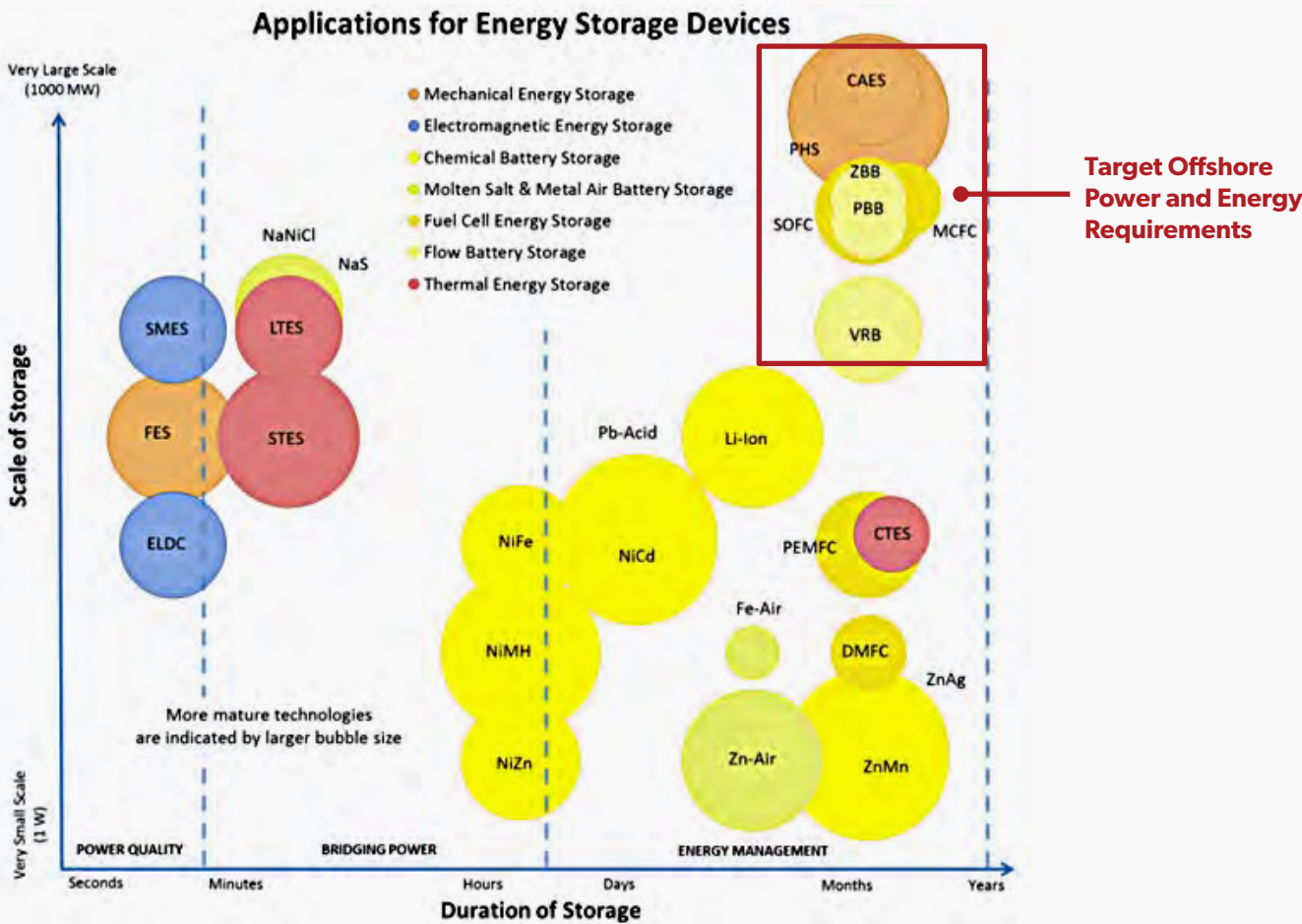


Figure 26. Graphical Representation of Energy Storage Technologies. (Sabihuddin et al, 2015)

Storage Technology - Capacity Estimation

Energy Storage Requirements with Onshore Solar Developments

Helps understand the balance between over-sizing generation vs. storage development costs. Incorporates round trip efficiencies, to determine levelized cost of energy and storage.

- 500 MW, 750 MW, and 1,000 MW developments

* Using average monthly mean daily global insolation (kWh/m²) for the province to determine energy storage requirements.

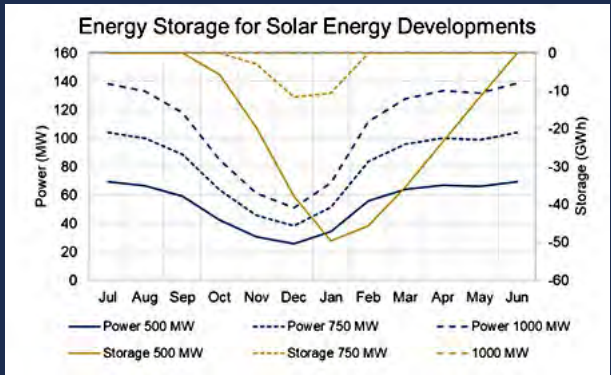


Figure 27. Estimated Energy Storage Requirements for Onshore Solar Energy Developments

Solar Development	500 MW	750 MW	1000 MW
Minimum Monthly Average Power Supply	26 MW	39 MW	51 MW
Maximum Storage Requirements	50 GWh	12 GWh	0 GWh

Table 13. Storage Assessment Results

Energy Storage Requirements with Onshore Wind Developments

- 75 MW, 100 MW, and 125 MW developments

* Using seasonal mean wind speeds at Ephesus 1 to determine energy storage requirements.

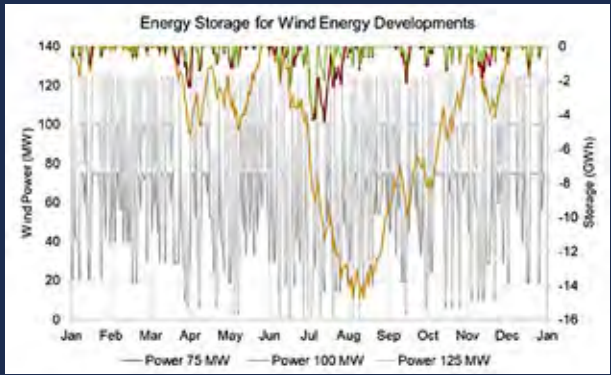


Figure 28. Estimated Energy Storage Requirements for Onshore Wind Energy Developments

Onshore Wind Development	75 MW	100 MW	125 MW
Minimum Monthly Average Power Supply	40 MW	52 MW	62 MW
Maximum Storage Requirements	15 GWh	4 GWh	4 GWh

Table 14. Storage Assessment Results

Storage Technology - Pumped Storage Hydro

Pumped storage hydro (PSH) constitutes 99% of energy storage in the world across over 300 separate installations, with a total nominal capacity of 169 GW globally.

The operating principle of PSH is through the pumping of water from a lower-level reservoir into and storing it in a higher basin reservoir during the off-peak times or energy curtailment periods and flowing the water in the reverse direction through turbines when electricity is required.

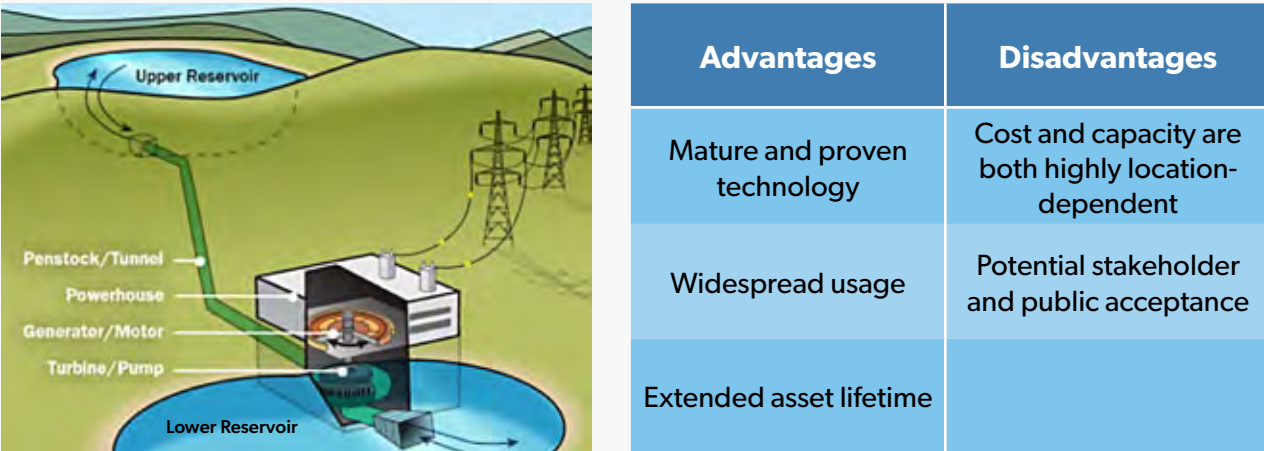


Figure 30. Typical Schematic of a Pumped Storage and Hydro Scheme

- The Long Range mountains located on the West Coast of Newfoundland provide storage opportunities where the elevation differential between the lower and higher reservoirs can range between 300 m and 500 m.

Criteria	Value
Power Management Characteristics	Hours-Months
Power Rating Range	1 MW – 3 GW
Energy Capacity Range	100 MWh – >8 GWh
Energy Volume Density (@300 m head)	0.7 kWh/m ³
Energy Mass Density (@300 m head)	0.0007 kWh/kg
Round-Trip Efficiency	64%
Power CAPEX / Power OPEX	\$4,500/kW / \$45/kW/yr
Energy CAPEX / Energy OPEX	\$10/kWh / \$0.5/kWh/yr
Technology Readiness Level	9

Table 15. Pumped Hydro Energy Storage Assessment Results

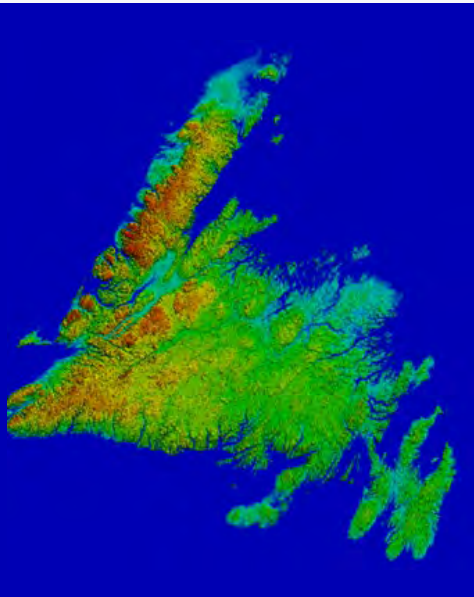


Figure 29. Digital Elevation Model Heat Map of Newfoundland

Storage Technology – Underwater Energy Storage Spheres

- Field prototype testing is currently underway for industrial manufactured spheres which operate under a similar premise as PSH, but located underwater. Similar to traditional PSH, when surplus power is available, water is pumped, in this case out of the spheres to effectively store energy. When power is required, water is allowed to flow back into the spheres with the movement of water spinning the turbine as a means to generate power.
- In 2016, a 3 m diameter test sphere was deployed in 100 m of water. Development of 30 m diameter spheres are envisaged, which at a depth of 1,800 m would have a capacity of about 10 MW and 40 MWh of energy per unit.

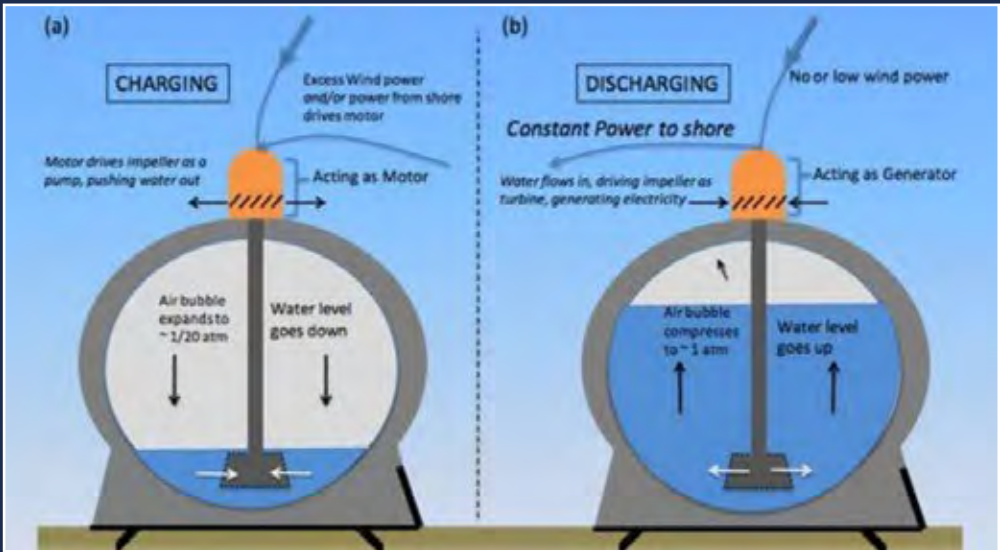


Figure 31. Fraunhofer Energy Storage Sphere Operating Principal (Fraunhofer IEE, 2022)



Figure 32. 3 m Diameter Fraunhofer Test Sphere Deployed in 100 m of Water in 2016 (Left) Deployment Concept of 30 m Spheres (Right) (Fraunhofer IEE, 2022)

Fraunhofer IEE. (2022). Deep sea pumped hydro storage StEnSea-Stored Energy in the Sea.

Storage Technology - Batteries



Figure 33. Typical Schematic of a Battery Storage Scheme

Advantages	Disadvantages
Significant forecasted costs reductions	Technology dependent self-discharge rates
Modularity	Prohibitive large scale capital development costs for long-duration use
Not location specific	Low energy mass density.
	Potential for fire hazards

Criteria	Value
Power Management Characteristics	Minutes - Hours
Power Rating Range ¹	3 kW – >300 MW ^{1,2}
Energy Capacity Range ¹	0.3 kWh – >2,270 MWh ¹
Energy Volume Density	150 kWh/m ³
Energy Mass Density	0.12 kWh/kg
Round-Trip Efficiency	81%
Power CAPEX / Power OPEX	\$250/kW / \$30/kW/yr
Energy CAPEX / Energy OPEX	\$325/kWh / \$0.5/kWh/yr
Technology Readiness Level (onshore / offshore)	9 / 8

* Offshore installation includes an additional \$100M for vessel capacity and \$500k/year of additional OPEX.

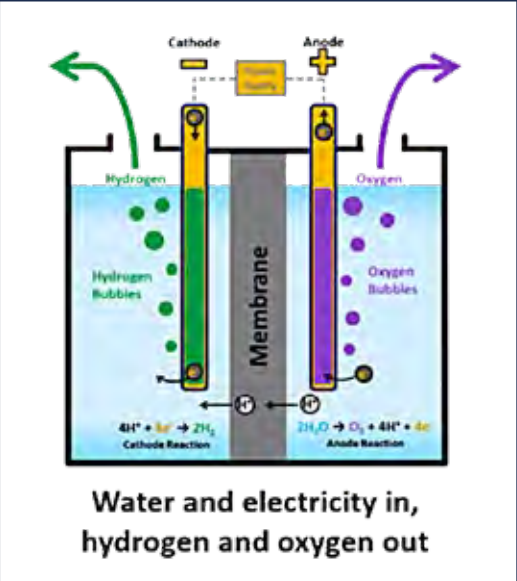
¹ (Luo et al., 2015)

² (International Renewable Energy Agency, 2019)

Table 16. Battery Energy Storage Assessment Results

- Batteries are widely in use for small-scale applications including electric vehicles and consumer electronics. More recently, battery systems have been utilized for more industrial-scale applications including those related to bridging power and bulk energy systems.
- In a conventional battery, the energy is stored in the electrode material with ions (e.g. lithium) transferring from one electrode to another. In a flow battery, the energy is stored in an electrolyte solution held in tanks external to the cell stacks, with electrons transferring from one chemical component to another within the solution as it circulates across membranes inside the stacks.
- Lithium Ion batteries are the most prevalent technology today.

Storage Technology - Hydrogen



(U.S. Department of Energy 2022)

Advantages	Disadvantages
Significant technology growth and opportunity	Low energy conversion efficiencies of the various process steps
Significant forecasted cost reductions	Bulk high-density storage challenges
Modularity	Capital costs of the hydrogen systems could be considered prohibitive.
High energy density as liquid	Low energy density as compressed gas



Criteria	Value
Power Management Characteristics	Hours – Months
Power Rating Range	3 kW – >300 MW
Energy Capacity Range	0.3 kWh – >2,270 MWh
Energy Volume Density (liquefied H ₂)	2,620 kWh/m ³
Energy Mass Density (liquefied H ₂)	39 kWh/kg
Round-Trip Efficiency (including liquefaction and transportation)	25%
Power CAPEX / Power OPEX	\$6,000/kW / \$150 / kW/yr
Energy CAPEX / Energy OPEX	\$30/kWh / \$0.5/kWh/yr
Technology Readiness Level (onshore / offshore)	8 / 7

Table 17. Hydrogen Storage Assessment Results

- With the abundance of renewable energy resources within the province, the production of green hydrogen through electrolysis shows significant potential in the near term in Newfoundland & Labrador.
- Proximity to the high population density Northeastern seaboard and Europe, provides an economic opportunity to supply a low carbon fuel to an export market
- Functionally, electrolyzer and fuel cells operate in reverse process from each other.
- In an electrolyzer system, input electricity is utilized to produce hydrogen gas, while in a fuel cell system, the hydrogen gas is consumed to produce electricity.

Storage Technology - Compressed Air

- Operating principle of compressed air energy storage (CAES) is through the injection of high-pressure air into geological structures (e.g., mines, aquifers, salt caverns, depleted hydrocarbon reservoirs) with suitable cap rocks, or into pressure vessels (e.g. pipes and balloons) during off-peak demand periods where excess renewable energy generation can be utilized.
- When energy is required to fulfill an imbalance between supply and demand, or when energy is more expensive, the system is depressurized such that the air flow drives a turbine for electricity generation.
- Total nominal capacity of CAES is approximately 1.2 GW globally.
- Two system types: conventional compressed air energy storage (C-CAES) and adiabatic ('no thermal losses') compressed air energy storage (A-CAES).
- Accumulator type systems which combine the high-power density of fluids and the high energy density of compressed air in a single energy storage system.



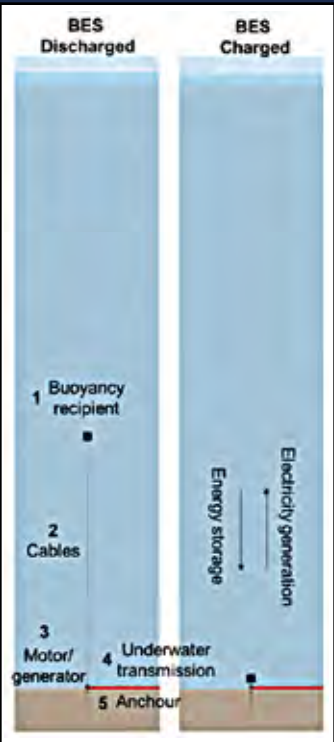
Figure 34. Typical Schematic of Accumulator Type Compressed Air System (Hydrostar, 2022)

Criteria	Value
Power Management Characteristics	Minutes - Hours
Power Rating Range	3 kW – >300 MW
Energy Capacity Range	0.3 kWh – >2,270 MWh
Energy Volume Density	150 kWh/m³
Energy Mass Density	0.12 kWh/kg
Round-Trip Efficiency	81%
Power CAPEX / Power OPEX	\$1,600/kW / \$25/kW/yr
Energy CAPEX / Energy OPEX	\$100/kWh / \$1/kWh/yr
Technology Readiness Level (onshore / offshore)	9 / 8

Table 18. Compressed Air Energy Storage Assessment Results

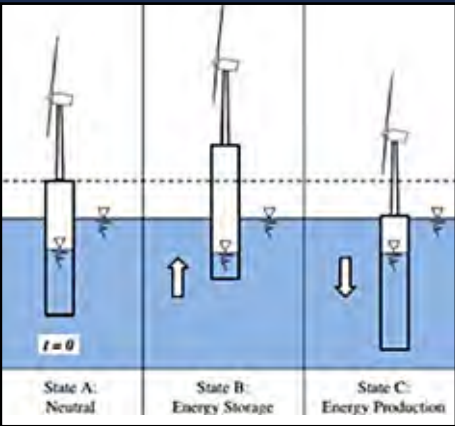
Hydrostor (2022). <https://www.hydrostor.ca/>

Storage Technology - Buoyancy



- Operating principle of buoyancy energy storage (BES) systems is based on the mechanical work associated with pulling a buoyant object below water to store energy and allowing the object to float upwards during the energy generating cycle.
- Several conceptual buoyancy energy storage systems have been proposed, though there are limited operational case studies for reference.
- Compressed gases typically include air or lower density gases such as helium or hydrogen.
- During periods of excess generation, energy is stored in the system as the buoyancy device is lowered in the water column by the motor and cable system.
- Whereas in periods of energy demand, the buoyant device is slowly raised through the water column, thus spinning the generator and producing electricity.
- Alternative buoyant hydraulic energy storage (BHES) system where the potential energy of the mass of the floating structure is the energy storage device.

Advantages	Disadvantages
Potential usage within offshore applications	Low energy conversion efficiencies of the various process steps
The simplistic concept	Operating limitations of the ascending and descending speeds due to underwater drag
	Intense marine environment associated with the FPSOs may be technically challenging



Criteria	Value
Power Management Characteristics	Hours - Months
Power Rating Range	10 MW - 100 MW
Round-Trip Efficiency	80%
Power CAPEX / Power OPEX	\$6,000/kW / Undetermined
Energy CAPEX / Energy OPEX	\$105/kWh / Undetermined
Technology Readiness Level	7

Table 19. Buoyant Energy Storage Assessment Results

Hunt et al., 2021

Criteria	Energy Storage		
	Pumped Storage	Battery (Li-Ion)	
	ONS	ONS	OFS
Technical			
Capacity (MW)	Bulk energy management (hours - days)	Short duration energy balancing (minutes - hours)	Short duration energy balancing (minutes - hours)
Round-Trip Efficiency (Wire to Wire)	64%	81%	81%
Power (kW) FPSO (Peak)	70,000	70,000	70,000
Capital Cost (\$/kW)	\$4,500	\$250	\$275
OPEX (\$/kW)	\$45	\$30	\$33
Energy (kWh), 2 days equivalent at 50 MW per FPSO	2,400,000	2,400,000	2,400,000
Capital Cost (\$/kW)	\$15	\$325	\$358
OPEX (\$/kWh)	\$0.25	\$0.50	\$0.55
Total NPV (\$million)	\$435	\$960	\$1,050
Total NPV (\$million) Efficiency Compensated	\$680	\$1 ,185	\$1,296
Relevant Case Studies	Sir Ad am Beck, ON Canyon Creek, AB (I/P)	Many systems commercially developed.	Pre-commercial Only
Technology Readiness Level	9	9	9
Non-Technical			
Marine Ecosystem Conservation			
Marine Navigation			
Fish and Fish Habitat			
Terrestrial Wildlife			
Migratory Birds and Bats			
Wilderness and Ecological Reserves			
Parks			
Electrical Power Control Regulations			
Public Utilities Act			
First Nations			
Social License	Muskrat Falls		

Energy Storage		
Hydrogen (Polymer Electrolyte Membrane (PEM), Cryogenic Tank Storage)	Compressed Air Energy Storage	Buoyancy Energy Storage
ONS	ONS	OFS
Bulk energy management (hours - days)	Bulk energy management (hours - days)	Bulk energy management (hours - days)
25%	45%	80%
70,000	70,000	70,000
\$6,000	\$1,600	\$6,000
\$150	\$25	\$150
2,400,000	2,400,000	2,400,000
\$30	\$100	\$105
\$0.50	\$1	\$1
\$810	\$630	\$920
\$3,240	\$1,400	\$1 ,150
Evolugen, Québec (20 MW green hydrogen) Thyssenkrupp, Québec (88 MW)	Huntorf, Germany (290 MW for 4 hours) McIntosh, Alabama (110 MW for 26 hours)	Pre-commercial only
8	7/8	7
Explosion Risk / New		
Explosion Risk / New		

3.4 Energy Transmission Technologies

Energy Transmission Technology – Hydrogen

- The transportation of H₂ is most efficient when the fuel is in a liquid state, accomplished by cooling it below its boiling point of -253° C, and through this its volume is reduced over 800 times as compared to its gaseous form.
- The liquid hydrogen (LH₂) is stored at cryogenic temperatures in highly insulated tanks for transportation, before returning to a gaseous state where it can be utilized within a fuel cell system to generate electricity.
- Onshore transmission of liquid hydrogen is currently accomplished with commercial transport trucks and small volume storage tanks, while bulk overseas carrier storage and bulk storage are in the early stages of commercialization.
- Potential alternative - conversion of hydrogen gas into ammonia as an energy carrier.



Figure 35. Liquid Hydrogen Bulk Carrier Schematic ‘Suiso Frontier’ (ERIA, 2020)

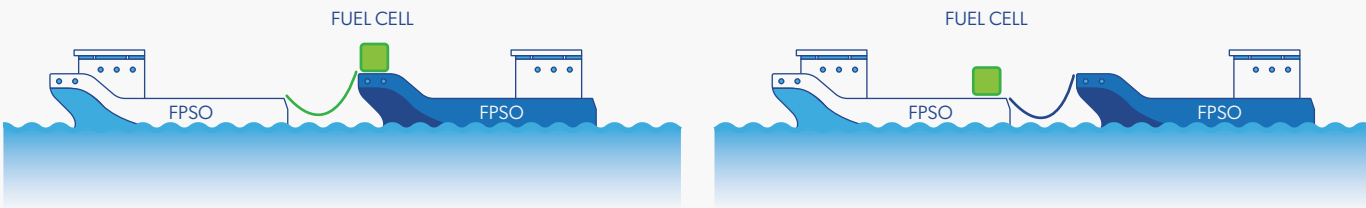


Figure 36. Comparison of Concepts for Hydrogen Energy Transfer from Supply Vessel to FPSO

- Transferring energy from the carrier vessel to the FPSO is a significant challenge to overcome. There is no known technology or system available to safely transfer liquid hydrogen from one vessel to the other on open seas.
- Potential solutions may include utilizing a flexible piping system to transfer LH₂ from the carrier to the FPSO, or utilizing transferable bulk storage tanks containing LH₂, or the transfer of electricity from the LH₂ carrier with the associated fuel cell generating equipment to the FPSO.
- Alternatively, individual storage tanks containing bulk liquid H₂ could be transferred between the bulk carrier to the FPSO via an onboard crane.

ERIA (2020), ‘Review of Hydrogen Transport Cost and Its Perspective (Liquefied Hydrogen)’, in Kimura, S., I. Kutani, O. Ikeda, and R. Chihiro (eds.), Demand and Supply Potential of Hydrogen Energy in East Asia – Phase 2. ERIA Research Project Report FY2020 no. 16, Jakarta: ERIA, pp.60-89.

Energy Transmission Technology – Hydrogen Storage



Figure 37. Liquefied Hydrogen Storage Tank & Offloading Terminal (Kobe, Japan)'

- Learnings from the maritime Liquefied natural gas (LNG) industry can be transferred to transport of liquid hydrogen. The challenges with liquid hydrogen in the shipping industry are more significant as Liquefied hydrogen (LH₂) is approximately 90° C colder than LNG.



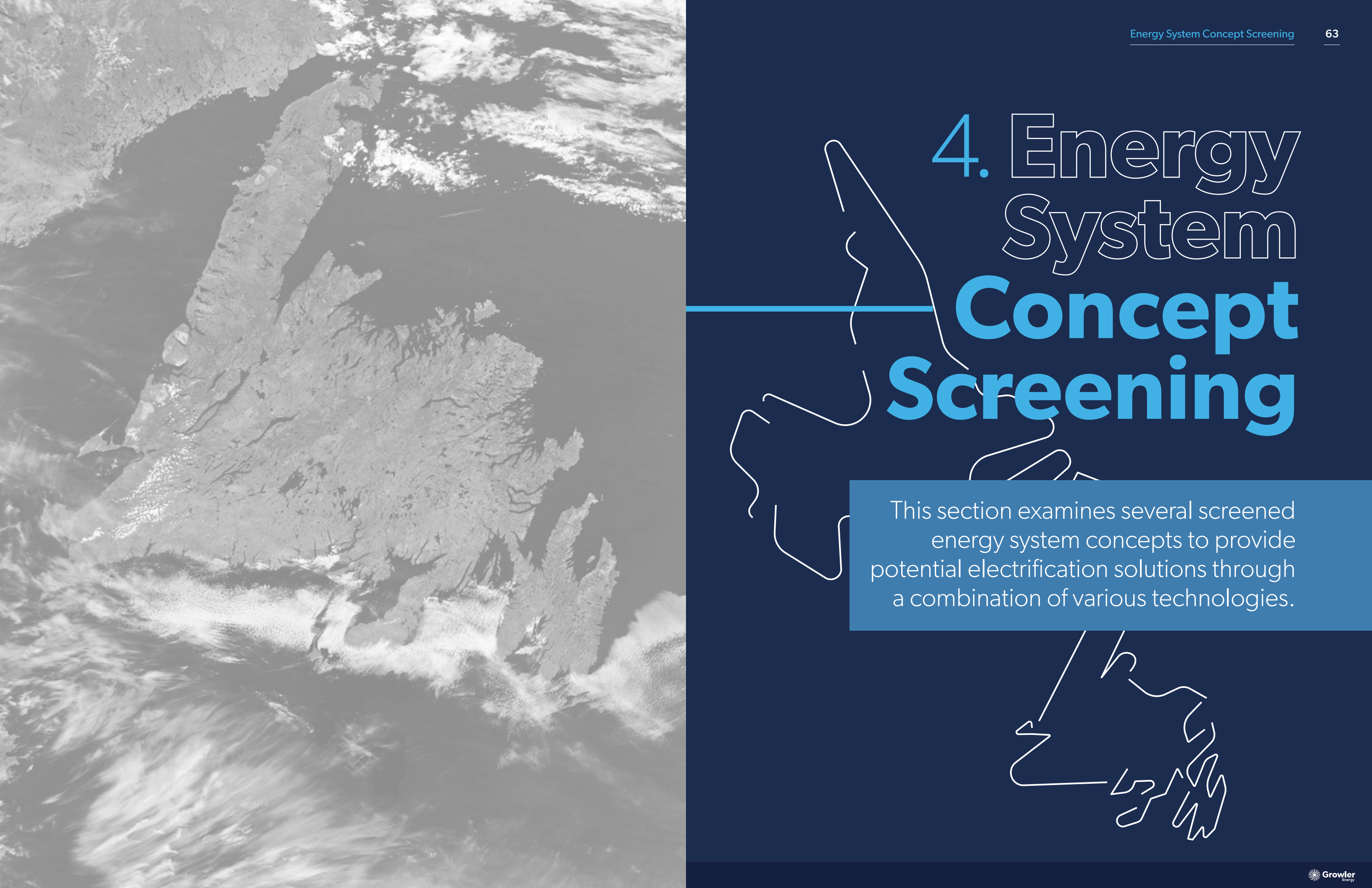
Figure 38. Liquefied Hydrogen Storage Tank (NASA, 2015)

Advantages	Disadvantages
Ability to be stored in bulk quantities	Absence of technology to effectively transfer liquid hydrogen on open seas
Modular ability of hydrogen related systems	Absence of existing bulk storage carriers

Criteria	Value
Transmission Efficiency - Liquefied hydrogen / Ammonia (LH ₂ / NH ₃)	98% / 85%
Technology Readiness Level	8 / 9

Table 20. Hydrogen Energy Transmission Assessment Results

Kawasaki Heavy Industries (n.d.). Kawasaki Hydrogen Road - Paving the way for a hydrogen-based society.
NASA (2015). Liquid Hydrogen—the Fuel of Choice for Space Exploration.



4. Energy System Concept Screening

This section examines several screened energy system concepts to provide potential electrification solutions through a combination of various technologies.

4.1 Energy System Concepts

A set of mutually exclusive energy system concepts were developed. The system concepts incorporated a combination of the screened technologies to provide potential electrification solutions.

Energy system **replacement** concepts were developed by combining the generation, storage, and transmission technologies identified in the technology screening exercise.

- Firm energy supply to the FPSO’s is accomplished through the utilization of energy storage technologies, thus eliminating the need for natural gas-fired backup generation.

Energy system **displacement** concepts were developed by combining the generation and transmission technologies identified in the screening exercise.

- The direct supply of intermittent renewable energy to the FPSOs was intended to reduce the FPSO’s overall emissions intensity, but not act as a firm energy supply source.

Energy Supply	Energy Storage	Energy Transmission
Onshore Wind	Pumped Hydro Storage	Subsea Cable
Hydroelectric	Batteries	Hydrogen
Offshore Wind	Hydrogen	
Utility Supply		

Concept Scenario

1. Offshore Wind with Subsea Cable
2. Onshore Wind with Pumped Storage and Subsea Cable
3. Onshore Wind with Hydrogen Storage and Shipment
4. Hydropower with Integrated Storage and Subsea Cable
5. Hydropower with Hydrogen Storage and Shipment
6. Utility Supply with Subsea Cable

Methodology

- Two operating scenarios: power and energy to a single FPSO, and simultaneously to three FPSO’s.
- Where natural gas combustion is required as backup power in the displacement concepts, the associated carbon tax was considered at \$30 per ton CO₂ at an emission rate of 0.45 tons CO₂ / MWh.
- Displaced natural gas was assumed to have an operational cost of \$15 / MWh of displaced energy.
- Surplus renewable energy sales in all scenarios was considered at a rate of \$60 / MWh.
- Determination of Net Present Value.
- Concept Traffic Light Assessment.
 - Technology Readiness Level
 - Technical Risk
 - Biophysical Environment
 - Socio-Economic
 - Regulatory
 - Stakeholder

Concept Screening (Phase 2)



Figure 39. Energy System Concept – Onshore Wind, Hydrogen Production, Hydrogen Transport



Figure 40. Energy System Concept – Offshore Wind and Subsea Cable

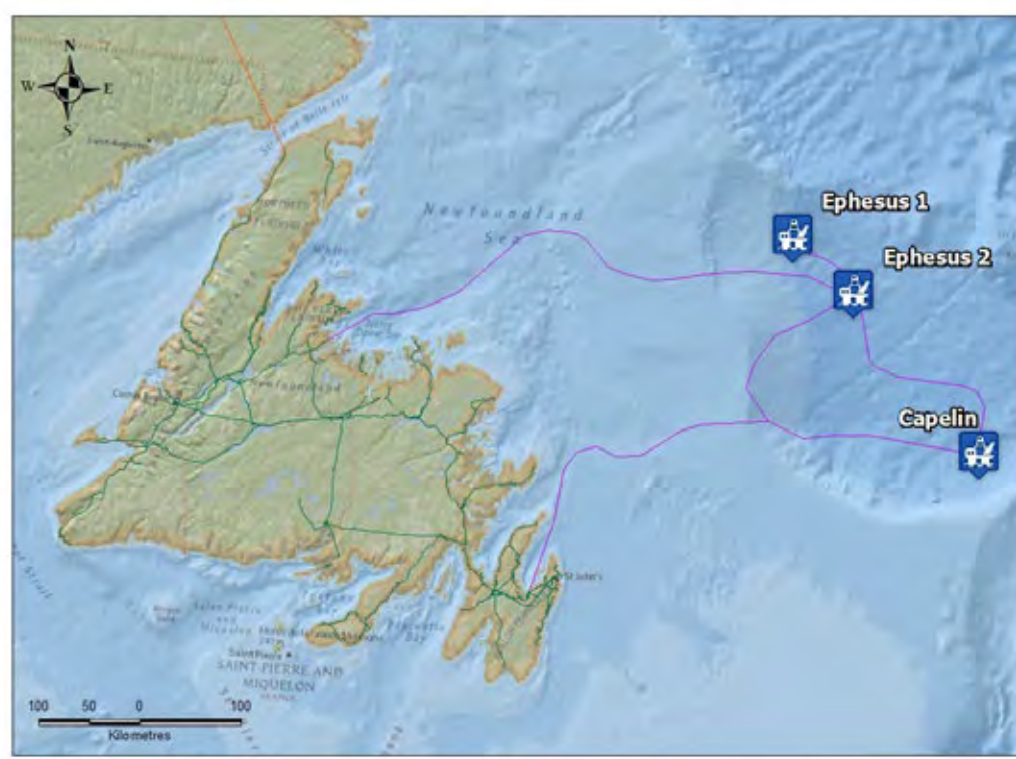


Figure 41. Energy System Concept – Utility Supply and Subsea Cable

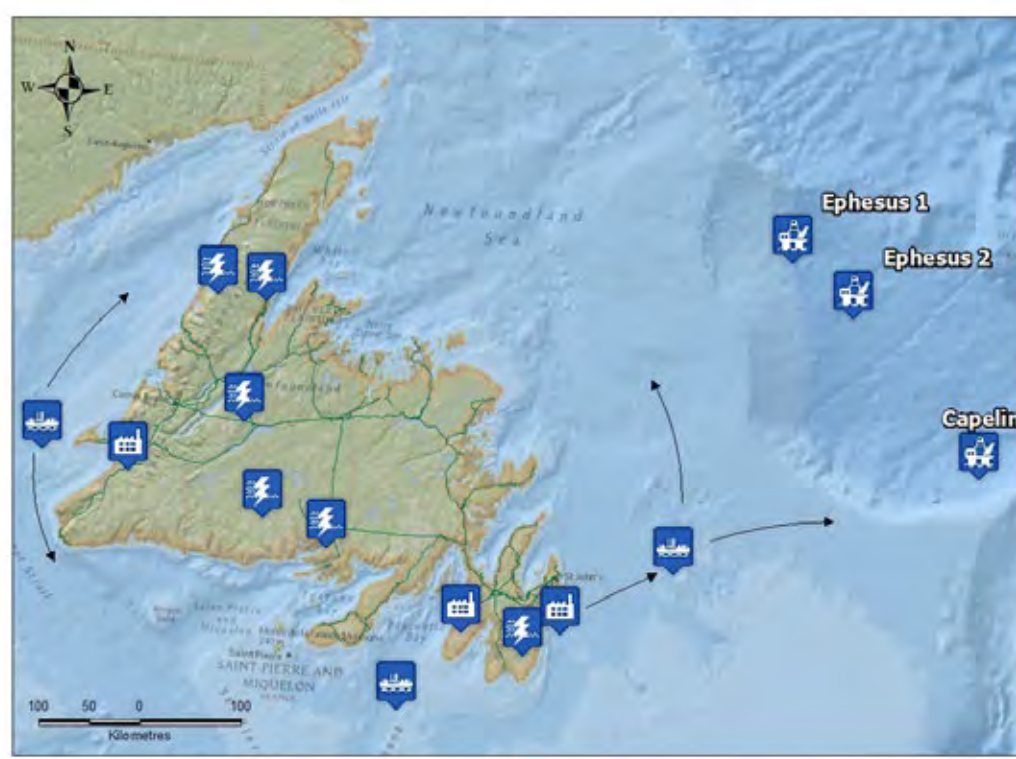


Figure 42. Energy System Concept – Hydropower, Hydrogen Storage and Shipping

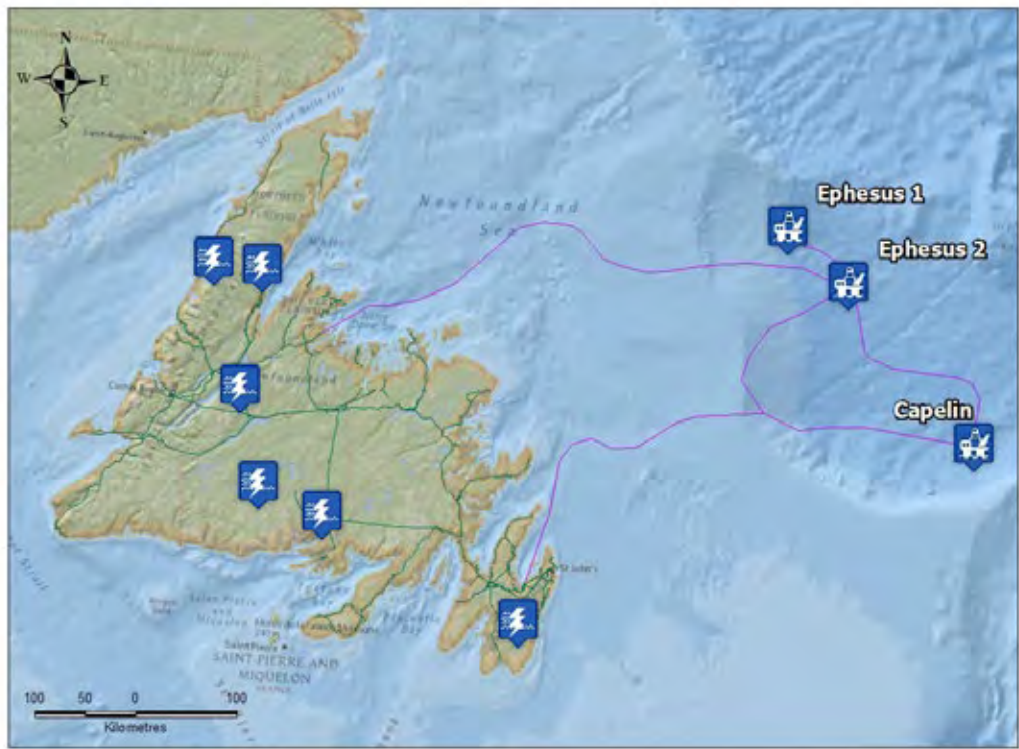


Figure 43. Energy System Concept – Hydropower and Subsea Cable

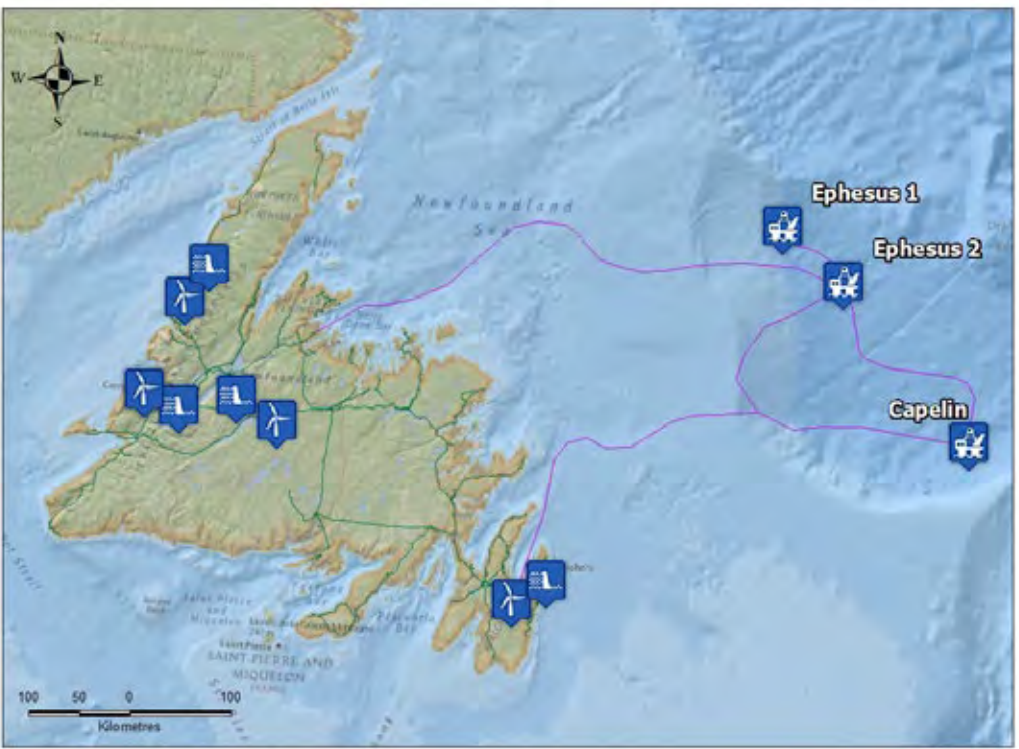


Figure 44. Energy System Concept – Onshore Wind, Pumped Storage Hydro and Subsea Cable

4.2 Net Present Value Analysis

Net Present Value of Energy Supply Concepts to Supply 1 or 3 FPSOs

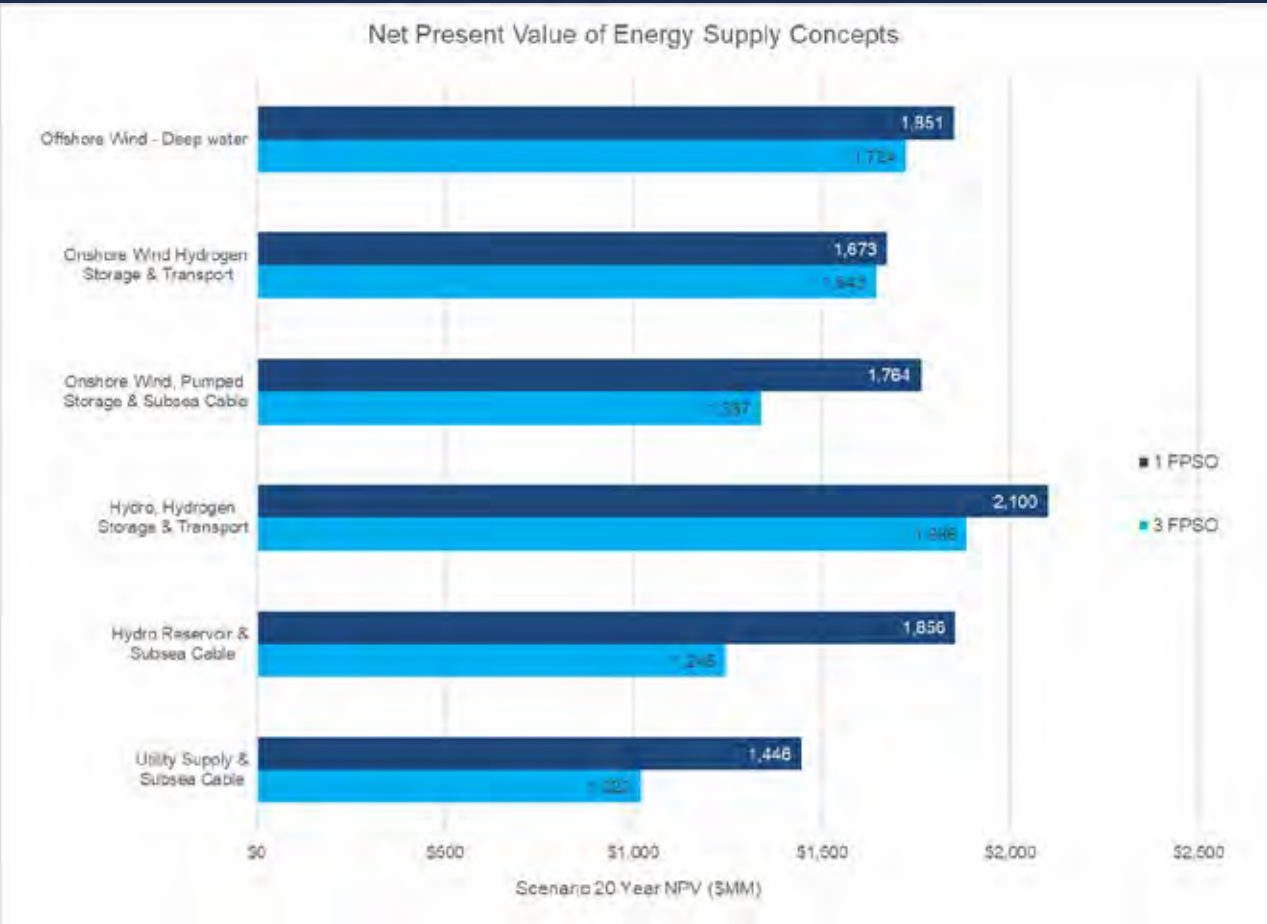



Figure 45. Energy System Concepts NPV Results Summary

Criteria	Onshore Wind Pumped Storage Subsea Cable	Onshore Wind Hydrogen Storage Hydrogen Transport	Integrated Hydro Subsea Cable	Hydro Hydrogen Storage Hydrogen Transport	Utility Supply Subsea Cable	Offshore Wind
Technology Readiness Level	9/9/7	9/8/8	9/7	9/8/8	9/7	8
Technical Risks	Subsea Cable	Hydrogen Shipping	Subsea Cable	Hydrogen Shipping	Subsea Cable	Ocean Conditions Ice Risk
Schedule	Subsea Cable	Tanker Ship	Hydro Facility Subsea Cable	Hydro Facility Tanker Ship	Subsea Cable	Floating Turbines
Constructability	Subsea Cable		Subsea Cable		Subsea Cable	Ocean Conditions
Strategic						Requires full FPSO natural gas capacity
Flexibility	Transmission Capacity		Hydro Facility Transmission Capacity	Hydro Facility	Transmission Capacity	
Health and Safety						
Biophysical Environment						
Local Infrastructure						
Local Benefits		Hydrogen Infrastructure		Hydrogen Infrastructure	Local Energy Sale	
Public Support						
Resource Use						
Protected Areas						
Regulatory						

Table 21. Energy System Concepts Traffic Light Results Summary



5. Detailed Energy System Concept Assessment

This section explores the two energy system concepts that were selected for advancement into the detailed energy system assessment

Two energy system concepts were selected for advancement into the detailed energy system assessment (Phase 3). The primary objectives within Phase 3 of the study were:

- Identifying and selecting favourable development locations,
- Developing system parameters,
- Completing detailed cost estimates, and
- Illustrating preliminary site layouts of the various systems’ components.

Concept 1 - Integrated onshore wind generation, pumped hydro storage, and subsea cable transmission energy system.

Concept 2 - Integrated onshore wind generation, hydrogen storage and hydrogen transport (transmission) energy system.

5.1 Onshore Wind Generation, Pumped Hydro Storage, and Subsea Cable Transmission

The Onshore Wind and Pumped Storage Hydro (PSH) scenario pairs the intermittent wind generation with a reactive PSH system to deliver a firm energy supply to the FPSO facility. The wind turbine generator (WTG) array and PSH facility are coupled with overland and subsea transmission infrastructure.

Since practical wind energy development at a site is generally greater than the FPSO’s energy requirements, there is an opportunity to “overbuild” the wind generation capacity. Doing this would limit the PSH reservoir water surface elevation range if required due to the size of the existing water body, practical dam height limitations, ice management, or environmental effects. Further, additional energy generation could be sold into the existing grid as a low cost energy source.

5.2 Onshore Wind Generation, Hydrogen Production, and Transmission

The Onshore Wind and Hydrogen scenario couples a wind generation facility with a hydrogen production facility located at a suitable storage and port location for transport to the offshore FPSO connected by a dedicated transmission line. An iterative approach was used to perform a rough assessment of the lowest combined capital cost of the wind array, hydrogen production, and liquid hydrogen storage system to fulfill the daily and annual energy requirements of the FPSO.

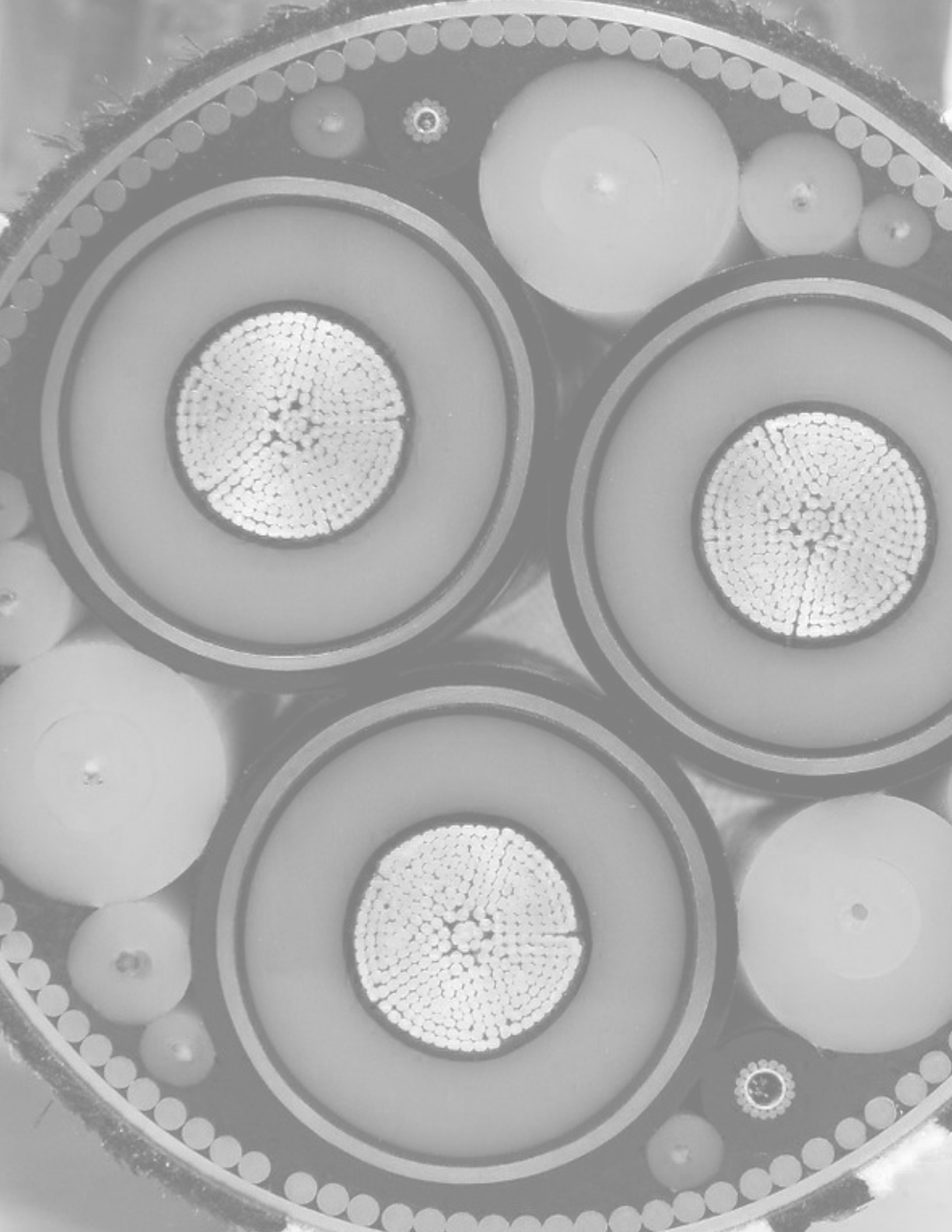
Hydrogen, as an energy carrier, would be produced via polymer electrolyte membrane electrolysis, powered by the wind array. The produced gaseous hydrogen would be transported via underground pipeline to the liquefaction facility where the gas is liquefied by cryogenically cooling it to below its boiling point. The liquefied hydrogen will be stored in highly insulated bulk tanks for offloading to a bulk marine hydrogen carrier which would then be transported to the FPSO location.

Onboard the FPSO, a fuel cell system would be utilized to produce the required electrical energy to service the FPSO with a continuous power demand of 50 MW.

Liquid hydrogen storage will buffer the wind energy generation variability to supply continuous firm power to the FPSO. Wind energy in excess of the daily demand would be utilized to produce and store liquid hydrogen. During periods when the wind power supply is below the demand of the hydrogen production facility, the PEM electrolyzers can be ramped down to match the power input, with the shortfall in energy demand fulfilled by the stored liquid hydrogen.

Summary

Newfoundland & Labrador has a sustainable development advantage due to the abundance of undeveloped, cost effective renewable energy resources. Large scale energy developers have already shown interest in developing this resource for export via green Hydrogen and others are eyeing the opportunity to set up domestic sustainable industries such as mining operations in Newfoundland and Labrador. This type of development will only serve to increase the value of the oil and gas resource by ensuring GHG emissions are limited.



6. Submarine Cables

This section outlines the various subsea cable transmission system alternatives under consideration

Two FPSO supply alternatives are considered:

- Run power cables to Orphan Basin South directly from an offshore course at Conception Bay, near the existing Solider’s Pond station, approximately 400 km.
- Run power from a new floating wind farm site at about 400 km water depth, about 55 km southwest from Orphan Basin South. Siting a floating wind farm in any deeper waters would pose significant engineering challenges due to long anchor mooring lines, high inter-turbine spacings and more robust designs for reliable dynamic power cables in deeper water.

Using DC cables would be the most practical way to fulfil the first alternative to run power directly from shore to an offshore FPSO. A variation for both alternatives would be to deliver shore or wind farm power to one FPSO and then sub-feed it to the second one with an AC cable connection. It is assumed that each FPSO would have a peak demand of about 70 MW, making the transmission capacity of the cables to the first of two FPSOs about 140 MW.

The application is uniquely challenging for at least the following reasons:

- Submarine cables would be exposed to iceberg scouring from the shore landing to about 200 m water depth, about 100 km from shore.
- Floating wind farm turbines, inter-array cables and collector station(s) could be impacted by iceberg collisions.
- Floating wind farm systems have so far only been installed to water depths of approximately 380 m (Gjoa; Jeroense, M. et al. 2010).
- FPSOs could also be impacted by iceberg collisions, and therefore would need to be able to change heading in all compass directions and to sail away from a possible iceberg collision. This would require the use of a disconnectable turret system to allow lowering of power cable connections (as well as flowline and umbilical connections) beneath the FPSO.

Four AC Cable System Alternatives were studied:

1 AC Cable transmission from shore to FPSO at 60 Hz

Location	Cable Length (km)	Max. Water Depth (m)	Nominal Voltage (V)	Transmission Capacity
Italy: Sicily - Malta	132	160	220	200 MW
Mainland Greece - Crete	135	950	150	2 x200 MW
Gjoa Platform - Norway	98.5 (static) + 1.5 (dynamic)	380 at platform 550 elsewhere	115 (90 at platform)	70 MVA (40 MW at platform)
Goliat Platform - Norway	105 (static) + 1.5 (dynamic)	350 at platform	123	75 MW
Martin Linge Platform - Norway	162	115 at platform 370 elsewhere	145	55 MW

Table 22. Longest AC Submarine Cables Globally

For comparative purposes, the longest in-service AC submarine cable transmission systems in the world are shown in the table above. The longest are considerably less than the 400 km needed to reach an Orphan Basin South FPSO. In summary, the distances from shore to the Orphan Basin South site are too far to be practical for AC transmission at 60 Hz power frequency levels.

2 AC Cable transmission from shore to FPSO at 20 Hz

There are disadvantages of using a Low Frequency Alternating Current (LFAC) for an offshore application, such as:

- 20 Hz transformers would have higher magnetic flux and losses compared to 60 Hz.
- 20 Hz transformers would be larger in size and weight.
- A frequency converter would be needed for offshore conversion from LFAC to the FPSO network power frequency (unless the FPSOs also use 20 Hz, which may be impractical).
- A tap changing transformer and/or STATCOM could be required at the onshore station, to help control voltage at the receiving end under all loading and off-loading conditions.

In summary, LFAC transmission is assumed to be overly complex and impractical for this 400 km application. It is also unlikely that an existing onshore power utility would accept ownership, operating, and maintenance responsibilities for such an AC connection system, likely providing a point of service at the onshore station.

3 AC Cable transmission to FPSO from a floating windfarm

A floating wind farm could be installed at ~400 m water depth, and then run AC cables to the FPSOs. The figure below shows a general cable configuration for a wind farm application using spar buoy floats for the wind turbine generators (WTGs). An installation in 400 m water depths would be considerably more complex but somewhat like the floating Gjoa (Jeroense 2010) and Goliat (Hobson, R. 2017) FPSO projects.

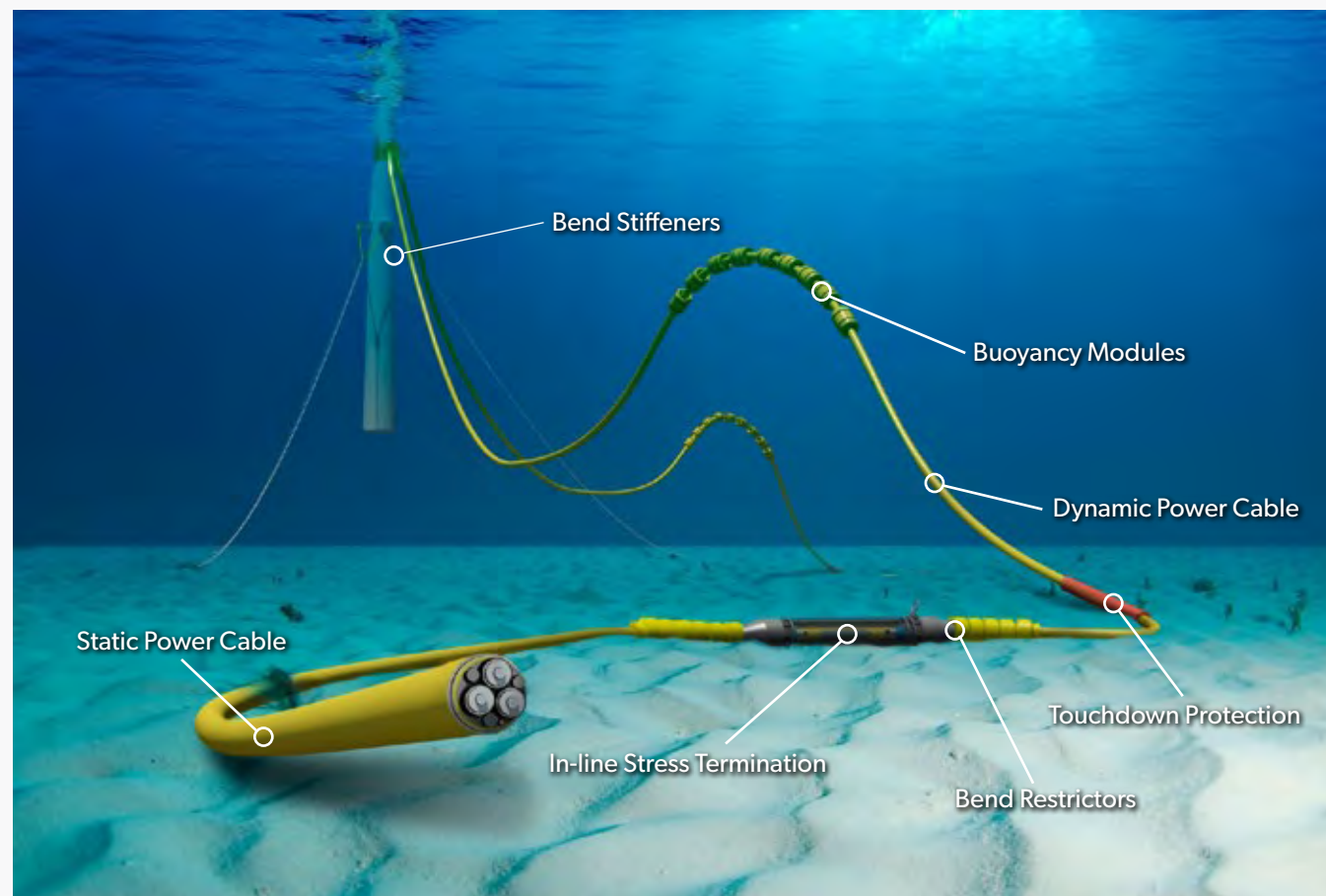


Figure 46. General Cable Configuration for a Wind Farm with Spar-Buoy Turbines (NREL and J. Baur)

- To deliver 140 MW peak to the first FPSO at an assumed capacity factor of 40%, the wind farm would need 30 X 12 MW WTGs with inter-array cables gathered at a floating collector station. The wind farm design would need to consider the number, layout and rating of WTGs, their ability to handle the six degrees of movement associated with floating structures, the array cable layouts, met-ocean data, ability to withstand aerodynamic and hydrodynamic forces, and methods to manage possible iceberg collisions.
- Presently, inter-array submarine cables with wet design insulation have been installed up to 69 kV. Wet design 145 kV Cross-Linked Polyethylene (XLPE) inter-array cables, which would facilitate transmission to an FPSO at the same voltage level without the use of expensive and heavy step-up transformers, are not yet available.
- In summary, delivering 140 MW with AC cables from a floating wind farm located in about 400 m water depth and 55 km from an FPSO in 1,250 m water depth, while avoiding iceberg collisions, would be overly complex and impractical.

4 AC Cable transmission between FPSOs

It is anticipated that a sub-feed cable connection from the main FPSO to a second 70 MW FPSO could be possible at the 145 kV level, as done between fixed bottom platforms Johan Sverdrup 2 and Gina Krog (Johannesson, K. et al. 2018). Due to the high-water depths at Orphan Basin South (~1,250m) and floating FPSOs, it is expected that cable designs for the dynamic sections would be similar to that shown in the figure below.



Figure 47. Dynamic AC Submarine Cable with Four Armour Layers and External High-Density Polyethylene (HDPE) Jacket

(credit: NKT)

Three DC cable transmission alternatives were studied:

1 DC Cable transmission to FPSOs

The figure below shows a typical configuration for supplying power from an onshore High Voltage Direct Current (HVDC) converter station to an offshore platform (or FPSO). The onshore station can be located far from landfall, at a convenient Point of Interconnection (POI), perhaps also requiring extensive use of underground HVDC cables.

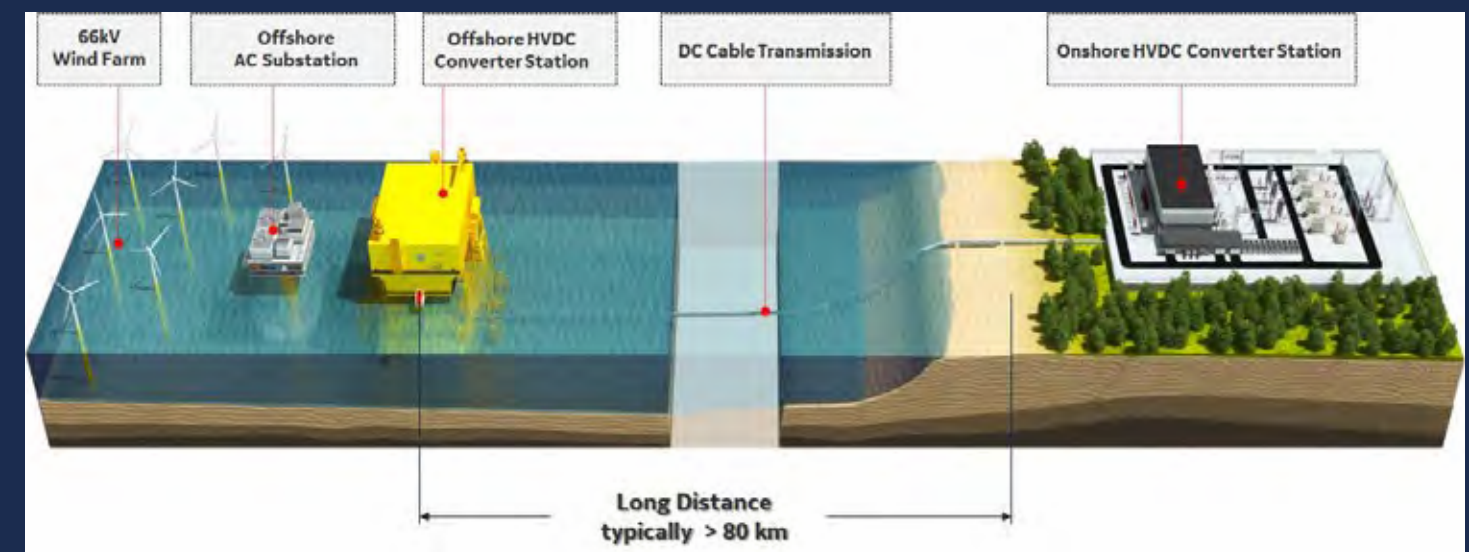


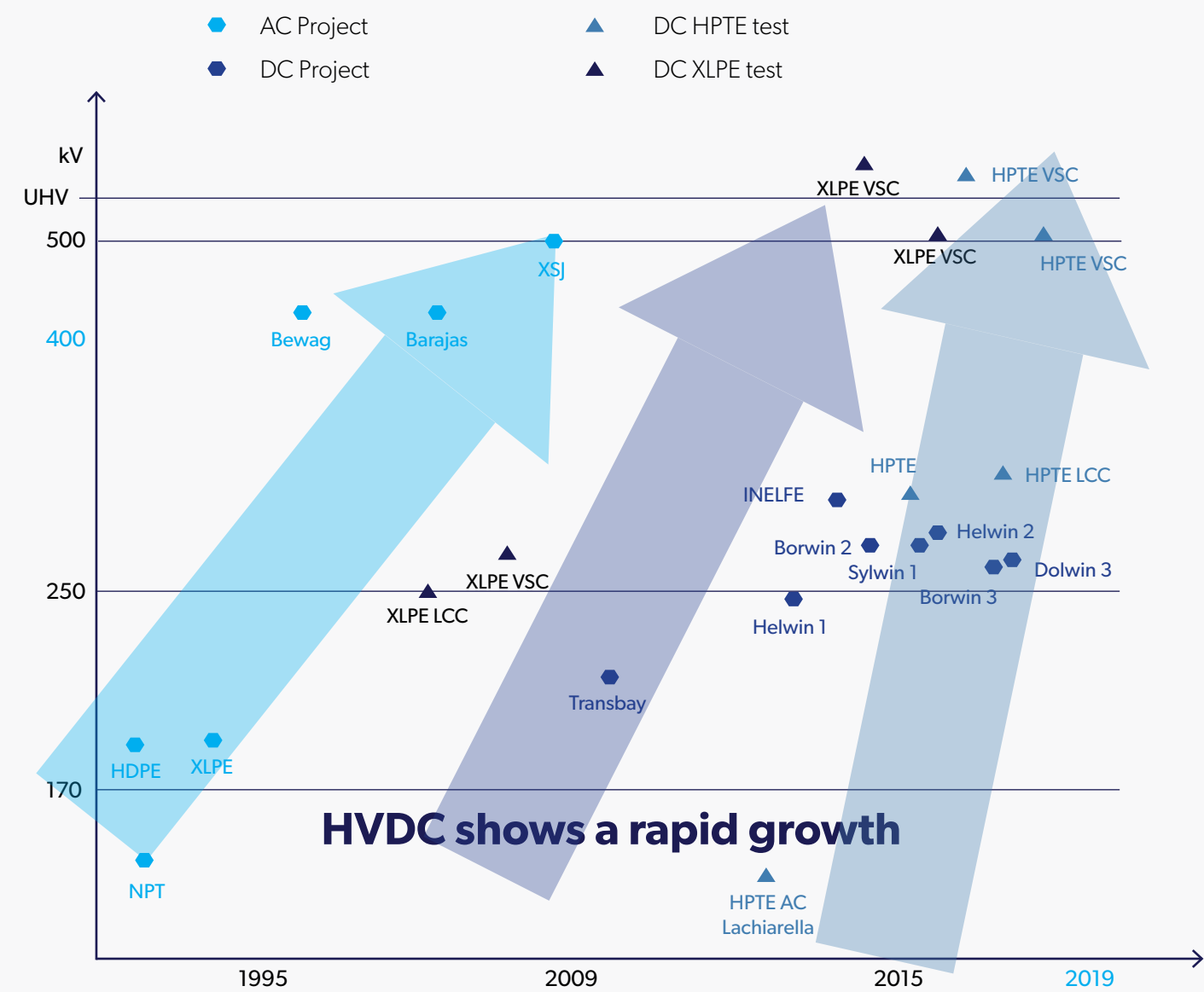
Figure 48. Bulk Power Transfer Between Onshore and Offshore HVDC Converter Stations

(credit: Treier et al. 2020)

The evolution of HVAC and HVDC cable systems over the last quarter century is shown in the figure below:

Development of HVDC cable systems has been especially rapid, driven by economic advantages of long distance interconnectors between countries and efforts to integrate offshore renewable generation. When distances exceed the critical length for HVAC, HVDC cable systems become more economic.

Evolution in High Voltage (HV) - Extra High Voltage (EHV) systems



Operating Wind Farms with HVDC Export Cable Connections

The table below provides a list of HVDC cable systems used to export offshore wind farm energy to onshore converters. What is important is not just the export of wind farm power, but rather the examples of rapid growth of HVDC transmission systems using submarine cables.

	Scheme	VSC Supplier	In Service	Power (MW)	Volatage (kV)	Cable route length (km)
1	BorWin1 - Germany	ABB	2010	400	±150	200
2	Zhoushan Island VSC - 5 Terminal	C-EPRI	2014	400/300/100	±200	129
3	DolWin1 - Germany	ABB	2015	800	±320	165
4	BorWin2 - Germany	Siemens	2015	800	±320	125
5	HelWin1 - Germany	Siemens	2015	576	±250	85
6	DolWin2 - Germany	ABB	2015	900	±320	135
7	SylWin1 - Germany	Siemens	2015	864	±320	205
8	HelWin2 - Germany	Siemens	2015	690	±320	135
9	DolWin3	Alstom	2018	900	±320	51.6
10	BorWin3 - Germany	Siemens	2019	900	±320	130

Table 23. Operating Wind Farms with HVDC Export Cable Connections (2022)

Operating High Voltage Direct Current (HVDC) Cable Systems to Offshore Production Platforms or FPSOs

In addition to the above wind farm applications, there are many more point-to-point applications using HVDC cables with extruded insulations. More directly relevant to this study are the examples in the table below, describing known HVDC cable system applications transmitting onshore power to offshore production platforms or FPSOs.

	Scheme	VSC Supplier	In Service	Power (MW)	Volatage (kV)	Cable route length (km)	Water Depth at Platform (m)
1	Troll - Norway fixed & floating	ABB/ABB	2005/15/24/26	184 (after 2015)	±60	68	330
2	Johan Sverdrup - Norway (floating)	ABB/NKT	2019/22	100	±80	200	120

Table 24. Operating HVDC Cable Systems to Offshore Production Platforms or FPSOs (2022)

2 Bundled DC Cables

Typically, HVDC Voltage Source Converters (VSCs) are configured to provide a symmetrical mono-pole system, with one positive and one negative polarity cable bundled together with a fibre optic cable and laid together. Refer to the picture below for one of two 200 kV cables. The figure below shows the bundled configuration.



Figure 50. ±200 kV XLPE Insulated HVDC Submarine Cable

(credit: Prysmian)

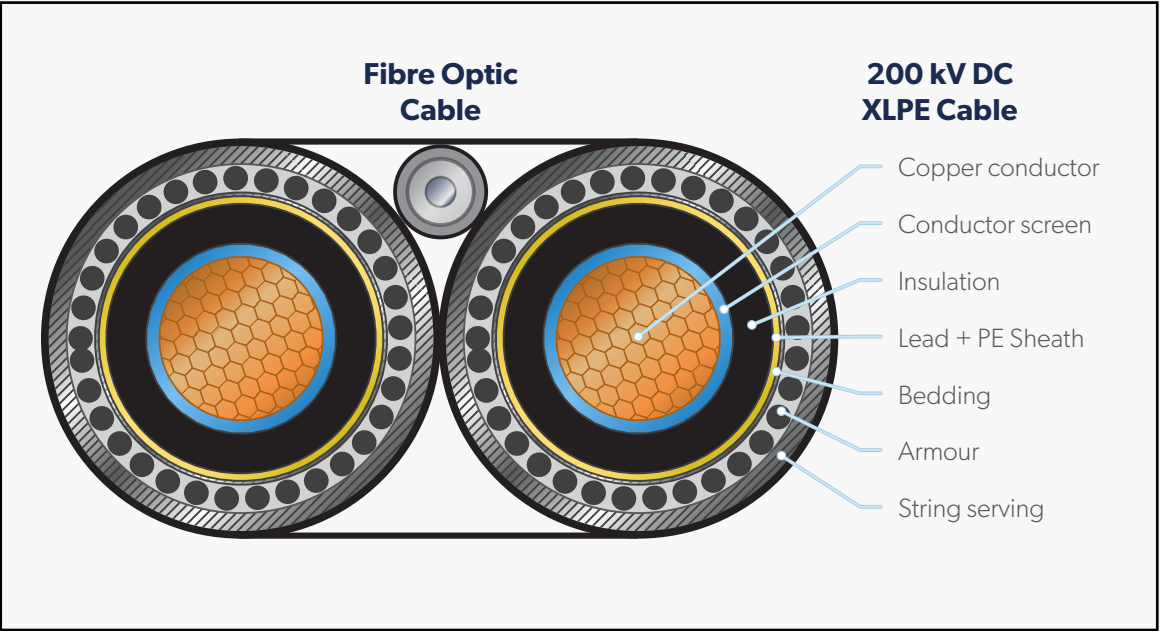


Figure 51. ± 200 kV Cables Bundled Together with a Fibre Optic Cable

The advantage of bundling is that a complete circuit can be laid and buried in one operation. However, it is necessary to maintain equal tension in all cables during laying, which requires specialized cable laying equipment. This becomes more difficult as water depths increase, with about 600 m being a maximum feasible water depth for laying bundled cables from a state-of-the-art cable laying ship.

It is unlikely that laying bundled cables would be feasible for the 400 km distance to the Orphan Basin FPSOs in 1,250 m water depth. In addition, it would be very difficult to design and install bundled dynamic cables to ascend in a controlled manner from the sea bottom up to FPSOs. Instead, individual cables would need to be laid separately.

3 Integrated Return DC Cables

An alternative to using bundled DC cables is to apply a single integrated return cable (IRC), as shown in the figure below for the EstLink2 project between Estonia and Finland. With this type of cable, the centre conductor is insulated to the desired DC voltage and the concentric conductor serves as a medium voltage metallic return. In this way the DC system can operate successfully as a monopole.

Submarine Cable

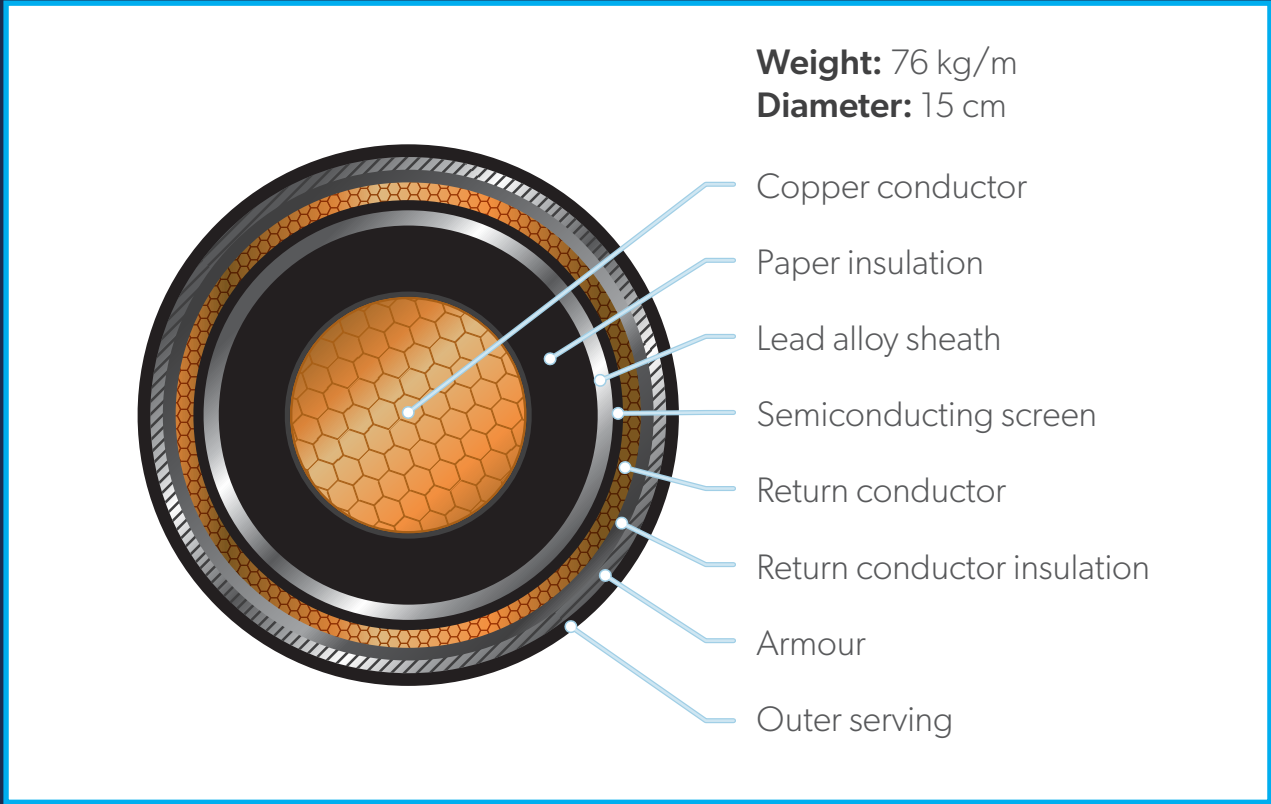


Figure 52. ± 450 kV Integrated Return Cable as Applied for the 170 km 600 MW EstLink2 Connection
(credit: FINGRID elering)

- It is important to note that the EstLink2 cable used mass impregnated paper lapped insulation. This makes it unsuitable for dynamic applications to FPSOs because the registrations of paper tape layer butt gaps and internal paper tape slipping could be negatively impacted by structure movement.
- However, another company has completed tests on IRC cables using extruded insulation for ± 250 kV, 300 MW, which would be satisfactory for dynamic cable ends (CIGRE 2008) as well as the static cable lengths.
- With modifications for the dynamic cable ends, likely with additional armour layers and an external HDPE jacket to add bending and axial stiffness, it would more easily facilitate installation for the 1,250 m rise from the sea bottom to an Orphan Basin South FPSO.

To summarize, preliminary investigations suggest that the most reliable and technology-ready transmission system from an onshore source to an Orphan Basin South FPSO would be a DC cable system. DC cable systems are proven for long distances and voltages up to ± 500 kV. They would be satisfactory for delivering 140 MW from shore for 400 km to an FPSO in 1,250 m water depth, preferably at a low voltage such as ± 80 kV or ± 150 kV, to reduce converter costs. It would probably also be most acceptable to a NL power utility connected to the sending end station, considering their experience with the Labrador-Island Link and Maritime Link HVDC systems.



7. Risks & Opportunity

This section explores the risks and opportunities associated with the offshore electrification alternatives in Newfoundland & Labrador.

7.1 Strengths, Weaknesses, Opportunities, & Threats

The assessment was conducted using a strengths, weaknesses, opportunities, and threats (SWOT) approach to explore the potential barriers to implementing the short-listed generation/transmission alternatives.

The SWOT outcomes associated with the major generation and transmission alternatives that were short-listed throughout the study are included in the following sections. They include:

- 1. Onshore Wind
- 2. Offshore Wind
- 3. Hydro (Pumped Storage)
- 4. Submarine Cable Transmission (HVDC)
- 5. Hydrogen Transshipment

Onshore Wind

SWOT	Category	Description
Strength	Technical	Onshore wind potential in Newfoundland & Labrador is significant; it represents close to 40% of the developable onshore wind potential amongst Canadian provinces.
Strength	Technical	There is an established electrical transmission system with both HVAC and HVDC capabilities. There are major substations near areas of high development potential.
Strength	Technical	Onshore wind facilities currently operate in NL; there is an existing O&M supply chain network in the province (albeit modest).
Strength	Environment	Onshore wind generation has low emissions relative to most other generation sources. This would most certainly result in emissions reduction at the end-use facility (i.e., help meet ESG targets and offset carbon pricing).
Strength	Technical	The NL workforce is well-positioned for both the design and installation of wind facilities. Strong core of trades and technical knowledge in a small population. Atlantic Canada is among the lowest business cost locations within G8 countries.
Weakness	Technical	Onshore wind, on its own, is not dispatchable and therefore requires the development of a storage facility to serve as a generation source for offshore. Storage technology is improving but is still expensive relative to generation.
Weakness	Technical	Previous studies have highlighted that adding wind energy (due to the intermittency of wind) on the existing NL grid would result in grid stability issues. This may cause reluctance to allow for grid interconnection.

SWOT	Category	Description
Weakness	Environment	Onshore wind carries a significant footprint; the development of an onshore wind facility results in the removal of forested areas as a carbon sink. Same applies to the overland transmission system required for interconnection.
Weakness	Environment	The footprint of wind facilities can also negatively impact the migration of both avian and terrestrial animals. This needs to be closely considered from both an environmental and cultural perspective (i.e., impact on hunting activities).
Opportunity	Technical	Electrical interconnection to the North American grid represents an opportunity to sell surplus wind energy produced to the spot market. This could ensure profitability of new facilities.
Opportunity	Stakeholder	There is, in general, a positive perception of wind generation in the province. It is believed that the industry/development would garner a strong interest from local labour markets.
Opportunity	Stakeholder	Additional generation on the insular part of the province would be looked upon favourably from an energy security perspective, especially in the winter months.
Opportunity	Stakeholder	Wind production for use in offshore facilities would be looked upon favourably by investors in energy markets. It would illustrate a company or region’s willingness to meet ESG targets.
Threat	Stakeholder	There is some uncertainty with the ability to distribute electricity across the utility’s grid. While there is some precedence here, it is not clear if this would be met with resistance.
Threat	Regulatory	Newfoundland & Labrador is a relatively closed market in terms of generation. Private onshore wind development is not currently legal in NL (Bill C61), although reviews of legislation are currently underway (based on the NL Renewable Energy Plan actions). <i>Note: On April 5, 2022, the NL Government announced they are lifting the current moratorium on wind development. By lifting the existing moratorium to enable onshore wind development, the NL government is allowing companies to proceed through an approval process for wind development. Details on this process have not yet been released.</i>
Threat	Stakeholder	Onshore wind suffers from the NIMBY effect (“Not in My Backyard”). While there is plenty of ‘out of plain sight’ locations in NL, this may meet resistance with hunting associations, cabin owners etc.
Threat	Policy	While NL has gone through periods where independent power generation has been supported (NUGs program etc.), the current environment may not be conducive to large scale private renewable development.

Offshore Wind

SWOT	Category	Description
Strength	Technical	There is a strong knowledge base in the province pertaining to floating and moored structures. The skill sets developed in the oil and gas sector lend well to the offshore wind sector.
Strength	Technical	Technological improvements have increased the cost effectiveness of offshore wind developments. Direct DC conversion and other advancements have improved the transmissibility of offshore wind.
Strength	Stakeholder	The remote nature of offshore wind overcomes the “Not in My Backyard” effect; generally speaking, people are more accepting of offshore wind due to this principle.
Strength	Environment	Offshore wind generation has low emissions relative to most other generation sources. This would most certainly result in emissions reduction at the end-use facility (i.e., help meet ESG targets and offset carbon pricing). It doesn’t require any habitat destruction to implement, as well.
Weakness	Environment	Noise generation from offshore wind facilities can be an issue for wildlife (i.e., bats and migratory birds). This is both an environmental and regulatory concern (since there is no Canadian precedence for offshore wind).
Weakness	Technical	Collection cabling from the offshore wind facility to the FPSO are a technical barrier to this development strategy; qualifying dynamic cables for this type of harsh environment is a technical gap in the industry that has yet to be closed.
Weakness	Technical	Offshore wind is non-dispatchable, which may result in grid stability issues on the platform. Significant storage capability would have to be developed, or wind would have to serve as a fuel displacement strategy (instead of a replacement strategy).
Weakness	Technical	While floating wind technology has improved, wind location sites for the current project are in very deep waters with high sea states and ice infestation. In general terms, these are conditions that push the current design envelope for offshore wind.
Weakness	Technical	The distance from shore is significant, adding significantly to workover, inspection, and maintenance costs. Response times to any issues at the wind facility would be slow and thus could be considered a weakness from an asset integrity perspective.
Weakness	Environment	The footprint of wind facilities can also negatively impact the migration of both avian and marine animals. This needs to be closely considered from both an environmental and cultural perspective (i.e., impact on fishing activities).
Opportunity	Stakeholder	There is a regional interest in offshore wind, predominantly because of its appeal as a potential major capital construction opportunity. It would gain strong support by public, industry associations, and unions.

SWOT	Category	Description
Opportunity	Stakeholder	There is, in general, a positive perception of offshore wind generation in the province. It is believed that the industry/development would garner a strong interest from local labour markets.
Opportunity	Stakeholder	Offshore wind production for use in offshore facilities would be looked upon favourably by investors in energy markets. It would illustrate a company or region’s willingness to meet ESG targets.
Threat	Policy	There is no precedent for offshore wind development in Newfoundland & Labrador (or Canada); legislation is not mature for this industry, which is a barrier to this technology.
Threat	Regulatory	<p>Newfoundland & Labrador is a relatively closed market in terms of generation. While legislation is directed at prohibiting onshore wind, Bill C61 (prohibition of wind) would also affect offshore wind. Reviews of legislation are currently underway (based on the NL Renewable Energy Plan actions).</p> <p><i>Note: On April 5, 2022, the NL Government announced they are lifting the current moratorium on wind development. By lifting the existing moratorium to enable onshore wind development, the NL government are allowing companies to proceed through an approval process for wind development. Details on this process have not yet been released.</i></p>

Hydro (Pumped Storage)

SWOT	Category	Description
Strength	Technical	There is a mature, well-developed hydro skill set in the province; with much of the existing electrical system powered by hydro (both utility and non-utility), there is an established industry in NL.
Strength	Technical	There is an established electrical transmission system with both HVAC and HVDC capabilities. There are major substations near areas of high development potential. Please note that pumped storage would be paired with onshore wind generation in this scenario.
Strength	Technical	Pumped storage facilities are easy to maintain and have long life spans. It is likely that a new build pumped storage would out-live any extractive facility.
Strength	Environment	Pumped storage in Newfoundland & Labrador can utilize natural water storage + elevations to ensure a low environmental footprint. Furthermore, there could be opportunities to 'charge' existing hydro facilities by 'wind pumping' from one water body to another. This would be a low emissions/low footprint strategy.
Strength	Technical	Pumped storage could (and would) be a welcomed source of power in the insular part of the province from an energy security perspective. It is highly possible that additional capacity would be a welcomed addition to the NL grid, especially during winter months.
Weakness	Regulatory	Obtaining permits for altering bodies of water are notoriously onerous and subject to lengthy and often delayed approvals processes. May have a negative impact on schedule associated with offshore electrification.
Weakness	Environment	As a counterpoint to the above 'strength', GHG emissions caused by manufactured reservoirs or excessive flooding could destroy habitat and carbon sinks, eroding GHG reduction goals.
Opportunity	Technical	Electrical interconnection to the North American grid represents an opportunity to sell surplus capacity (hydro capacity is a premium product) to the spot market. This could ensure profitability of new facilities.
Opportunity	Stakeholder	Additional generation on the insular part of the province would be looked upon favourably from an energy security perspective, especially in the winter months.
Opportunity	Stakeholder	Hydropower for use in offshore facilities would be looked upon favourably by investors in energy markets. It would illustrate a company or region's willingness to meet ESG targets.

SWOT	Category	Description
Opportunity	Stakeholder	The utility may look at this concept and explore opportunities to upgrade existing hydro facilities to increase storage or output. While not considered likely, it is certainly a technically viable option.
Threat	Stakeholder	At present, there is a very poor public perception of hydro in Newfoundland & Labrador. While it is a major provincial resource, it's been highly politicized and is now synonymous with poor project decision making.
Threat	Stakeholder	There is some uncertainty with the ability to distribute electricity across the utility's grid. While there is some precedence here, it is not clear if this would be met with resistance.
Threat	Stakeholder	Hydro suffers from the NIMBY effect ("Not in My Backyard"). While there is plenty of 'out of plain sight' locations in NL, this may meet resistance with hunting associations, cabin owners etc.
Threat	Policy	While NL has gone through periods where independent power generation has been supported (NUGs program etc.), the current environment may not be conducive to large scale private renewable development.

Submarine Cable Transmission

SWOT	Category	Description
Strength	Technical	HV links are a reliable method for transmitting power over longer distances; the technology is mature and globally deployed.
Strength	Technical	An HV link presents the opportunity of cogeneration; while normal operations send power to the facility, an emergency scenario could send power for the facility to shore.
Strength	Technical	Ice/met-ocean risk modeling indicates a relatively low risk of contact; strategic routing could reduce this risk well below traditional acceptance criteria for submarine cables.
Strength	Technical	There are multiple HV substations, both AC and DC, across the province. This presents multiple options for landfall with a submarine cable without requiring extensive overhead lines onshore.
Strength	Environment	There is a relatively low environmental footprint associated with submarine cables. Some habitat loss to consider, but relatively low impact.
Weakness	Technical	It is possible that excessive demand for copper in the near future may significantly increase the price of HV cable systems. This would have a major impact on the economics of offshore electrification via power from shore.
Weakness	Technical	Deepwater dynamic cables have yet to be qualified for the deepwater/North Atlantic. There are still a number of technical gaps to close, associated with connection types, fatigue, ice interaction etc.
Weakness	Technical	Traditionally, submarine cables act as interconnections between major grids. They are generally cost prohibitive unless there’s an economy of scale. It is likely that it will require multiple facilities to make a submarine cable cost competitive with other solutions.
Opportunity	Regulatory	There are very few permits required for submarine cables, which aids in project schedule (and ultimately project cost).
Opportunity	Stakeholder	The utility has experience and skillsets associated with HV transmission and may look upon this ‘grid extension’ favourably as an extension of their customer base using a known technology (that they are comfortable with).
Threat	Stakeholder	As stated in generation sections, there is some uncertainty with the ability to distribute electricity across the utility’s grid. While an HV link is just an extension, the utility may discourage private connection to its grid.

Hydrogen Transshipment

SWOT	Category	Description
Strength	Technical	There is an established marine sector in Newfoundland & Labrador, with multiple developed ports, marine transportation networks and experienced shipping companies.
Strength	Technical	With the abundance of low-cost energy potential (i.e., wind), there is an abundance of resource available for hydrogen development.
Strength	Technical	A hydrogen mixing strategy, assuming technical barriers related to offshore transfer could be remedied, would be the least disruptive to current facility design.
Strength	Technical	Hydrogen has garnered global interest, with hydrogen ship technology moving into commercialization around the world.
Strength	Technical	Gas turbine providers have started making gas turbines that are able to accept combust hydrogen/natural gas mixtures. The offshore sector has also begun to look at the use of electrolyzers offshore, although deployment is in its infancy.
Weakness	Health & Safety	Hydrogen is highly volatile; there would be some cost associated with explosion proofing hydrogen systems at both the onshore terminal and offshore platform.
Weakness	Technical	Except for some industry consumption, there is limited activity and competency within the hydrogen sector in Newfoundland & Labrador.
Weakness	Technical	There is no existing gas pipeline network in-province, so there is very limited opportunity to leverage existing gas infrastructure for the purpose of hydrogen development/transshipment.
Weakness	Technical	While hydrogen ship technology is readily available, offshore transfer of gas (ship-to-platform) is a technical barrier to its use in offshore electrification.
Opportunity	Technical	Hydrogen export is an emerging focus area in Newfoundland & Labrador. It is possible that this is an emerging market in the province, and that the offshore sector could simply be an off-taker or benefactor.
Opportunity	Stakeholder	Emissions reduction via hydrogen electrification could be Newfoundland & Labrador’s launchpad into the hydrogen export market. This would be looked upon favourably by government.
Threat	Stakeholder	The Newfoundland & Labrador public is relatively unfamiliar with hydrogen technology, and the use of an emerging technology may be met with some resistance in terms of public perception.
Threat	Regulatory	There are essentially no regulations developed that pertain to or guide hydrogen transshipment development in NL/Canada. This could be a barrier to the use of hydrogen for offshore electrification.
Threat	Stakeholder	As stated in generation sections, there is some uncertainty with the ability to distribute electricity across the utility’s grid. While an HV link is just an extension, the utility may discourage private connection to its grid.

Pre-identified Strategic Studies

As outlined in the project methodology, the following characterization studies identify risks and opportunities as well as key gaps to be addressed. In addition to the previous assessment of available renewable energy resources, these include the following preliminary grid interconnection study; landfall assessments; ice risk assessments; environmental and regulatory risk identification; and GHG emissions opportunity assessment.

7.2 Preliminary Grid Interconnection Study

The Direct Current (DC) Power from Shore (PFS) concept consisting of an onshore and offshore converter system interconnected via a subsea cable arrangement is a constructable and technically feasible concept to supply an offshore FPSO vessel installation. The DC transmission system concept modelled in this study is deployed worldwide in several applications, typically in offshore wind generation, and oil and gas production facilities in Nordic Countries.

The DC Voltage Source Converter (VSC) type system is a flexible and versatile control platform. It can bidirectionally flow power, while directly controlling system voltage. This provides reliable power system stability and good power quality without the complicated control and compensation requirements of a Flexible Alternating Current Transmission System (FACTS) based system.

The concept scenarios modelled are based on steady state system load flow behavior at medium and high voltage class levels that are commonly utilized in utility power transmission networks worldwide. High voltage levels of 138 and 200 kV and a medium voltage of 75 kV were utilized in modelling scenarios. Standard Floating, Production, Storage and Offloading (FPSO) vessel main/normal operating bus voltage of 13.8 kV was also used to demonstrate compatibility with current, and typical offshore equipment and to further demonstrate that interconnection is possible between both systems.

The following were key criteria and assumptions used in the models:

- Shore based converter station is located 1 km from the utility interconnection point, fed from a typical overhead transmission line.
- The total length of the subsea cable to be 400 km.
- The total length of the subsea intertie scenario cable to be 50 km (between FPSOs).

Overall modelling suggests that a High Voltage Direct Current (HVDC) level system would operate optimally under the stated criteria, while the Medium Voltage Direct Current (MVDC) level system would be considerably constrained by the lower voltage level and the long distance involved with transferring the required power and energy. The HVDC option gives the most operational flexibility over the identified system scenarios.

Further to the system load flow modelling, each of the three NL Hydro HV terminal stations identified in the study are capable of supporting a PFS interconnection. Although each station would require varying degrees of expansion and upgrading to accommodate this, the identified levels of power transfer to supply the FPSO loads are possible under typical transmission system contingencies.

From a high-level load flow perspective, any of the four options studied would be technically feasible, dependent on reliability requirements, desired operational philosophies, and economic factors. Key deciding factors would be cable economics (power loss reduction versus insulation costs) and the levelized cost of energy.

HVDC with AC Intertie

- This point-to-point option with an AC intertie cable link between FPSOs (partial ring bus) can allow for a second supply in the event of a single subsea DC cable trip, the AC intertie would pickup the second FPSO essential loads via the healthy PFS DC subsea cable.
- A fast bus transfer protection and control scheme would ensure no disruption in service to any essential vessel loads, load shed all process loads (via vessel Power Management System (PMS) on the FPSO with the faulted cable), isolate the faulted cable via a controlled converter block function, and trip the FPSO converter incomer breaker.
- Overall, this option is technically feasible with operating voltages and power losses within an acceptable range.

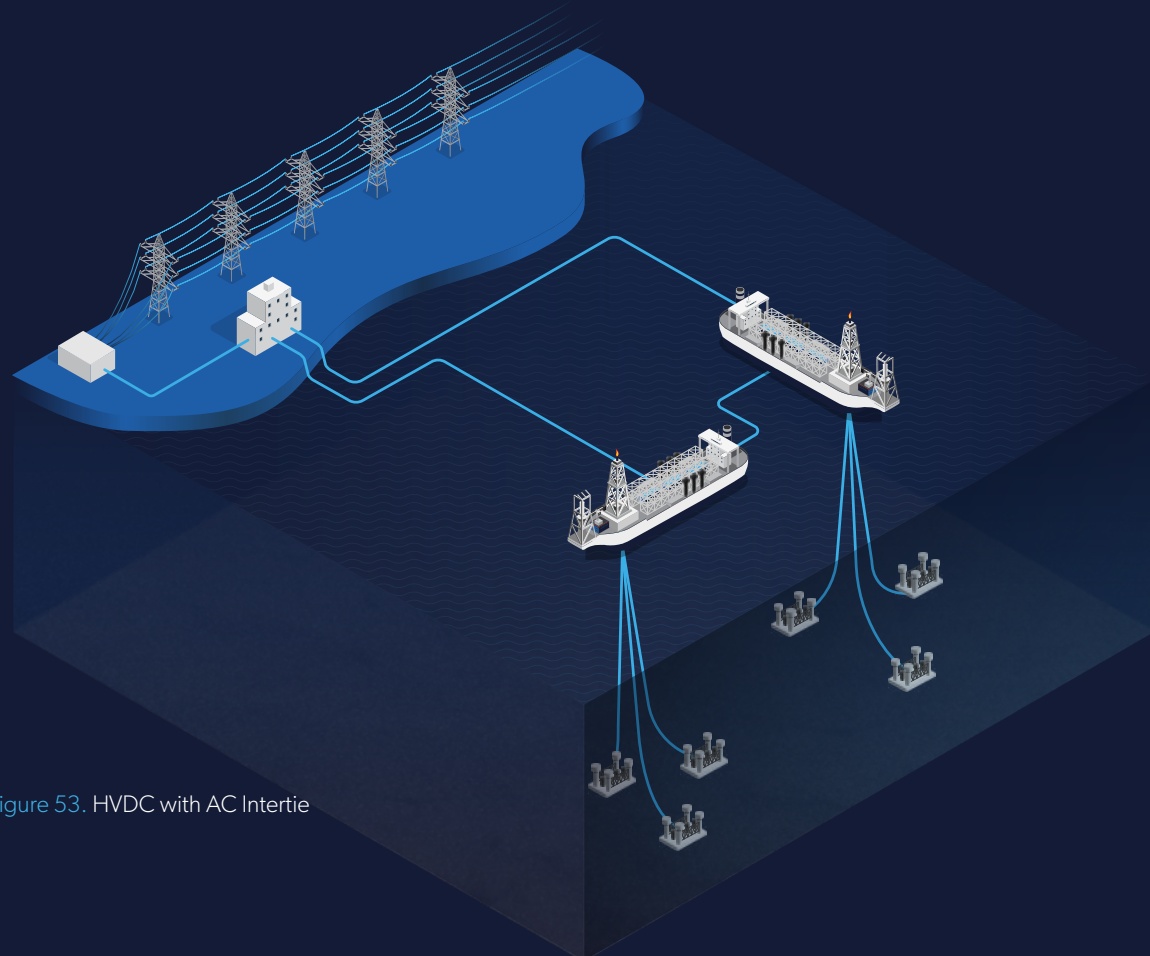
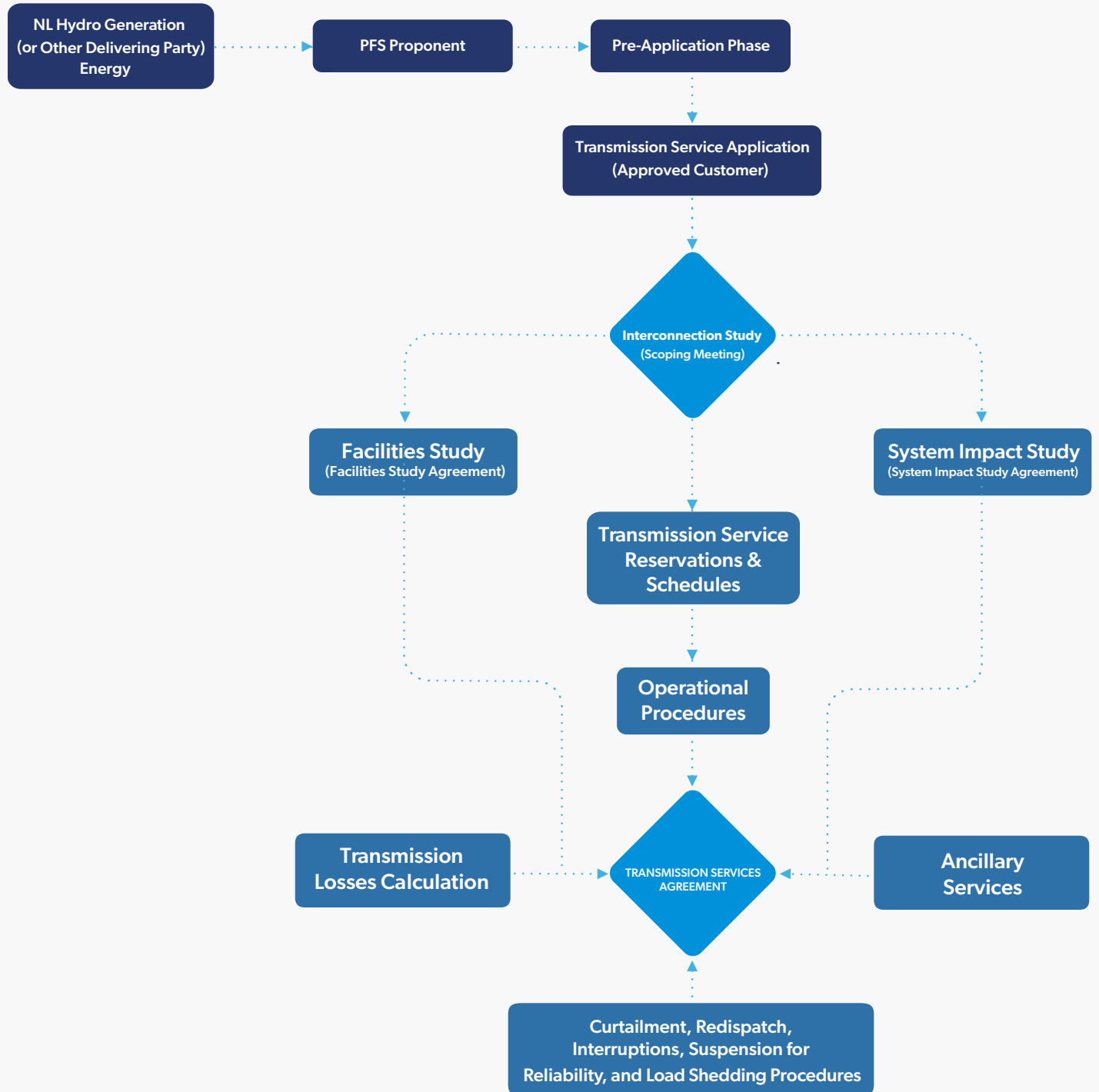


Figure 53. HVDC with AC Intertie

Detailed System Studies Identification, Grid Interconnection

- System load flow modelling under various scenarios and contingencies have been identified and modelled against each of the four preferred NL Hydro HV terminal stations. Further study is required to verify that firm energy supply is possible with a reliable power transfer capability to the designated customer reception point (i.e., DC converter station site).
- As follow-on work is completed for potential offshore FPSO sites, such as location, annual energy, loading requirements, dispatch, and system reliability requirement, further studies can better focus on the detailed requirements of the utility (NLSO) to ensure good utility practice and prudence, while aiding in the determination of constructability and feasibility for the offshore customer.
- Overall, any further development of a PFS concept or design basis should follow in close consultation with the Newfoundland and Labrador System Operator (NLSO) transmission system planning process to ensure success.

NLSO Application & System Integration Process



Summary

Grid connection seems technically feasible, however the availability of excess power on the grid would need to be further investigated with a NLSO Application for a specific project.

A decorative graphic at the top of the page. On the left, a series of horizontal and vertical lines represent a cable trench or structure. A thick blue horizontal line extends from this structure towards the right. Below this line, a white wavy line represents the seabed profile. A vertical white line drops from the blue line down to the seabed profile, indicating a landfall location. The section title '7.3 Landfall Assessments' is positioned to the right of the blue line.

7.3 Landfall Assessments

Landfall locations have been considered with the underlying premise that a trenched landfall is the most economical means, with the least risk on schedule, in areas with enough overburden to allow conventional trenching operations.

Currently there are a number of submarine power cables installed in coastal waters in Newfoundland and Labrador, from smaller cables servicing small island communities, such as the 25kV AC cables running from Portugal Cove-St. Phillips to Bell Island, to the 350 kV HVDC submarine cables crossing the Strait of Belle Isle. Most of the submarine cable landfalls on the island are protected by trenching the cable to the shore.

Where greater protection against external aggression is required, landfalls utilized Horizontal Directional Drilling (HDD), the longest being in the Strait of Belle Isle with HDD lengths up to approximately 2200 m. Protection of the cable can be further enhanced near shore with cast-iron articulated pipe protection, as seen in the following figure.

Rock outcrops and boulders can present significant challenges for a trenching operation, but if the material is suitable, a trench is the most efficient means of protecting the cables near shore.



Figure 54. Power Cable with Articulated Pipe Protection in Conception Bay

Landfalls involving cables pulled in from shore through a conduit installed by HDD is the best way to eliminate exposure to any external aggression between the entry point on land and the seabed exit location. HDD can be drilled in rock with high accuracy ensuring a favourable exit location can be selected avoiding boulders and allowing the best seabed exit completion strategy. The schematic shown below provides a general concept for the HDD operations. The rig on the right will drill the bore and install a pipe from shore to an optimal location on the seabed. Once complete, a winch onshore will pull the cable through the pipe and off the turntable from the cable lay vessel.

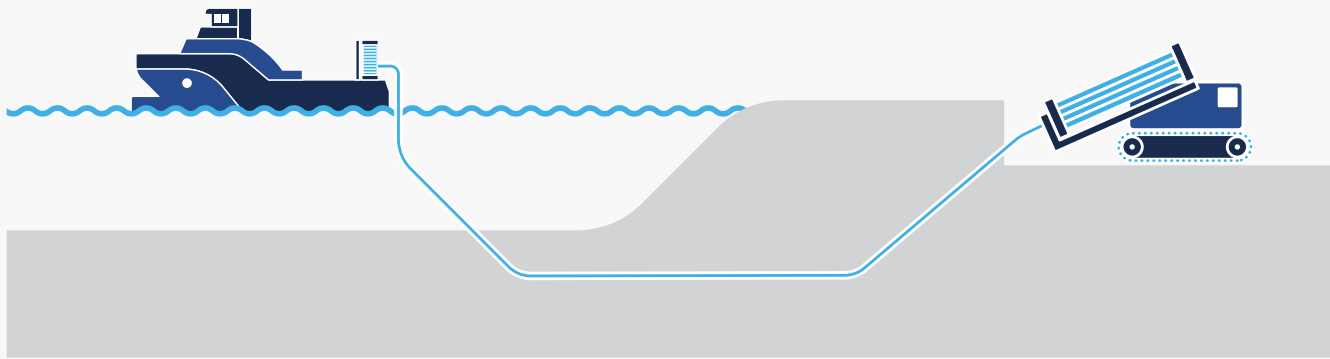


Figure 55. Schematic Showing Hdd Rig and Cable Lay Vessel

Marine and land surveys and should be undertaken as soon as the final cable route is selected. Sub-bottom profiling and grab sampling to investigate the seabed is important for avoiding boulders and identifying rock outcrops for finalizing the near shore route.

Landfall Potential Locations

Several options exist for a submarine cable landfall in Labrador that can reliably bring renewable energy to future offshore developments in the South Labrador Sea. In assessing the landfall options, connecting to existing hydroelectric sources was considered, as there is an abundance of power potential nearby in the Churchill River basin.

The Upper Churchill development is connected to the Muskrat Falls and together offer access to over 6 GW of renewable energy. There is also room for expansion of the hydro developments with the potential 2.2 GW Gull Island project and other smaller hydro projects and plant upgrades, which could produce more renewable energy from the Churchill River basin.

Three preferred landfall locations were recommended, as shown in the figure below.



Figure 56. Labrador Landfalls

Three Labrador regions were selected for futher investigation:

1 Happy Valley Goose Bay (HVGB)

The preferred method for the landfall approach in HVGB is trench burial to at least 1 m, extending perpendicular from the shoreline Beach Manhole (BMH) to at least 10 m water depth, then turning and following the best submarine cable route past the ferry terminal and through Lake Melville, continuing out to the Labrador Sea. The submarine cable route requires approximately 275 km of cable laying between islands, channels, and Lake Melville. The geotechnical conditions appear to be quite favourable for trenching operations, using a combination of excavator dug trench and plow burial.

Refer to the figures below.



Figure 57. HVGB Preferred Landfall Location Looking West



Figure 58. HVGB Preferred landfall location

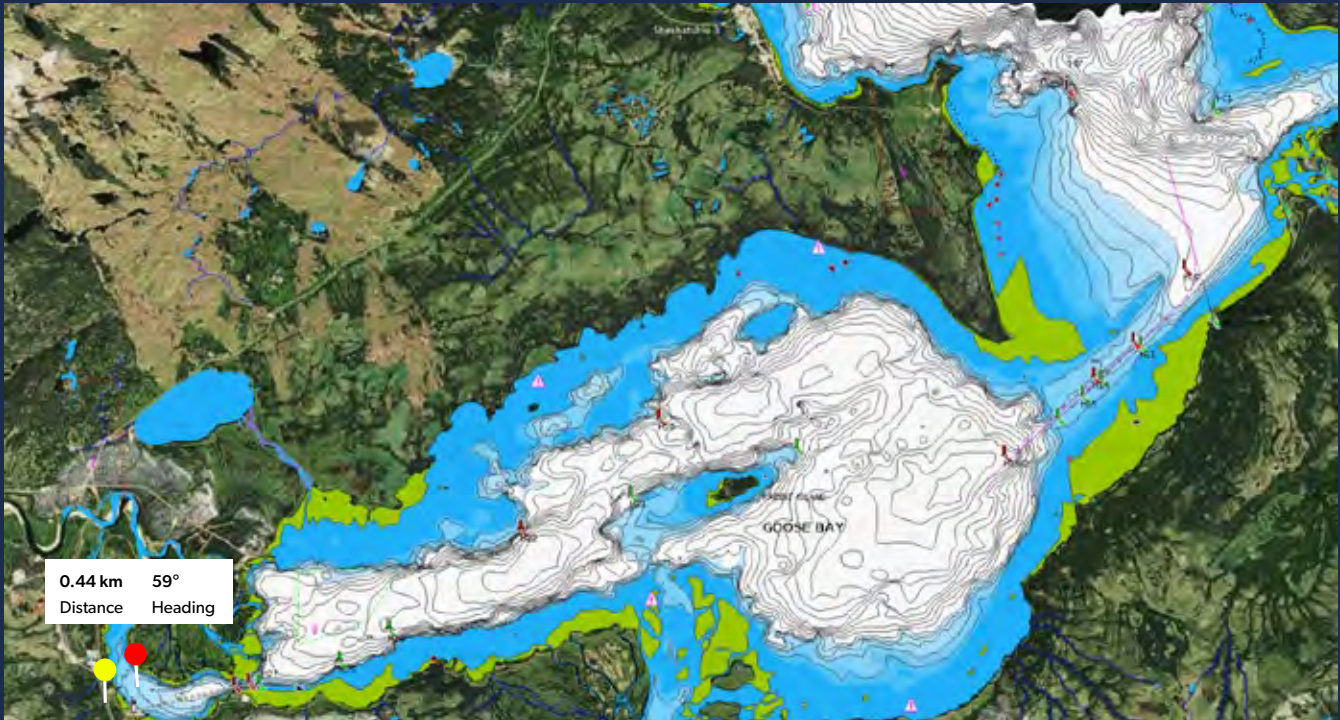


Figure 59. Navionics Bathymetry Between HVGB Preferred Landfall And Sheshatshiu

2 Sheshatshiu

The proposed landfall location is recommended primarily because it is within close proximity to the existing Right of Way (ROW). Less than one kilometer of new ROW would be required from the BMH until the line can run adjacent to the existing ROW, and continue for 38 km to the HVGB electrical substation. The figure below shows the BMH location along with the trench extended from the BMH straight into the lake on a 43 degree heading for approximately 920 m, where water depth is approximately 20 m. From this point, the cable will follow the best submarine cable route.

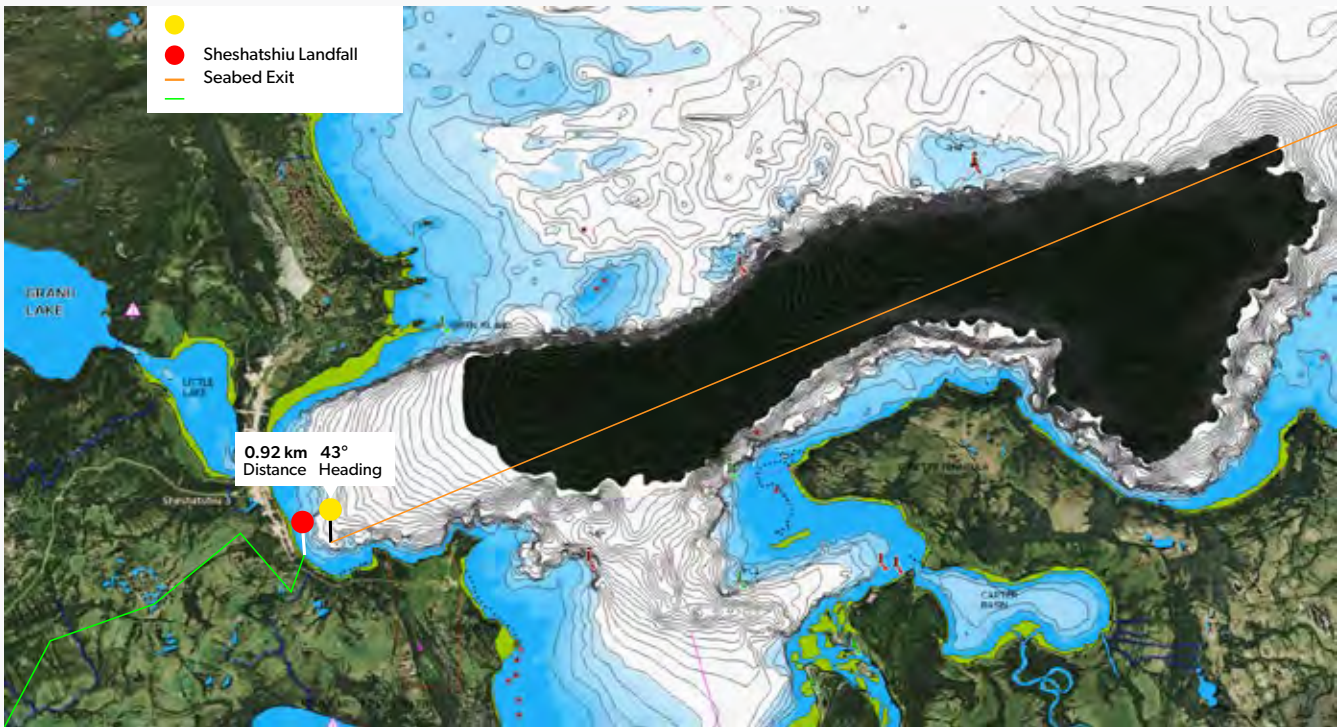


Figure 60. Navionics Showing Water Depths from Sheshatshiu Trenched Landfall

Landfall in Sheshatshiu offers many of the same benefits as HVGB, but requires approximately 30 km more overland transmission line to be constructed, directly offset by 30 km less submarine cable. The Sheshatshiu landfall enables avoidance of the narrow channel approaching Goose Bay required for a HVGB landfall.

The beach consists of a thick layer of fine-grained sands, extending into the lake, offering excellent suitability for trenching operations, as seen in the figure below. Trenching is the recommended method for landfall, with burial of at least 1 m.



Figure 61. Sheshatshiu Sandy Beach for Landfall, Looking East

The cables can continue to be buried in a land trench, extending from the BMH to a suitable location for a transition compound. See the figure below showing the preferred route from the landfall past the community.

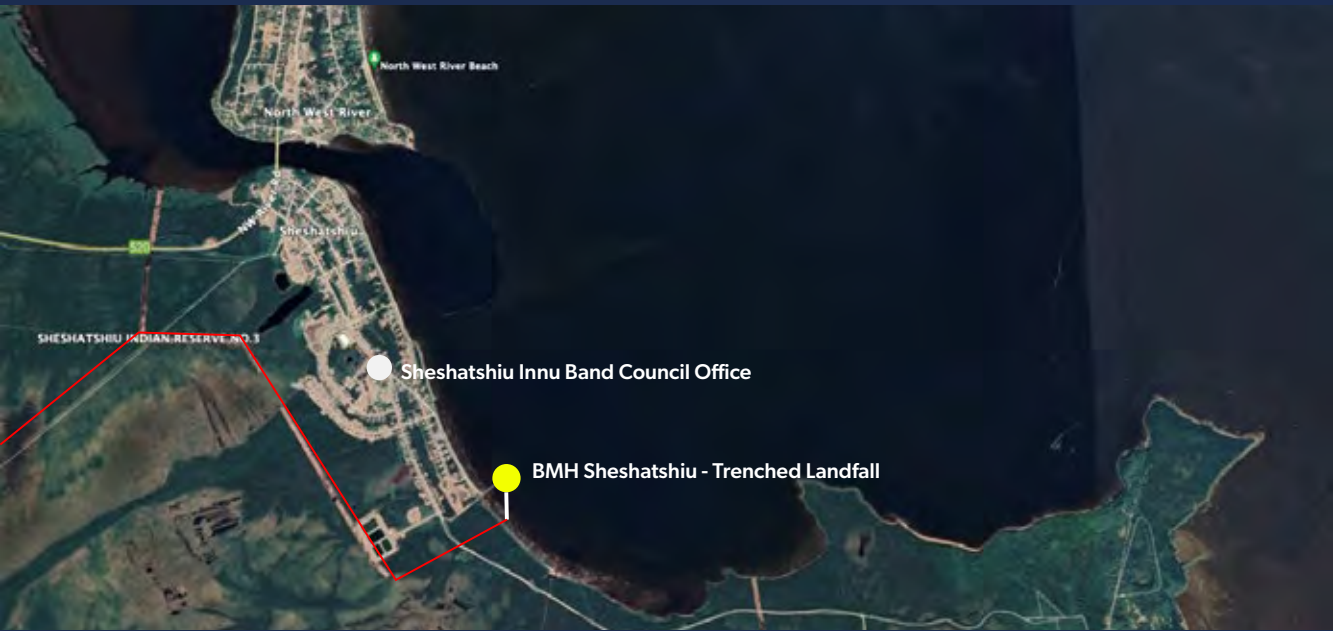


Figure 62. Sheshatshiu Terrestrial Routing from the Preferred Landfall, Adjacent to Existing ROW

3 Cartwright

A Cartwright landfall provides another option for connecting to Labrador that avoids the tight approach from the Atlantic Ocean through Lake Melville. This offers a shorter submarine cable route, but requires a longer overland cable route to make landfall at Cartwright.

A landfall in Cartwright allows for the shortest submarine cable component for connecting the Labrador offshore lease blocks, saving at least 275 km of submarine cable route, over the landfalls identified in Sheshatshiu and HVGB. The recommended method for landfall is HDD, since it is assumed that smaller iceberg interaction near shore will be a significant risk.

Rock outcrops from available imagery, coupled with the seabed bathymetry obtained from Navionics highlight a suitable landfall BMH location with a 620 m drilled bore to achieve 30 m water depth, as shown in the figure below.

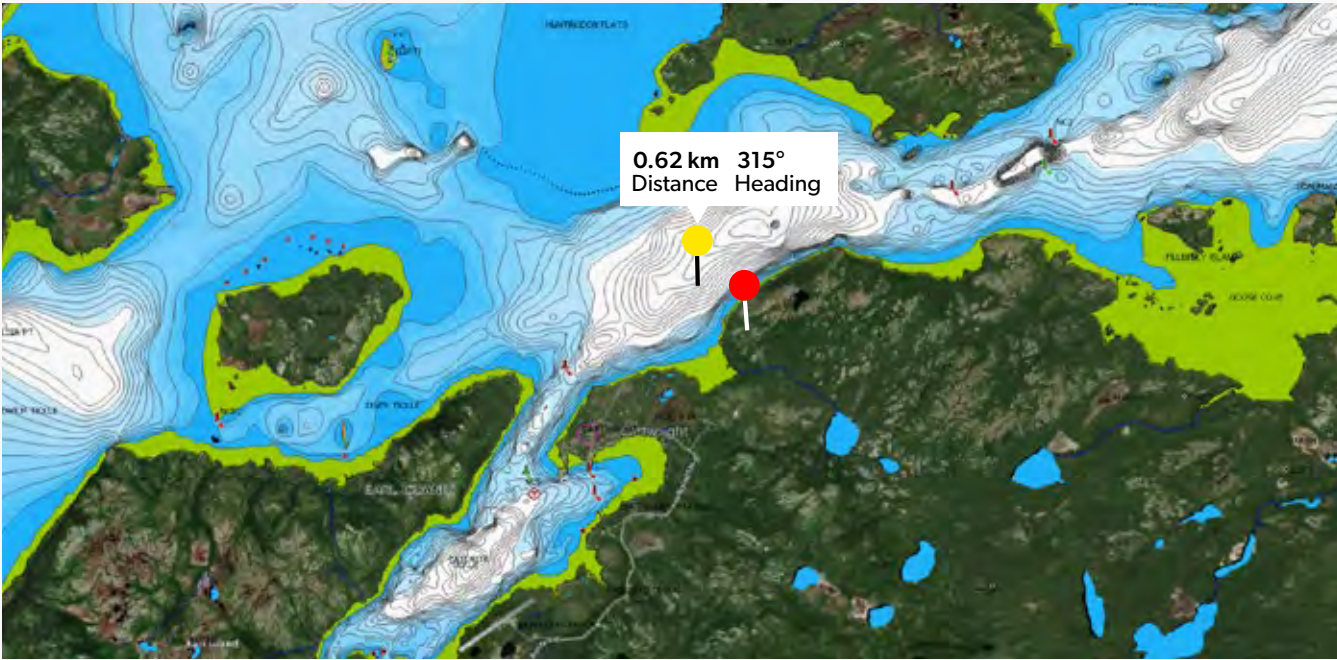


Figure 63. Cartwright Landfall with Navionics Bathymetry Showing the Water Depths

A direct line to the switchyard at Muskrat Falls would be the preferred transmission line route over the HVGB electrical substation option.

Newfoundland Landfall Potential Locations

Newfoundland landfalls were selected for assessment based on their proximity to the existing electrical infrastructure that could be capable of providing renewable energy to the Ephesus I and Ephesus II offshore developments. The figure below shows these landfalls in relation to the future offshore developments.

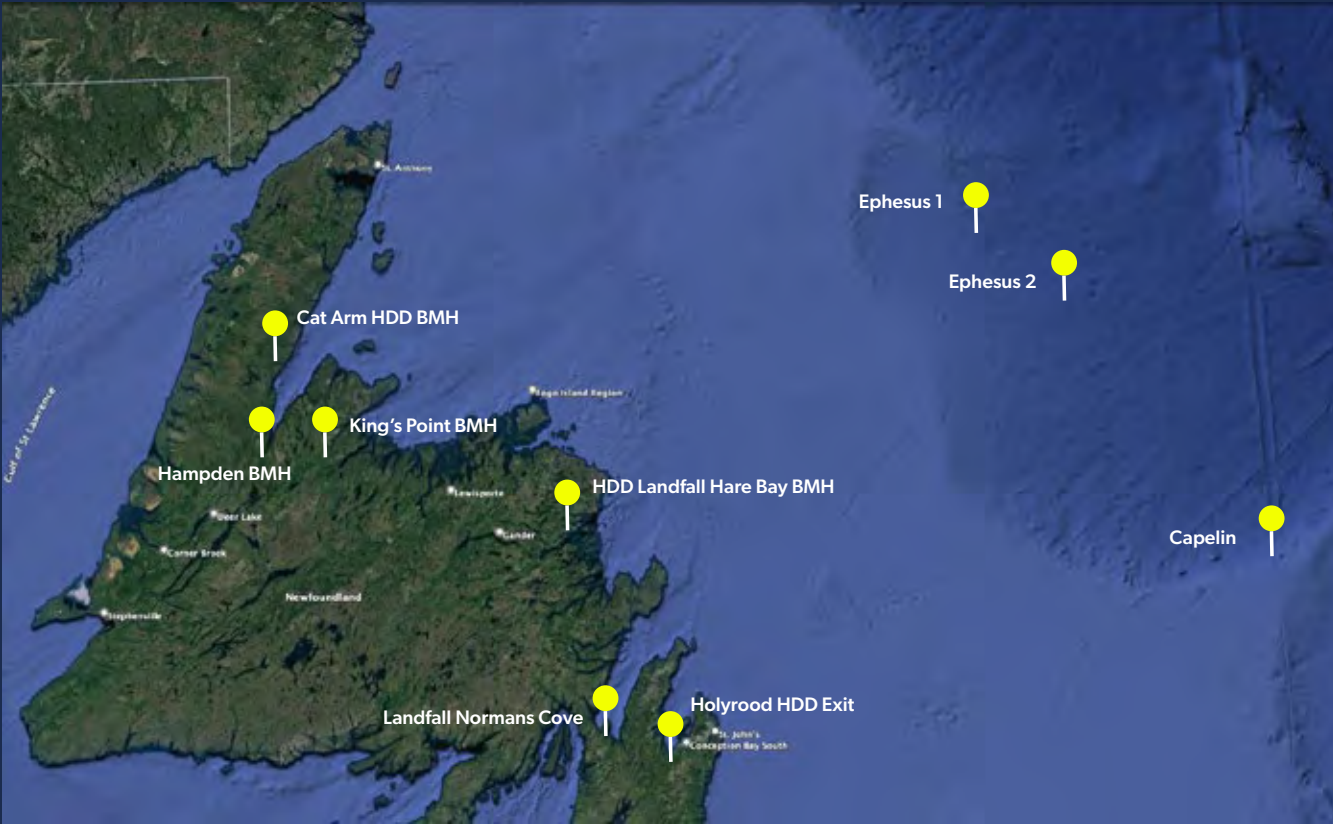


Figure 64. Overview of Newfoundland Landfall Assessments

Six Newfoundland landfall regions were selected for further investigation:

1 Holyrood

Holyrood was selected for landfall assessment based on its proximity to the Soldiers Pond switchyard, which converts HVDC power from Muskrat Falls to HVAC, which is then distributed amongst a number of HVAC lines to the Avalon Peninsula grid. There is currently a ROW with powerlines from the switchyard to the Holyrood thermal generating station on the shore of Conception Bay. This is the shortest overland transmission route between Soldiers Pond and the ocean.

Approximately 10 km of new transmission line is required to connect the Holyrood BMH to the grid at the Soldiers Pond Converter Station, as shown in the figure below.

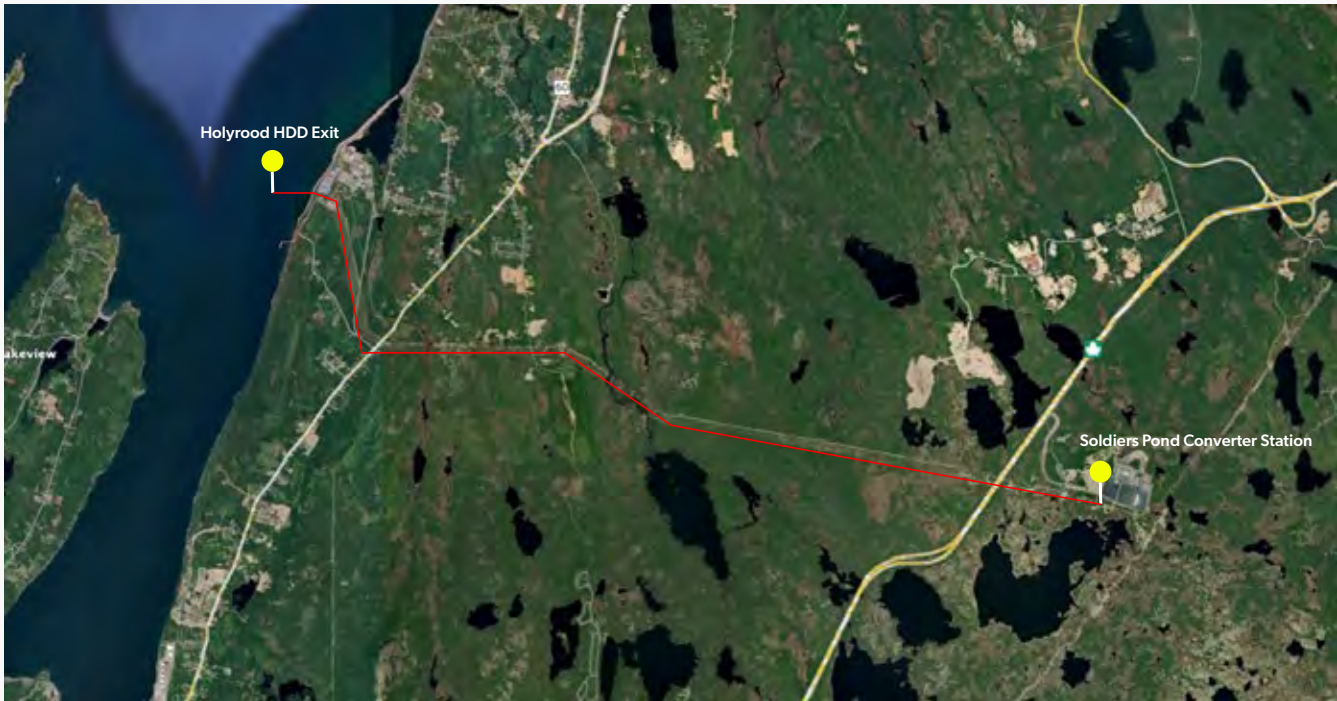


Figure 65. New Overland Transmission Route Adjacent to Existing ROW

The preferred landfall for Holyrood was identified as a location that would require minimal additional effort, utilizing HDD from BMH to 600 m horizontal displacement to the seabed exit, as seen in the image below. This exit location was selected as it avoids the steep sloping seabed at exit, the cable placement is between 10 m and 70 m water depth and it provides adequate cover depth to fully protect the cable at the shoreline. Close collaboration with Nalcor will be required to finalize the landfall location, along with ROW and interconnections at Soldiers Pond switchyard.

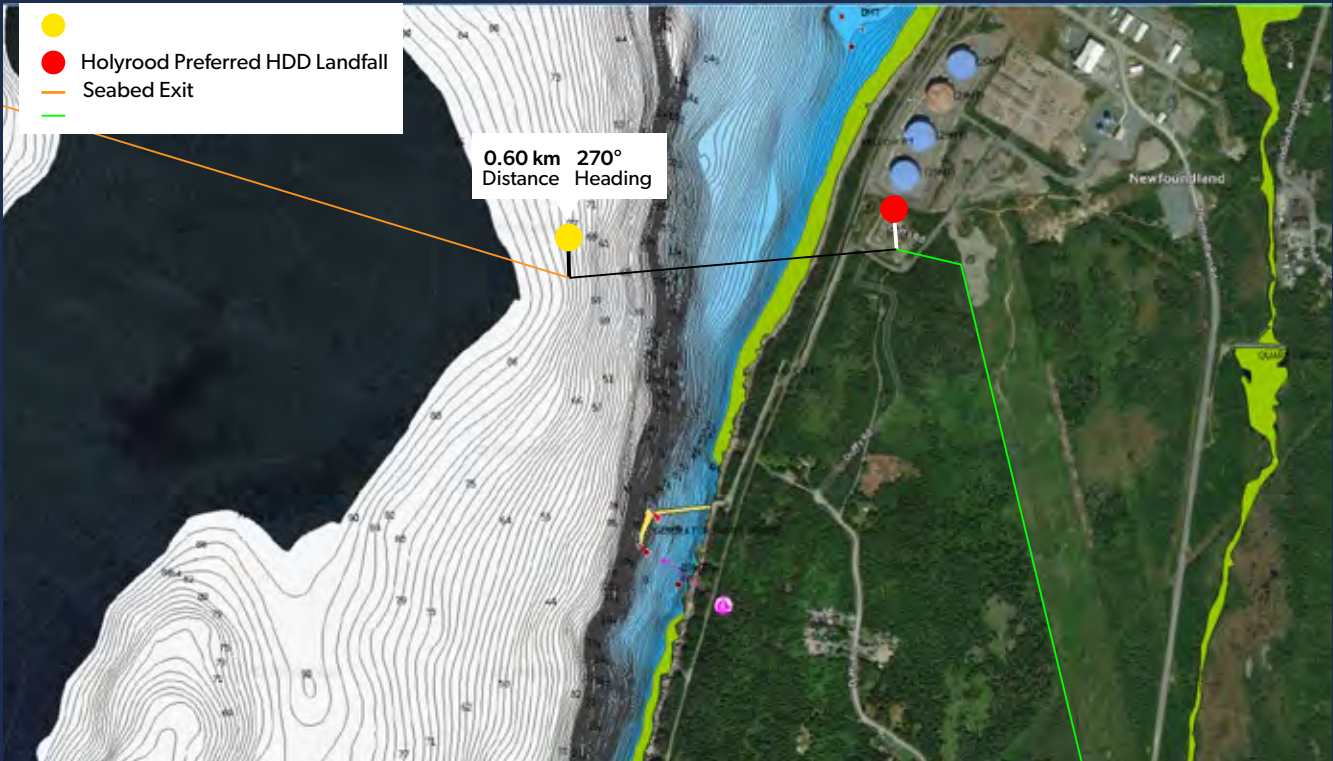


Figure 66. Preferred Holyrood Landfall

2) Chapel Arm - Norman's Cove

Chapel Arm was selected as a potential landfall since it is where Nalcor's Western Avalon Terminal Station is located with 230 kV service, and it has a favourable submarine route for the cable through Trinity Bay. The preferred landfall approach was found further up the coast at Norman's Cove, as shown in the below. HDD is recommended from this location out to 100 m water depth. The exit location and seabed bathymetry from Navionics is shown below. Approximately 5.6 km of new over-land transmission would be needed to connect the landfall to the Western Avalon Terminal Station.



Figure 67. Norman's Cove Preferred Landfall, Panoramic Photo

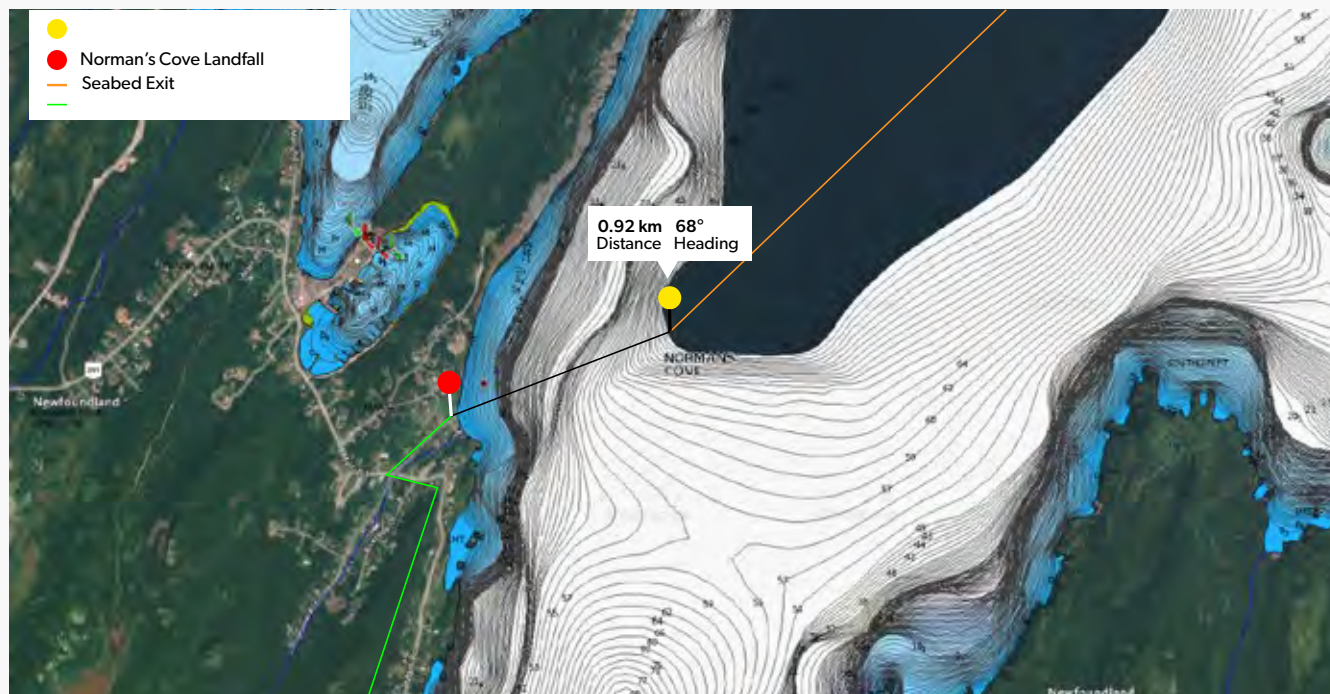


Figure 68. Norman's Cove Preferred Landfall

3 Hare Bay

Hare Bay landfall was considered as the closest landfall location to Ephesus I and II, with a well protected submarine approach. The preferred landfall BMH is as shown in the figure below. The landfall BMH is approximately 1.5 km from Hare Bay and would require a new road to be constructed, as well as a pad for HDD operations.

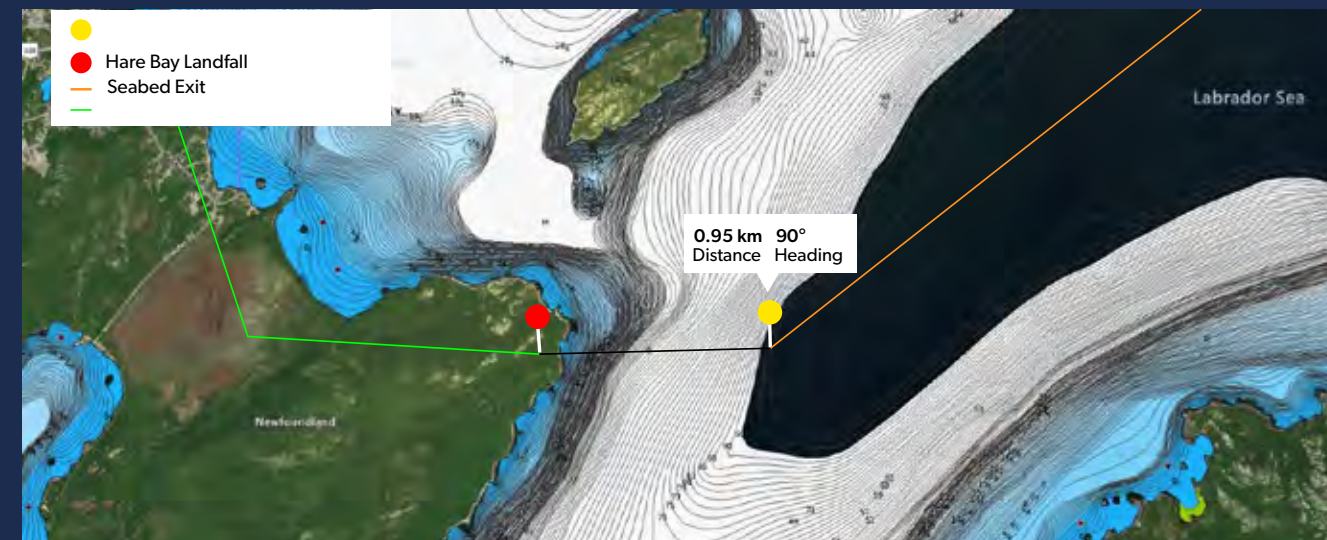


Figure 69. HDD Landfall in Hare Bay

The recommended method of landfall is HDD with an estimated 950 m bore enabling a subsea exit location in 100 m water depth. This exit location offers significant protection from any grounding icebergs that could make their way through the deep channel that is fairly narrow for over 30 km before opening into the greater Bonavista Bay. This landfall would require approximately 55 km of new transmission line from Hare Bay to the Gander Substation, mainly adjacent to existing ROW, as indicated in the figure below.

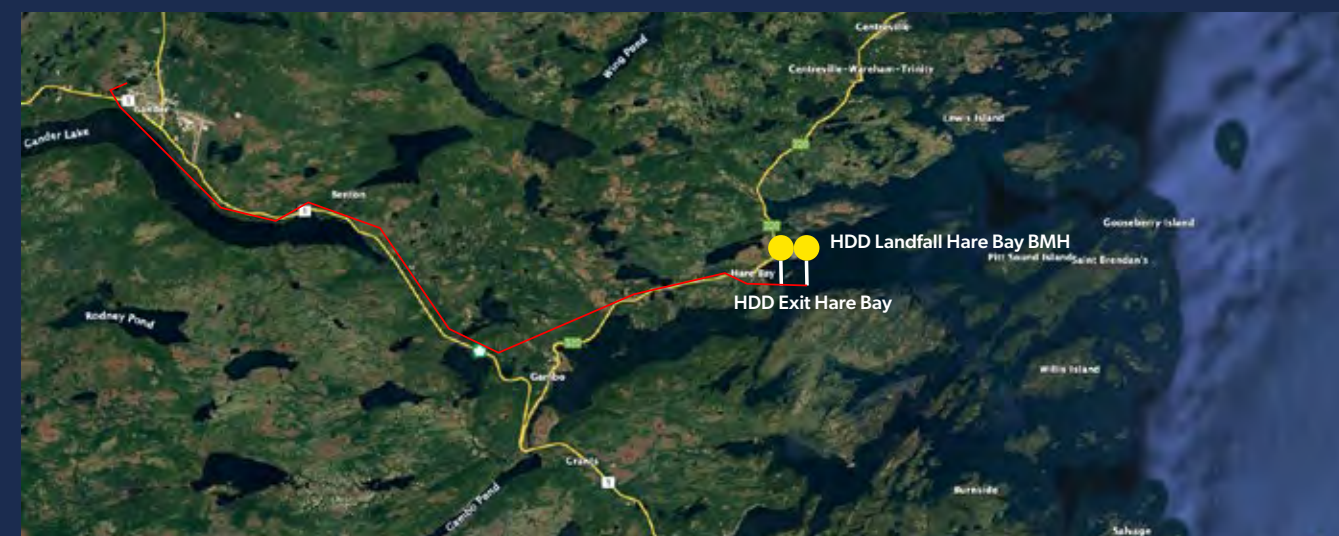


Figure 70. Terrestrial Route from Hare Bay to Gander Substation, Approx. 55 Km

4 King's Point

The recommended landfall BMH for King's Point is shown in the figure below. HDD is the recommended methodology, with a 600 m drill to a water depth of 90 m, at about 90° heading from the BMH to the submarine exit.

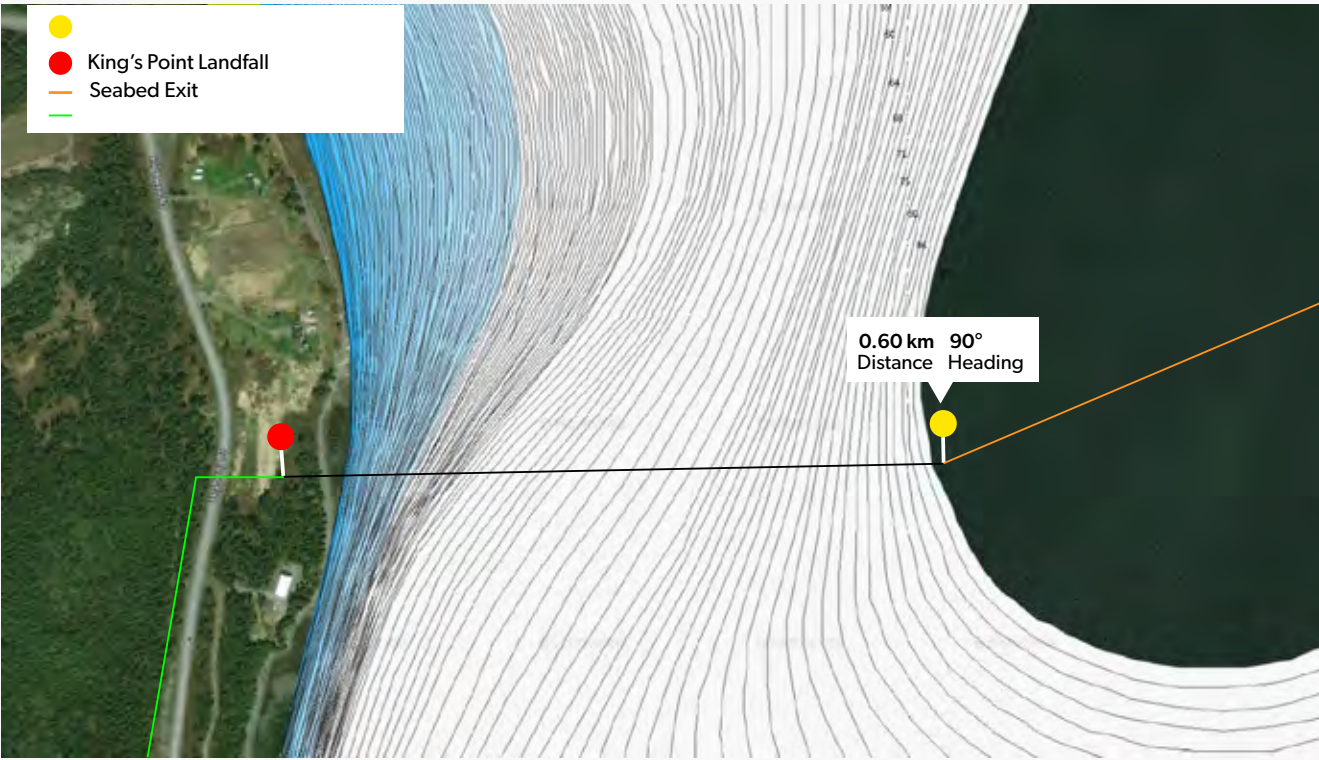


Figure 71. Kings Point HDD Landfall with Navionics Showing Water Depth 100 m at Seabed Exit

King's Point was selected because of the deep water protection offered in Green Bay. The narrow channel through the bay offers shielding from icebergs with water depths of over 200 m for over 10 km before reducing depth toward the landfall exit at 90 m water depth. The figure below shows the Navionics imagery for Green Bay, with the dark shaded water over 100 m water depth.



Figure 72. Green Bay Water Depths from Navionics Approaching King's Point Landfall

New overland transmission would need to be constructed. The closest existing grid connection point is at the Springdale Switchyard, approximately 20 km from the King's Point preferred landfall location, mainly following existing ROWs.

5 Hampden

Hampden is located at the bottom of White Bay, at the base of the Great Northern Peninsula. It is a deep bay offering some protection from icebergs due to the many grounding opportunities for icebergs prior to approaching the landfall. Hampden is the closest point to Deer Lake for a submarine cable to make landfall, at approximately 65 km away. This allows for an efficient tie into the grid for the existing hydroelectricity.

Recommended method for the landfall is a trench perpendicular to the shore with a BMH, as shown in the figure below. This is in the same area as the CANTAT-1 (Canada Trans Atlantic Telecommunications), CANTAT-2, and ICECAN cables landfalls. Given the successful installation of other cables buried in the area, the trenched landfall approach is assumed to be the best for the area. The recommended trench would be dug perpendicular to the road for at least 250 m, then turning and following the best submarine cable route through White Bay.



Figure 73. Hampden Landfall with Existing Submarine Telecommunications Cables

6 Cat Arm

The Cat Arm landfall was selected for assessment because it is an excellent opportunity to connect directly to the switchyard at the current Cat Arm hydro station, less than three kilometers away. The Cat Arm generating station currently transmits power along a 230 kV HVAC powerline directly to a switchyard in Deer Lake. The recommended landfall method for Cat Arm is HDD.

The best location identified requires a long drill at nearly 2,600 m, but this will enable it to reach 100 m water depth and effectively protect the cable, as shown in the figure below. This HDD operation will require a larger drilling rig spread than the shorter HDD drills noted in the other landfall assessments. A suitable rig to handle the torque and pullback contingencies will require the largest HDD rigs currently available, with ability to pump upwards of 4 m³/min from the mud pumps. A good water source nearby will be critical for continuing uninterrupted drilling operations and avoiding transporting water to the HDD location.

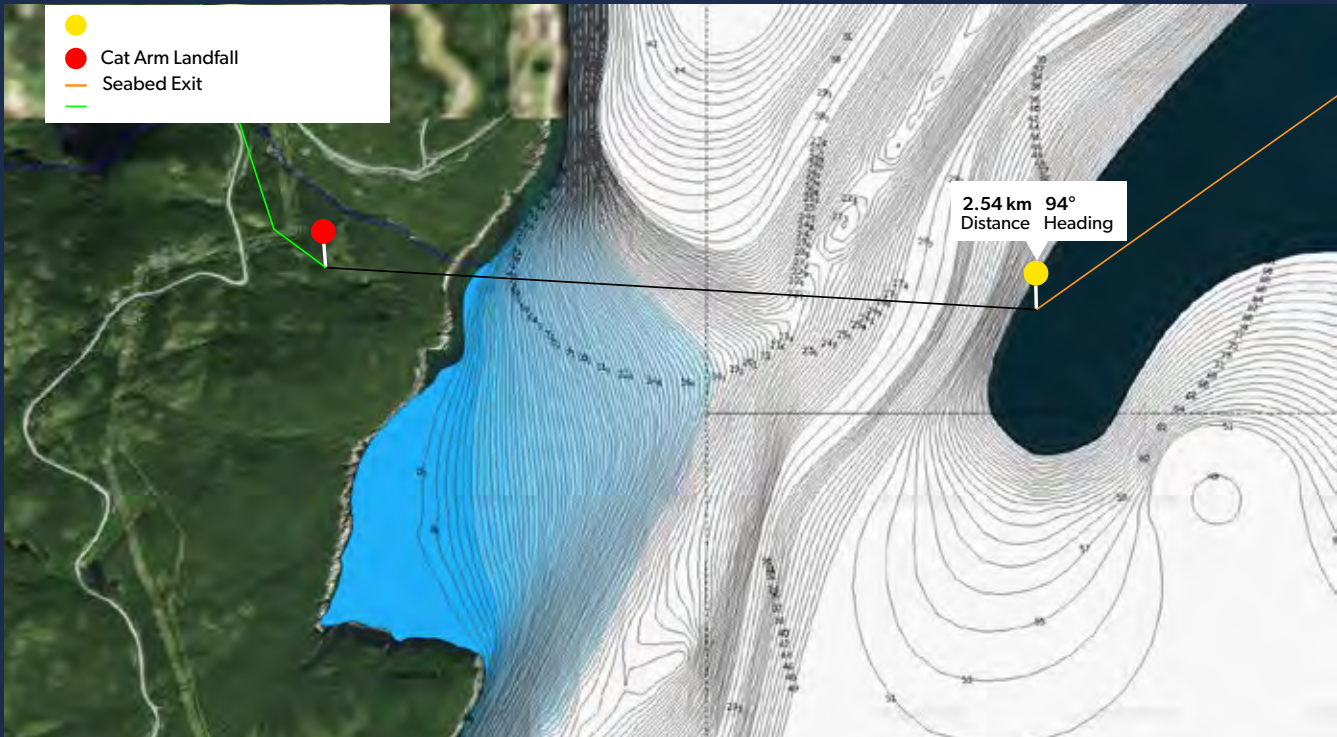


Figure 74. Cat Arm HDD Landfall

The main features of each landfall location are summarized in the table below:

Landfall Location	Nearest Terminal Station	Approx. Overland Transmission Length (km)	Recommend-ed Landfall Method (HDD or Trenched)	Drilled Bore/ Trenched Length (m)	Approx. Water Depth at Seabed Exit (m)
Happy Valley Goose Bay	HVGB Substation	9	Trenched	430	10*
Sheshatshiu	HVGB Substation	38	Trenched	920	20*
Cartwright	HVGB Substation	280**	HDD	620	30
Holyrood	Soldiers Pond	10	HDD	600	70
Norman’s Cove	Western Avalon TS	6	HDD	1,000	100
Hare Bay	Gander	55	HDD	950	100
King’s Point - Green Bay	Springdale TS	20	HDD	600	90
Hampden - White Bay	Deer Lake	65	Trenched	250	100
Cat Arm - White Bay	Cat Arm	3	HDD	2,600	100

Table 25. Landfall Location Main Features

* Trenched burial of subsea cable likely recommended beyond the landfall
** Overland Transmission offsets the near equivalent of submarine cable

Straight line distances from the landfall locations to each of the offshore development location is summarized in the table below:

Landfall Location	Straight Line Distances from Landfall locations (km)				
	Ephesus 1	Ephesus 2	Capelin	South Labrador 1	South Labrador 2
Happy Valley Goose Bay	810	870	1,080	425	525
Sheshatshiu	800	860	1,070	400	500
Cartwright	620	685	910	255	300
Holyrood	432	417	444	945	830
Norman’s Cove	450	440	475	925	820
Hare Bay	373	385	495	780	680
King’s Point - Green Bay	485	520	665	695	630
Hampden - White Bay	535	565	710	700	650
Cat Arm - White Bay	520	557	715	650	605

Table 26. Straight Line Distances From the Landfall Locations to Each of the Offshore Development Locations

Summary
There are many locations in Newfoundland and Labrador where cable landings would be technically possible.



7.4 Iceberg Interaction Cable Risk Analysis

Electrification of the offshore platforms requires laying of the power cables on the seabed.

In ice prone areas, scouring icebergs may pose a risk to the integrity of the subsea cables laid on, or trenched into, the seabed. The risk of iceberg keel interaction with power cables laying from various landfalls to offshore Labrador and the West Orphan Basin was investigated and the objectives were to:

- Calculate iceberg contact rates along proposed subsea cable routes to be used for providing power to offshore facilities;
- Perform numerical and physical modelling to assess whether iceberg contact events should automatically be treated as failure of the cables (loss of functionality); and
- Combine the annual iceberg contact rate estimates and probability of cable failure given contact to estimate annual failure rates for cables due to iceberg interaction.

All of the offshore facilities are in deep water (>1,000 m) far exceeding any known iceberg keel depth in the region. Power cables are not at risk from iceberg interaction at these locations, except possibly when rising from the seafloor to connect to the facilities. Iceberg contact is primarily a concern in shallower water near the cable landfall. In many cases, sheltered channels and deep bays provide protection from icebergs, and most of the landfall locations shown in the map below were selected to take advantage of these natural features. In particular, the inner Labrador Shelf has a multitude of channels which can be utilized in this manner (see figure below). These features are often not apparent in navigational charts or in available bathymetry data sets and require multi-beam surveys to be properly delineated.

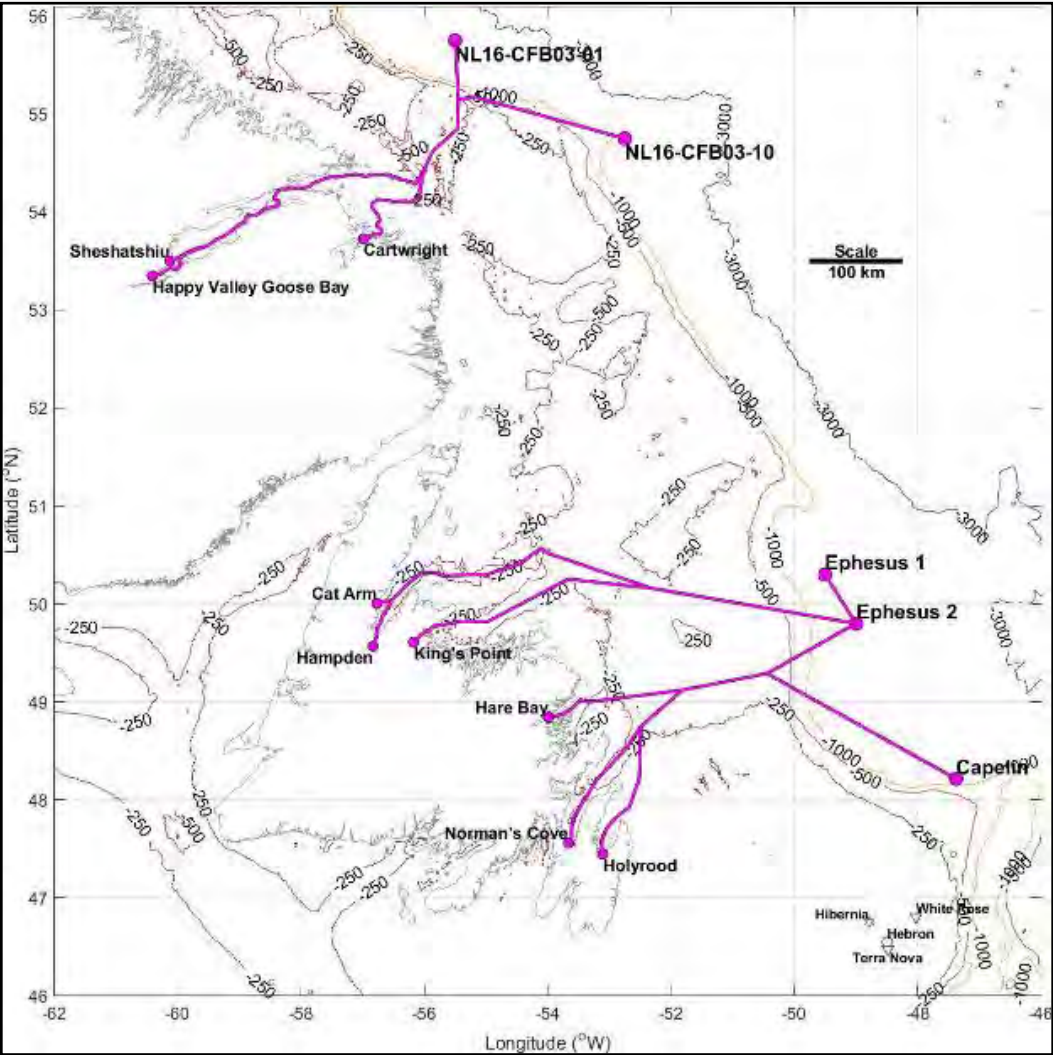


Figure 75. Cable Routes Considered in Iceberg Risk Analyses

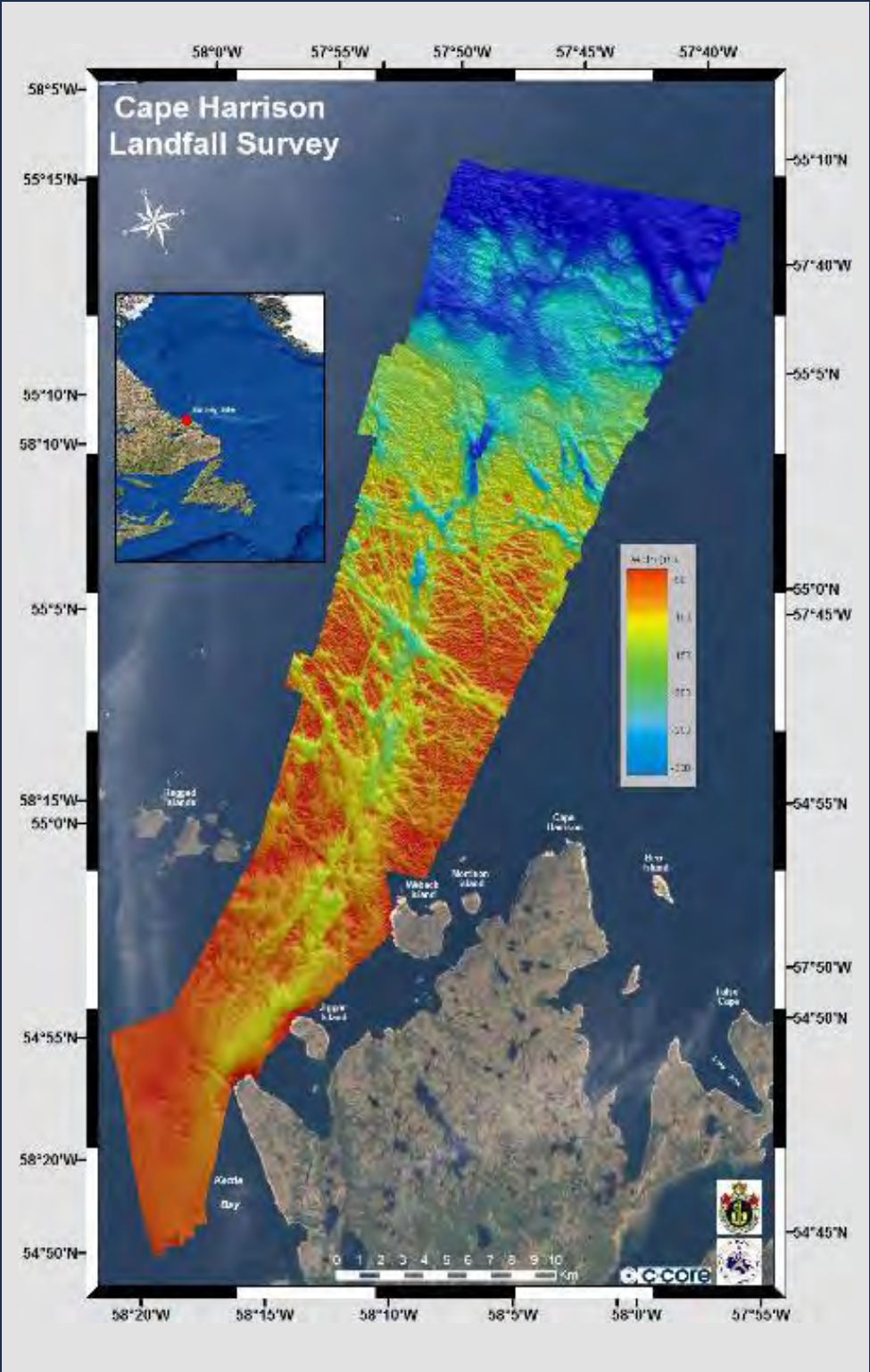


Figure 76. Multibeam Survey Showing Sheltered Channel at Cape Harrison (King and Sonnichsen, 2010)

Iceberg Contact Rate Analysis

Cables laid on the seabed are at risk from free-floating or gouging (scouring) icebergs (see figure below). Cables trenched into the seabed are only at risk due to gouging icebergs. If trenched, the risk to the cable will be a function of burial depth and the gouge depth distribution. Even minimal burial, with the crown of the cable just below the mudline, offers considerable risk reduction from placement on the seabed. In the analysis it is first assumed that the cable is laid on the seabed (except for the near shore approaches), then the case of minimal burial is considered and, if warranted, additional burial is considered.

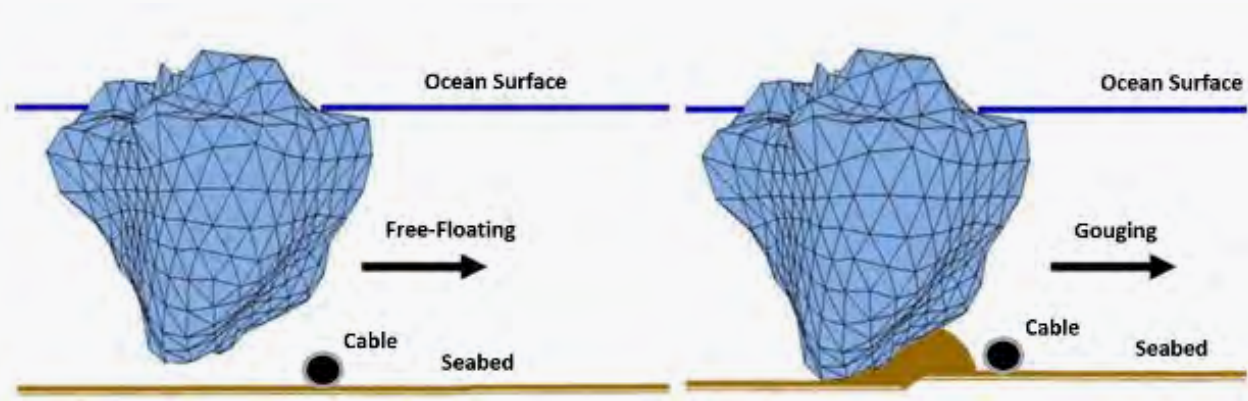


Figure 77. Iceberg Interaction with a Cable on the Seabed

There are two types of models that can be used to estimate iceberg contact rates with a cable laid on, or trenched into, the seabed:

- The Monte Carlo drift-based iceberg contact model that can account for local variations in bathymetry. It simulates distribution of iceberg groundings and incidences where iceberg keels are close enough to the seabed to contact subsea pipelines, cables and facilities (King, 2012; King et al., 2016). Refer to the figures below for modelled iceberg grounding rates.

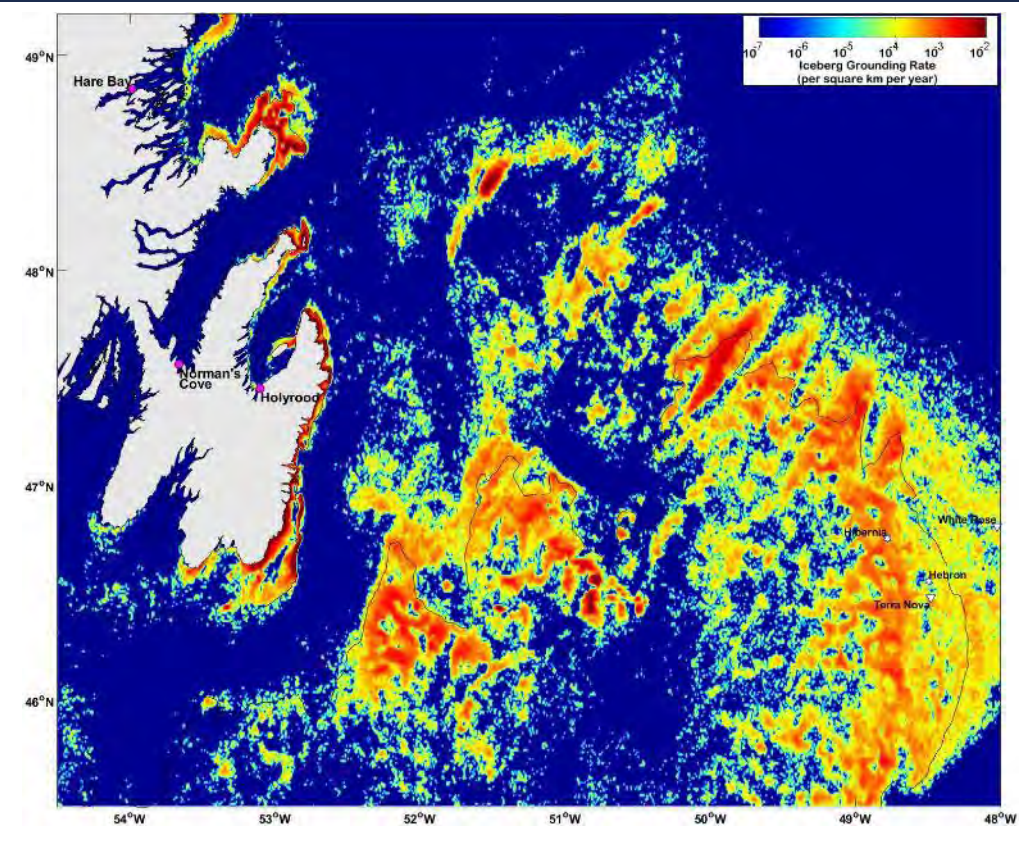


Figure 78. Modelled Iceberg Grounding Rates for the Grand Banks

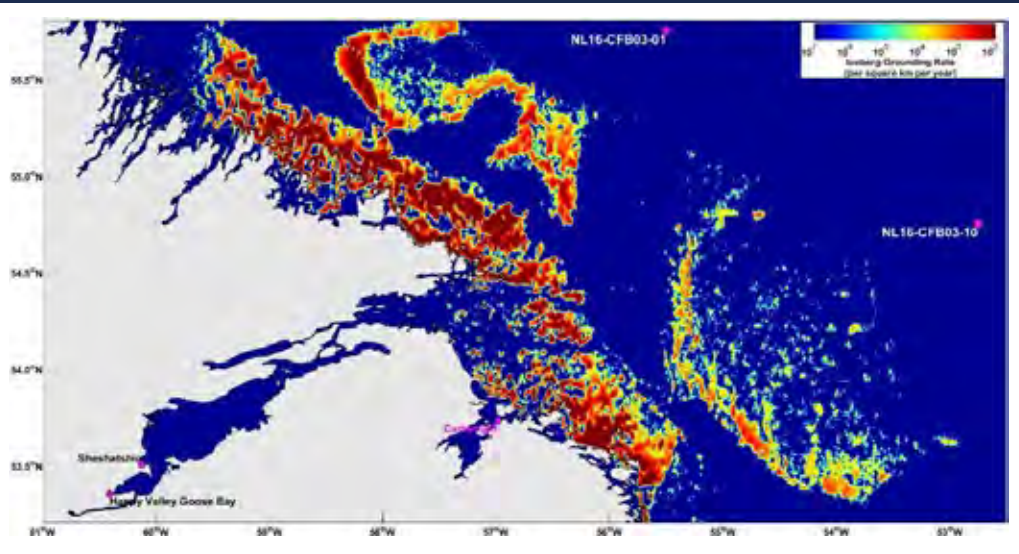


Figure 79. Modelled Iceberg Grounding Rates for Southern Labrador

- The Geometric Contact Model is a simple geometric model that uses the iceberg length draft ratio to predict the frequency of icebergs close to the seabed and grounding on the seabed.

Proportion of Iceberg Keels Contacting the Seabed or Cable

In areas covered by the Monte Carlo contact model the proportion of iceberg keels in the meter of water column immediately above the seabed is a model output. In areas where the Geometric Model is used it can be calculated using the iceberg waterline length distribution and the iceberg length/draft relationship. A comparison of iceberg waterline length and draft data is shown in the figure below.

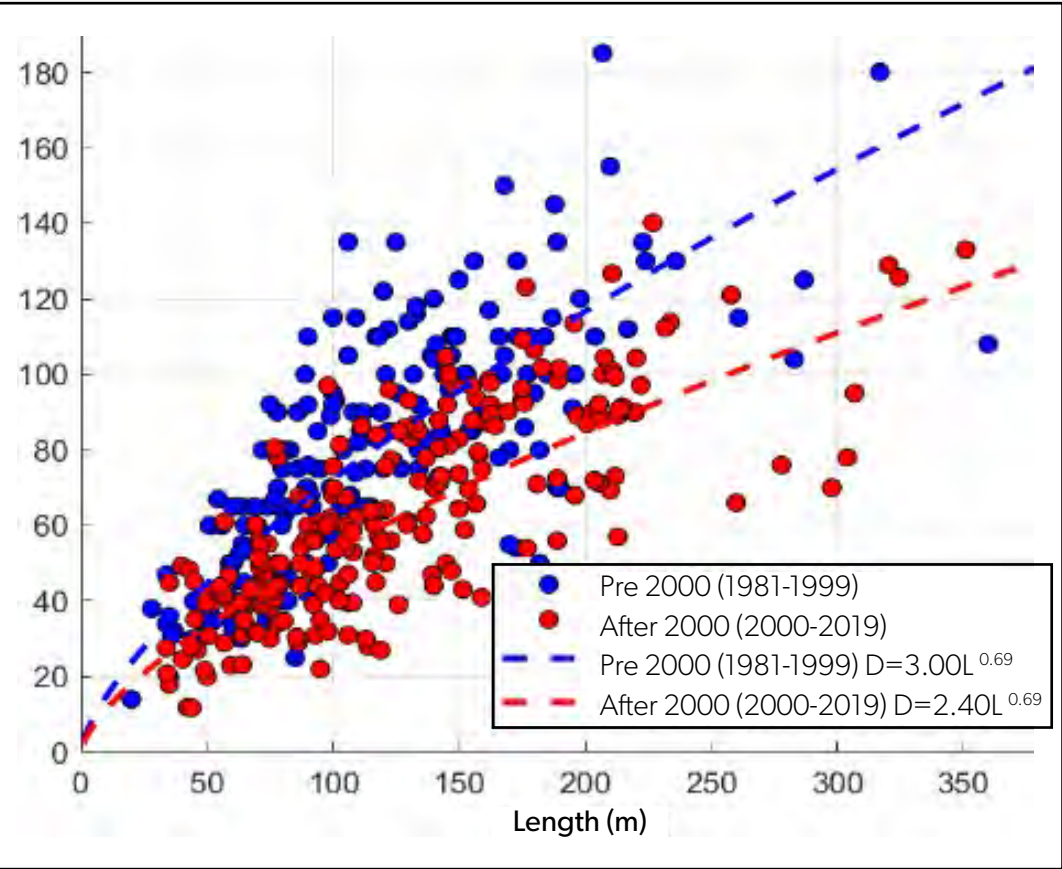


Figure 80. Iceberg Length/Draft Distribution, Pre and Post-2000 (Bruce et al., 2021)

The updated iceberg waterline length distribution and length/draft relationship can be used to derive the proportion of free-floating iceberg keels 1 m above the seabed for a range of water depths, as shown in the figure below.

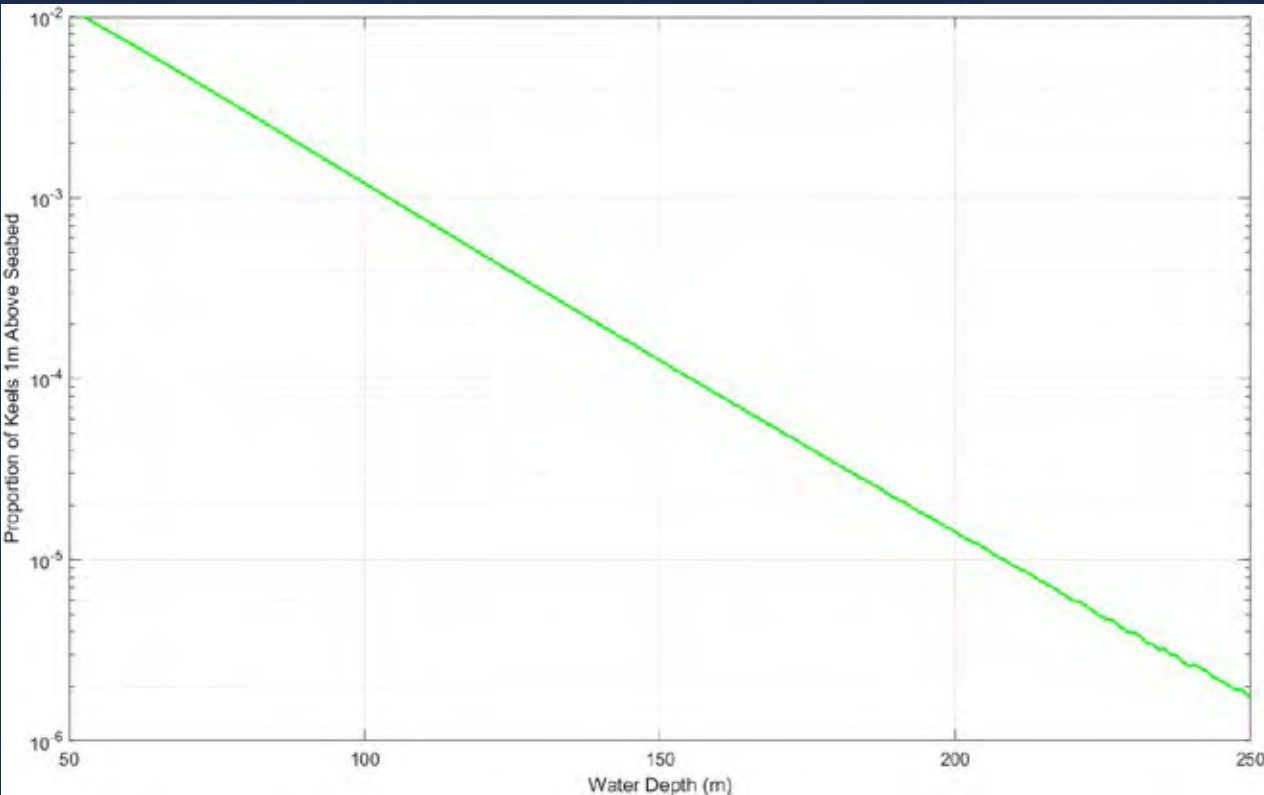


Figure 81. Proportion of Iceberg Keels 1 m above the Seabed

Iceberg Frequency

Iceberg frequency, or average areal iceberg density, is the average number of icebergs per unit area which would be determined over an extended period (e.g. years to decades) using numerous repeat surveys. Iceberg areal densities calculated for selected grid cells (refer to the map below) are listed in the table below.

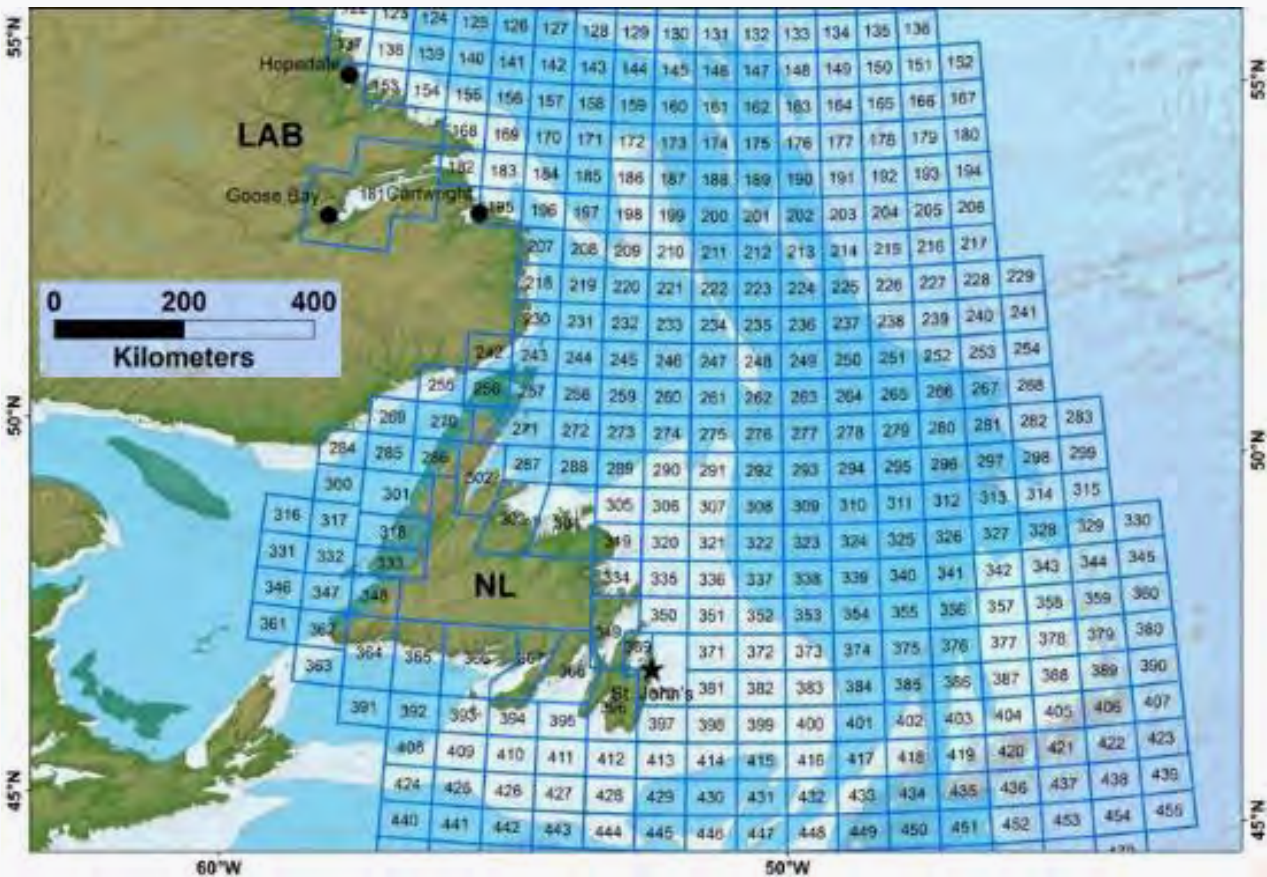


Figure 82. Grid Cell Locations (from C-CORE, 2017)

Location	Cell Number (C-CORE, 2017)	Average Annual Iceberg Density (km ⁻²)
Conception Bay	369	8.4×10 ⁻⁵
Trinity Bay	349	7.0×10 ⁻⁵
Outside Trinity/Conception Bay	350	1.1×10 ⁻⁴
Bonavista Bay	334	2.0×10 ⁻⁴
Bonavista North	319	4.7×10 ⁻⁴
Green Bay	303	3.3×10 ⁻⁴
White Bay	302	2.0×10 ⁻⁴
Cartwright	195	6.9×10 ⁻⁴
Groswater Bay	182	4.7×10 ⁻⁴
Cartwright Saddle	183	1.8×10 ⁻³

Table 27. Annual Iceberg Density Values from Nalcor Metocean Study (C-CORE, 2017)

Furrow and Pit Dimensions

Iceberg keel contacts with the seabed can leave scours (or gouges) which can be classified as furrows or pits, with furrows being longer linear features and pits being circular or oval features (refer to the figure below). Scour dimensions used in the analysis is based on data collected in the vicinity of the Makkovik Bank (King and Sonnichsen, 2014), as this data covers a greater water depth range and is considered more applicable.

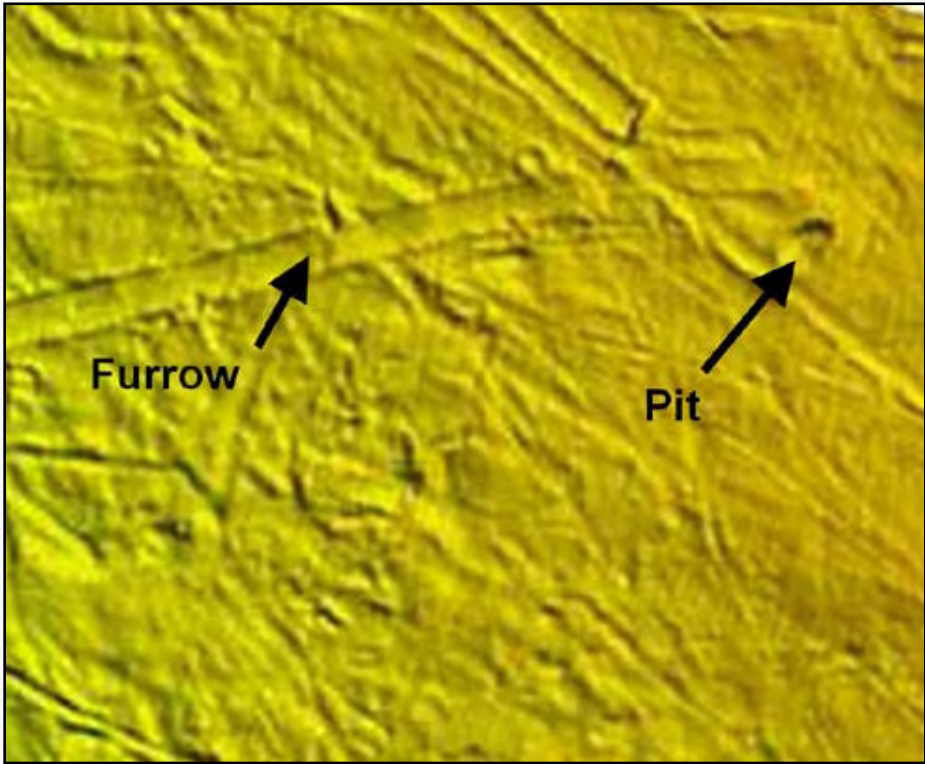


Figure 83. Furrows and Pits Formed from Iceberg Interaction with the Seabed (Ralph, King and Zakeri, 2011)

Iceberg Drift Speed

Mean iceberg drift speed is based on trajectory data, when available, and typical values for iceberg drift are 0.31 m/s (Grand Banks), 0.24 m/s (Makkovik Bank) and 0.22 m/s (Saglek Bank). Icebergs near shore (i.e. near cable landfalls) are typically grounded and can remain grounded for extended periods of time, and mean drift speeds may be reduced on the order of 90% (or more) compared with offshore drift speeds.

Seabed Slope

Seabed slope is based on bathymetric data and is a simple gradient based on change in water depth over distance. For applications to the cable risk, seabed slope is calculated directly from the seabed slope along the cable route, which almost always runs directly upslope/downslope (C-CORE, 2020a).

Route Analysis

The table below gives locations of the various cable landfalls. It is assumed that the cables are protected from ice interaction and other hazards for a limited distance from shore using directional drilling or other method (i.e. rock berm, etc.), so for risk analysis purposes the iceberg analysis begins at the submarine exit location.

Location	Beach Manhole		Submarine HDD Exit /Shore Protection	
	Latitude (°N)	Longitude (°W)	Latitude (°N)	Longitude (°W)
Sheshatshiu	53.50148	60.12472	53.50763	60.11693
Happy Valley Goose Bay	53.34918	60.41032	53.35118	60.40453
Cartwright	53.72613	56.98485	53.73028	56.99093
Cat Arm – White Bay	50.00572	56.76875	50.00337	56.73302
Hampden – White Bay	49.56835	56.83110	49.56907	56.83423
King’s Point – Green Bay	49.60942	56.17575	49.60995	56.17160
Hare Bay	48.84288	53.98305	48.84240	53.97012
Norman’s Cove	47.56152	53.66160	47.56472	53.64908
Holyrood	47.44833	53.10155	47.44830	53.10952

Table 28. Cable Route Landfall Locations

The figure below shows cable route endpoints, as well as areas covered by the Monte Carlo iceberg contact model. In areas not covered by either of the Monte Carlo models the Geometric Model was used in the risk analysis. Cable routes in deeper water are irrelevant in terms of iceberg risk and were not considered in detail.

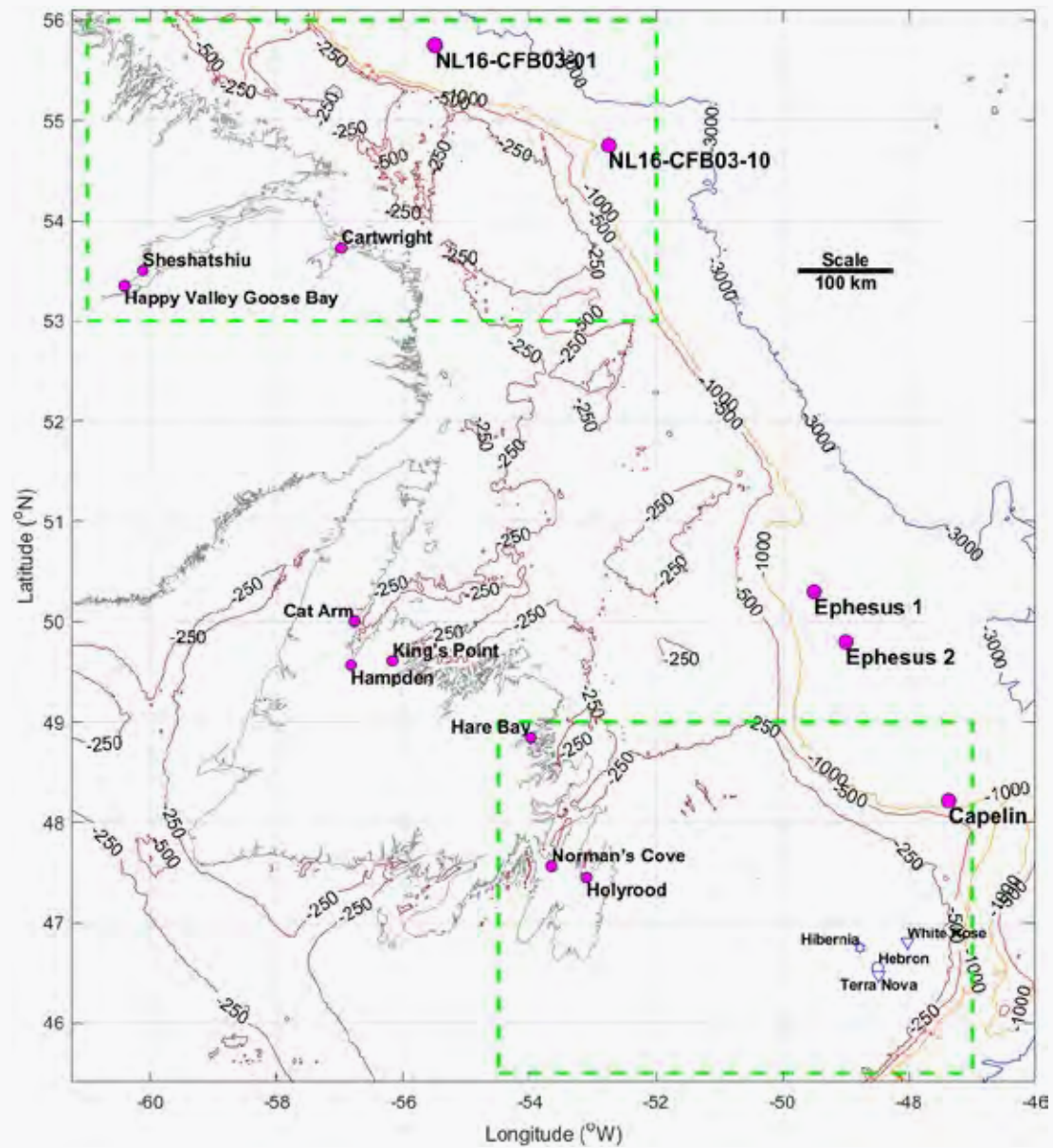


Figure 84. Potential Cable Landfall Locations, Offshore Locations of Interest

Sheshatshiu and Goose Bay

These two sites can be considered together since they would use almost the same cable route, except for the final landfall locations. The cable routes pass through Lake Melville, where iceberg presence is considered negligible, into Groswater Bay where a sheltered channel provides protection against icebergs, and then into the Cartwright Saddle where the water is sufficiently deep to provide protection against iceberg interaction. The figures below show routes running from Sheshatshiu and Happy Valley Goose Bay out to the NL16-CFB03-01 and NL16-CFB03-10.

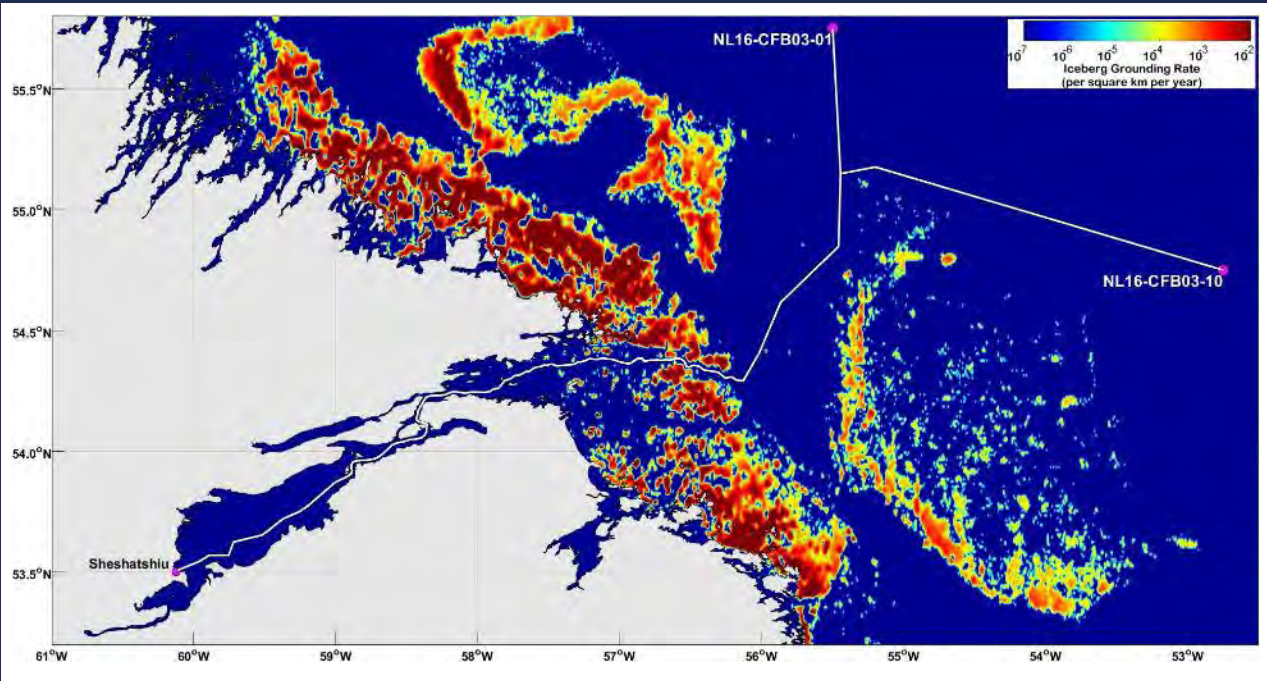


Figure 85. Proposed Cable Routes from Sheshatshiu to Offshore Labrador

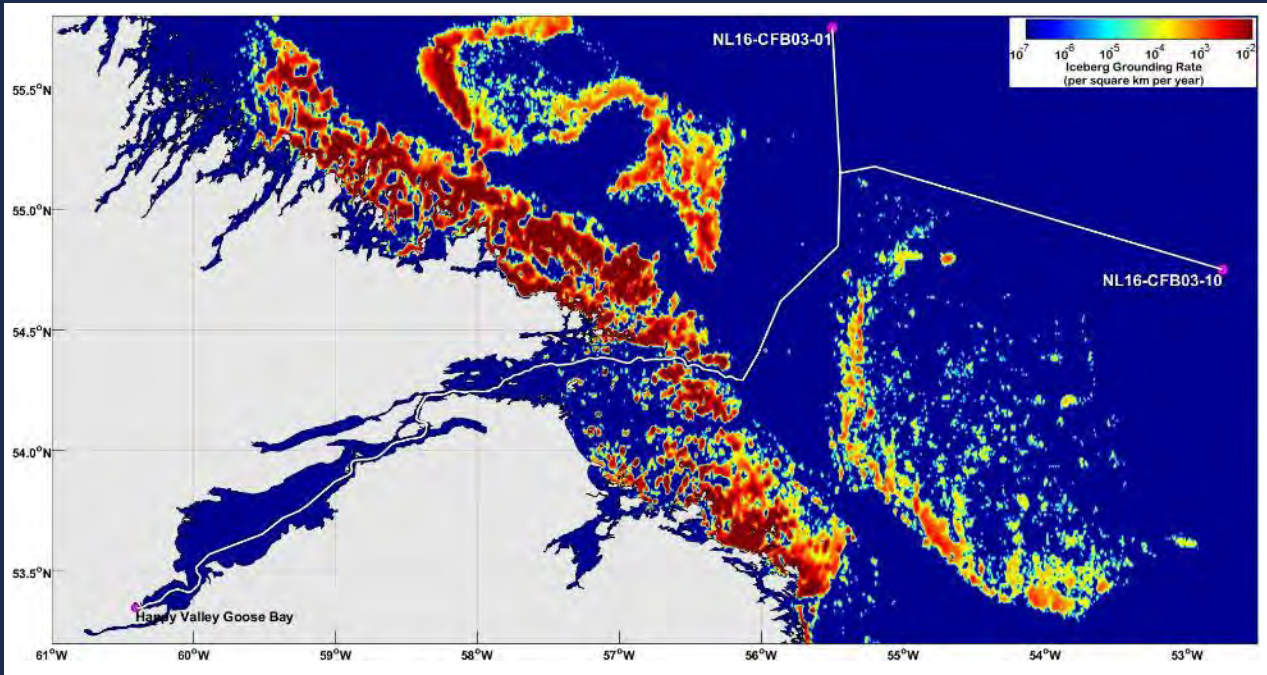


Figure 86. Proposed Cable Routes from Happy Valley Goose Bay to Offshore Labrador

Cable route lengths from shore given in the table below.

Landfall	NL16-CFB03-01	NL16-CFB03-10
Sheshatshiu	495.2	607.5
Happy Valley Goose Bay	525.5	637.9

Table 29. Cable Route Lengths (km) from Sheshatshiu and Happy Valley Goose Bay to Offshore Labrador

The results of the Monte Carlo model indicate no iceberg risk for a cable laid on, or trenched into, the seabed. Given the role of local bathymetry in sheltering the cable, any further consideration of this cable route option should include the collection of detailed seabed surveys.

Cartwright

The proposed cable routes from Cartwright to offshore Labrador are shown in the figure below. Cable route lengths from the beach manhole to NL16-CFB03-01 and NL16-CFB03-10 are 308.2 km and 420.6 km, respectively.

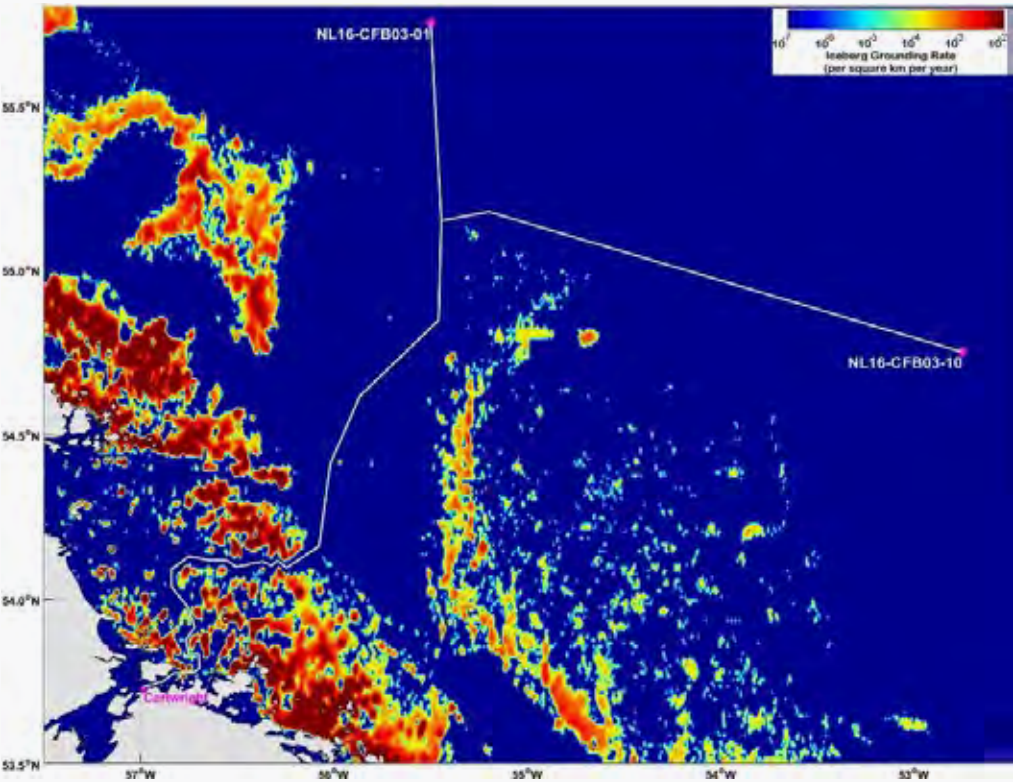


Figure 87. Proposed Cable Routes from Cartwright to Offshore Labrador

The figure below shows the water depth profile and modelled iceberg grounding rates along Only

the cable route to NL16-CFB03-10 is shown, but both routes are identical until reaching deep water outside Cartwright Saddle. Iceberg risk is limited to the first 50 km of the route, and due to the sheltered nature of the route the risk levels are quite low.

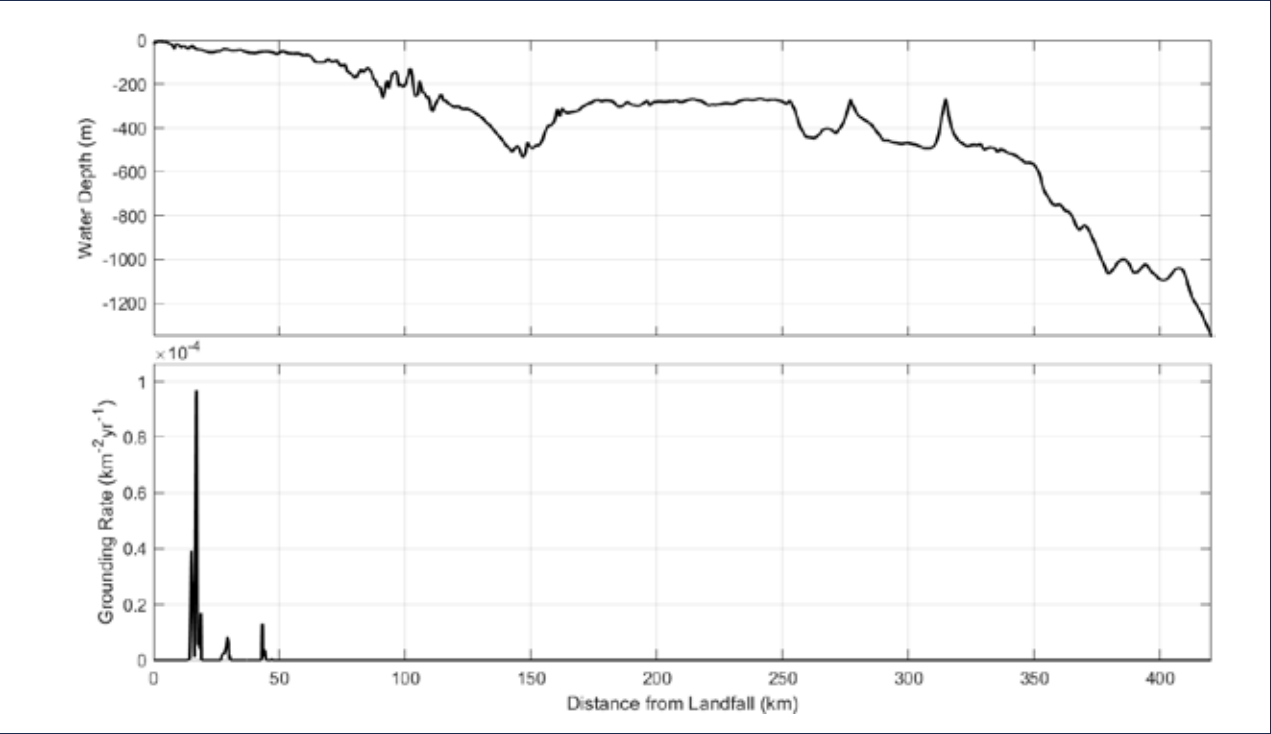


Figure 88. Water Depth and Iceberg Grounding Rate Along Route from Cartwright to NL16-CFB03-10

The table below summarizes results of the risk analysis outputs.

Exposed Length (km)	Return Period for Iceberg Keel Contact (years)				
	On Seabed	0 m Cover	1 m Cover	2 m Cover	3 m Cover
12.9	2,200	100,000	410,000	1,400,000	3,500,000

Table 30. Return Period (years) for Iceberg Keel Contact with Cable for Cartwright Landfall

Cat Arm – White Bay

The 585 km route from Cat Arm to Ephesus 1 in the West Orphan Basin is shown in the figure below.

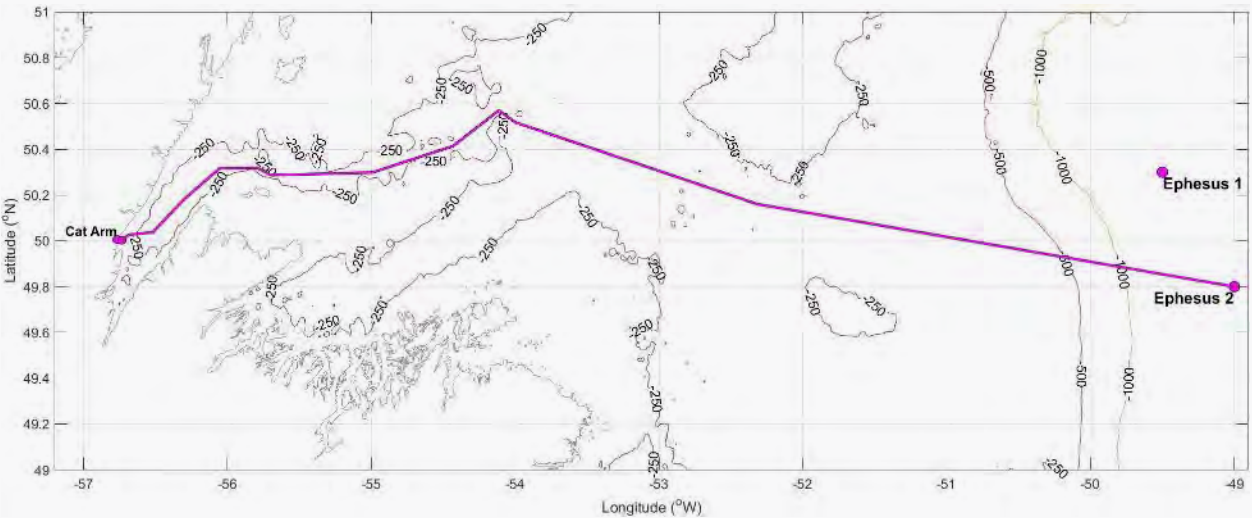


Figure 89. Proposed Cable Route from Cat Arm to the West Orphan Basin

The cable is exposed to icebergs for the first 8.5 km after it exits the HDD bore. The figure below shows the water depth profile and modelled iceberg grounding rates along the cable route.

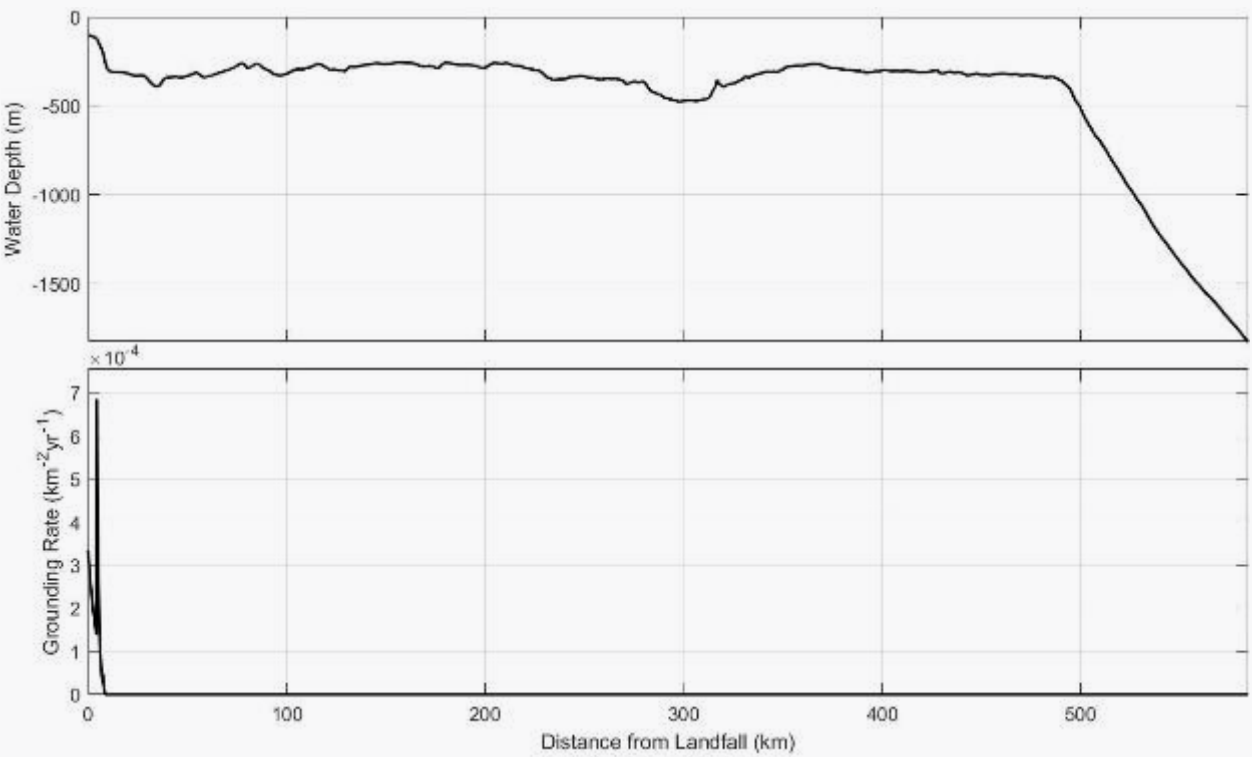


Figure 90. Water Depth and Iceberg Grounding Rate Along Route from Cat Arm to the West Orphan Basin

The table below summarizes results of the risk analysis outputs.

Total Length (km)	Exposed Length (km)	Return Period for Iceberg Keel Contact (years)				
		On Seabed	0 m Cover	1 m Cover	2 m Cover	3 m Cover
585	8.5	2,400	4,800	8,500	19,000	39,000

Table 31. Return Period (years) for Iceberg Keel Contact with Cable for Cat Arm Landfall

Hampden – White Bay

The 626 km route from Hampden to Ephesus 1 in the West Orphan Basin is shown in the figure below. Iceberg risk to the cable is limited to the first 15 km after exiting the HDD bore.

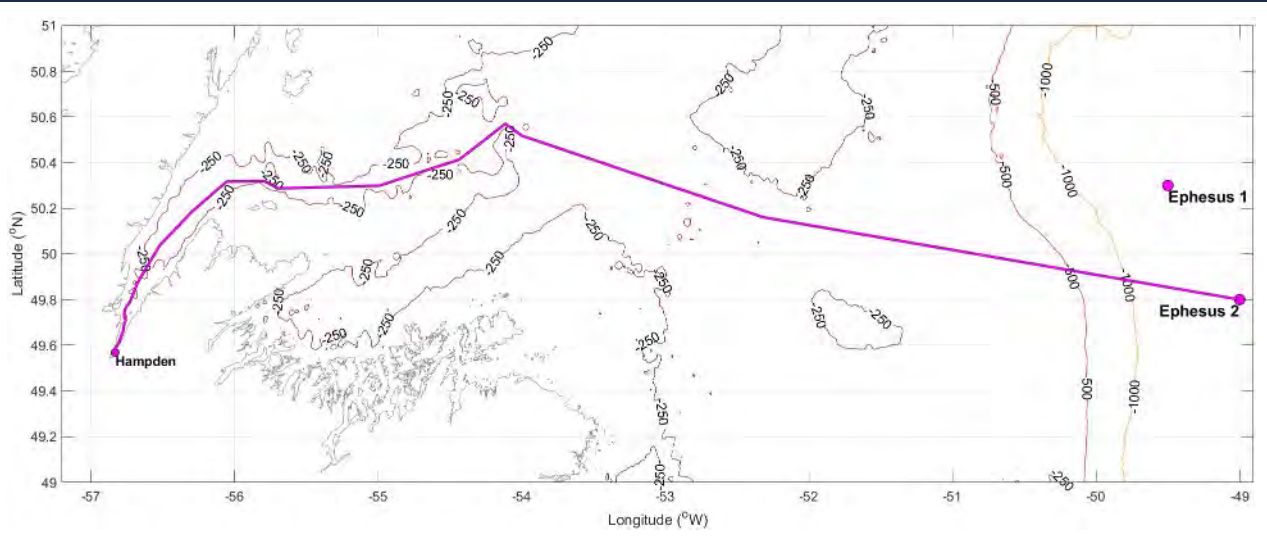


Figure 91. Proposed Cable Route from Hampden to the West Orphan Basin

The table below summarizes the results of the risk analysis outputs. The majority of risk occurs in the first 300 m when the cable first exits the HDD bore at 100 m water depth and descends a steep slope to 150 m water depth. Due to the sheltering effects the cable length exposed to iceberg keel contacts is 6.7 km.

Total Length (km)	Exposed Length (km)	Return Period for Iceberg Keel Contact (years)				
		On Seabed	0 m Cover	1 m Cover	2 m Cover	3 m Cover
626	6.7	3,200	3,400	6,200	14,000	29,000

Table 32. Return Period (years) for Iceberg Keel Contact with Cable for Hampden Landfall

King’s Point – Green Bay

The 535 km route from King’s Point to Ephesus 1 in the West Orphan Basin is shown in the figure below. Iceberg risk to the cable is limited to the first 16 km after exiting the HDD.

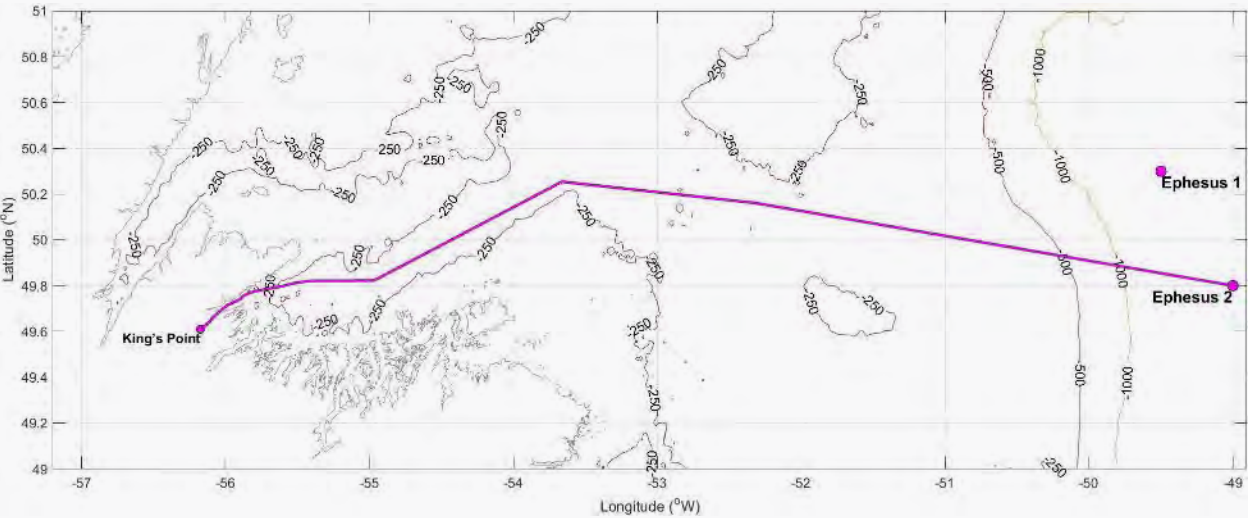


Figure 92. Proposed Cable Route from King’s Point to the West Orphan Basin

The table below summarizes the analysis outputs. The majority of risk occurs in the first 2 km when the cable first exits the HDD bore at 50 m water depth.

Total Length (km)	Exposed Length (km)	Return Period for Iceberg Keel Contact (years)				
		On Seabed	0 m Cover	1 m Cover	2 m Cover	3 m Cover
535	16	500	610	1,600	4,400	9,900

Table 33. Return Period (years) for Iceberg Keel Contact with Cable for King’s Point Landfall

Hare Bay

Although the Hare Bay landfall site is inside the bounds of the Monte Carlo iceberg contact model, a review of the bathymetry data used in the Monte Carlo grounding model showed that it did not capture the complex bathymetry of the site, with numerous islands with deep channels and variable water depths. The proposed route is shown in the figure below. The cable exits the HDD bore at 100 m water depth.

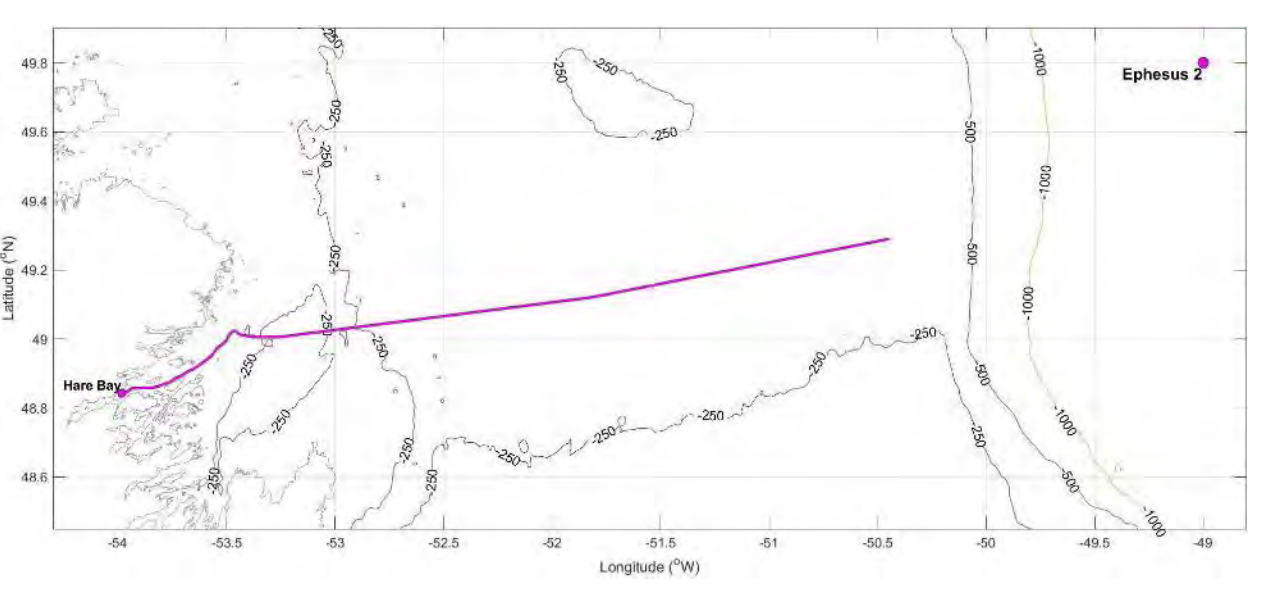


Figure 93. Proposed Cable Route from Hare Bay to the West Orphan Basin

The water depth profile along the landfall portion was digitized and water depths were compared with the surrounding bathymetry to assess the potential for sheltering of the seabed from iceberg interaction. The portion of the cable route immediately after exiting the HDD bore is sheltered along the selected channel by the 100 m “shoal” approximately 18 km along the cable route. Shallow water prevents deeper draft icebergs from reaching the site by drifting along the shore, and the channel used by the cable route to access deeper water is relatively narrow and sheltered by surrounding islands. Hence, it was decided to use the output of the Monte Carlo iceberg contact model (refer to the figure below) in the risk analysis.

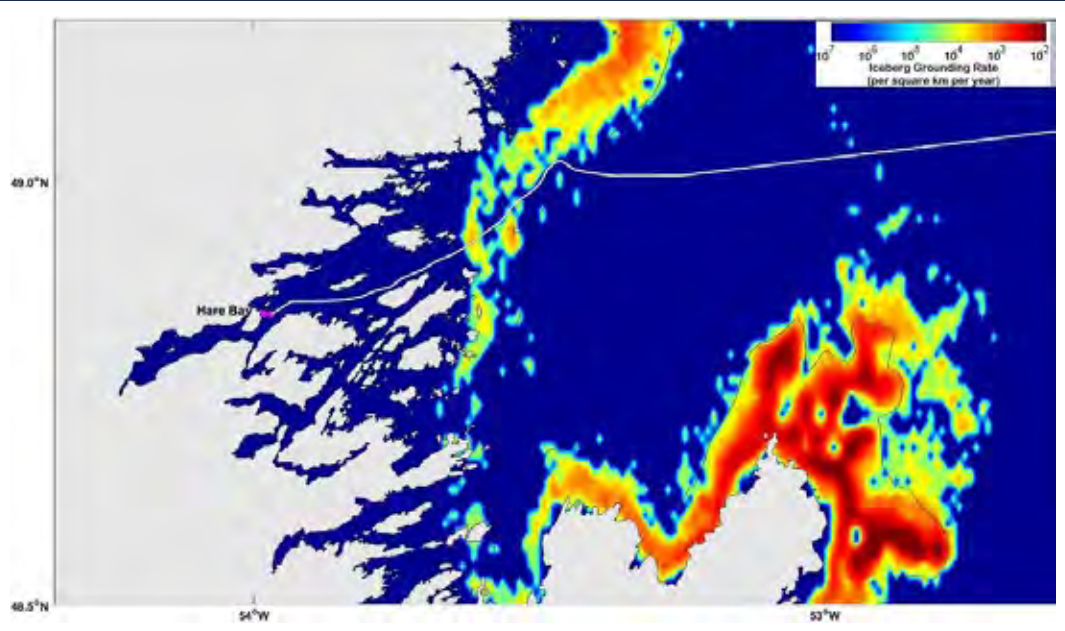


Figure 94. Proposed Cable Route from Hare Bay to West Orphan Basin with Monte Carlo Iceberg Contact Model Output

The table below summarizes results of the risk analysis outputs.

Total Length (km)	Exposed Length (km)	Return Period for Iceberg Keel Contact (years)				
		On Seabed	0 m Cover	1 m Cover	2 m Cover	3 m Cover
267	17.4	22	7,900	10,000	18,000	31,000

Table 34. Return Period (years) for Iceberg Keel Contact with Cable for Hare Bay Landfall

Norman’s Cove

The proposed Norman’s Cove cable landfall route is shown in the figure below. The Monte Carlo contact model shows no iceberg risk along this route, and no further analysis was conducted.

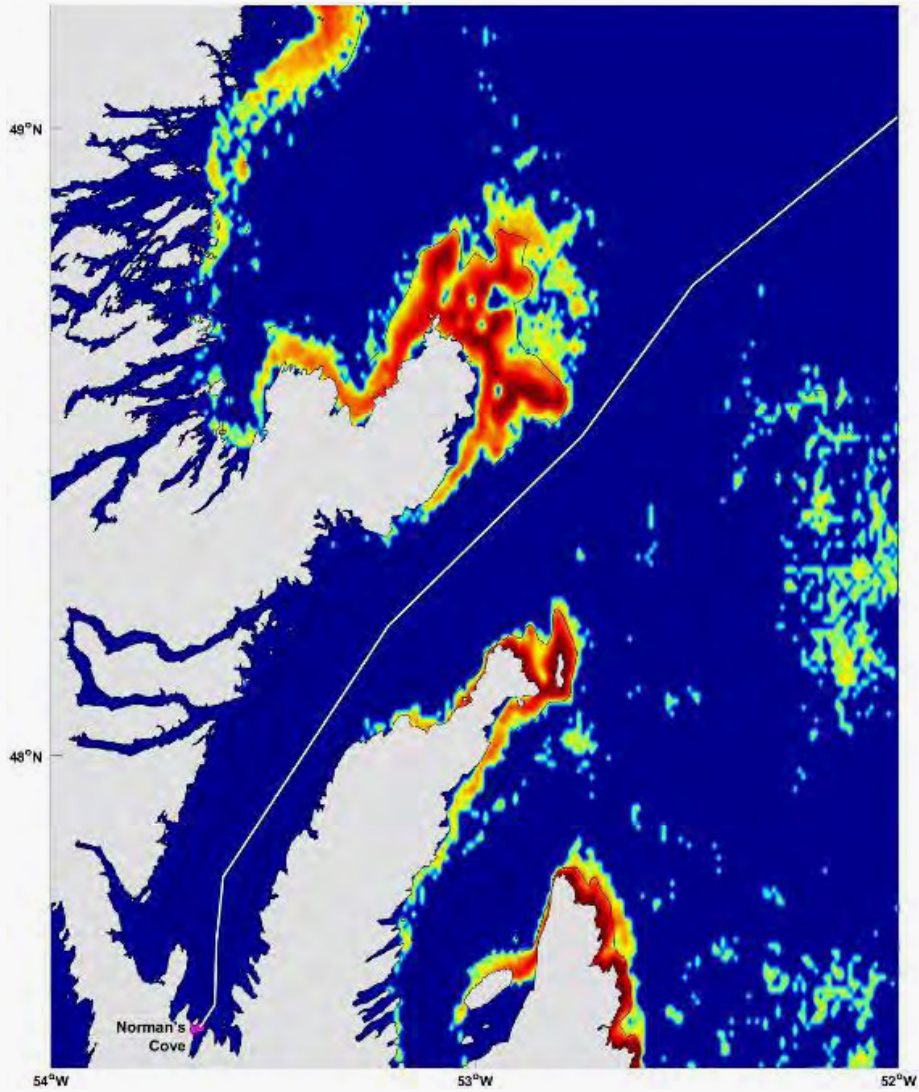


Figure 95. Proposed Cable Route from Norman’s Cove to West Orphan Basin

Holyrood

The proposed Holyrood cable landfall route is shown in the figure below. Any iceberg risk is limited to the first few kilometers after it exits the HDD bore.

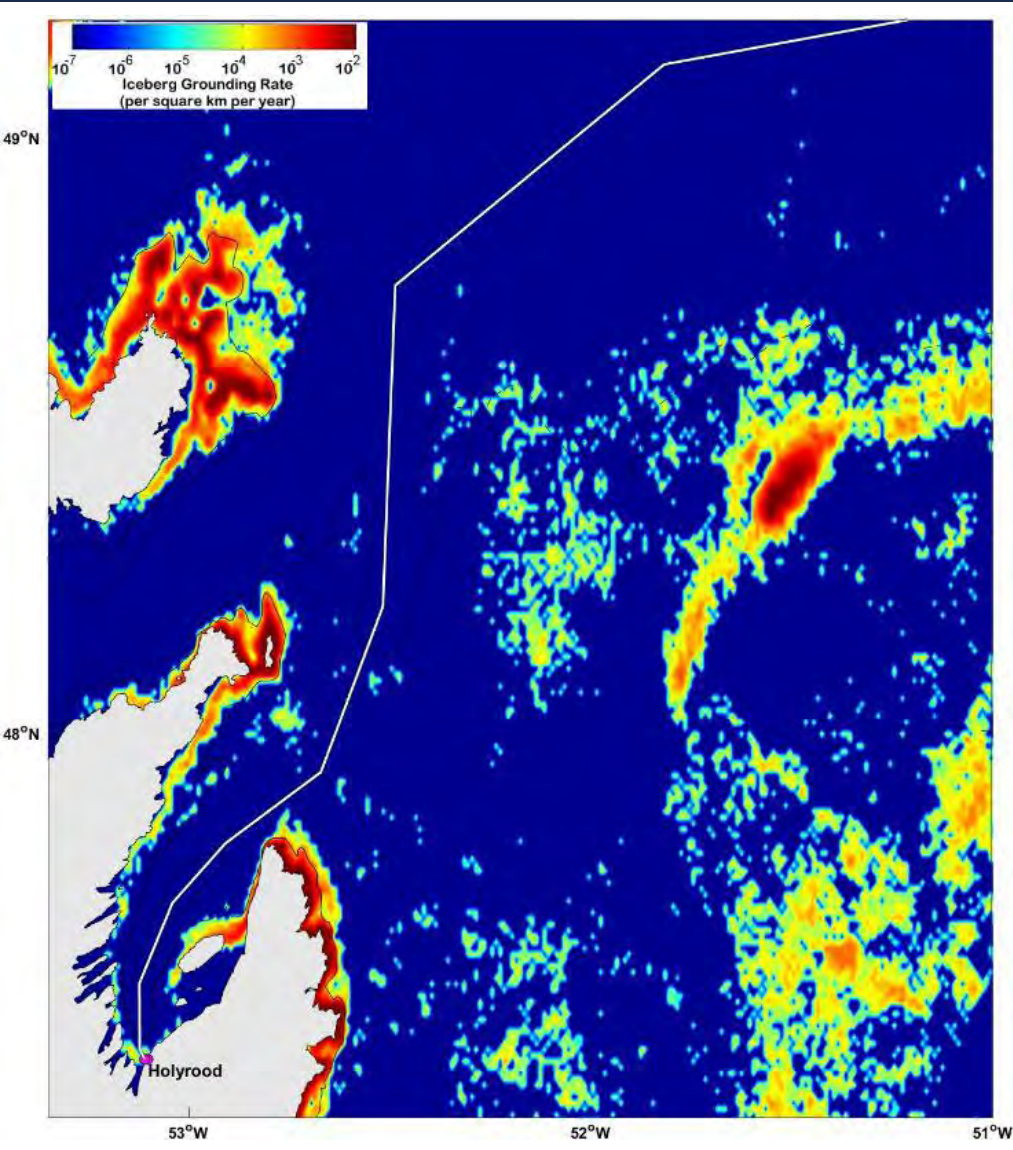


Figure 96. Proposed Cable Route from Holyrood to West Orphan Basin

The table below summarizes results of the risk analysis outputs.

Total Length (km)	Exposed Length (km)	Return Period for Iceberg Keel Contact (years)				
		On Seabed	0 m Cover	1 m Cover	2 m Cover	3 m Cover
326	3.1	160	40,000	190,000	630,000	1,600,000

Table 35. Return Period (years) for Iceberg Keel Contact with Cable for Holyrood Landfall

7.5 Cable Testing

Cable testing assessed the local response of cable samples to iceberg keel interaction. The internal structure of the subsea cables are relatively complicated and consist of several layers (see figure below). To assess the damage done on the cables due to an external load, visual inspection of the cables after the interaction is critical, hence cable samples that can resemble the structure and mechanical behavior of the potential subsea cables to be used offshore Newfoundland were tested. Two types of cable samples were used in this study, 123 mm single core High Voltage Direct Current (HVDC) copper cable and a 218 mm three core High Voltage Alternating Current (HVAC) aluminum cable.



Figure 97. Cross-section of a 123 mm Single Core HVDC Copper Cable (left) and a 218 mm Three Core HVAC Aluminium Cable (right)

The assessment of the iceberg keel interaction with subsea cables was done in two steps: estimating the loads during a keel interaction event and assessing the subsea cables mechanical behavior under side load.

Approach

To estimate the loads applied to the cables during an ice keel interaction event, a series of ice crushing experiments were conducted on a large scale 2.4 m • 1.4 m • 1 m ice sample at velocities ranging from 0.1 m/s to 0.5 m/s and indentation depths of 2 cm to 12 cm. A cylindrical steel indenter with outer diameter of 15 cm (6 inch) was used during this testing program to resemble a typical HVDC subsea cable.

The ice crushing test data was obtained by moving the indenter horizontally against the ice sample while maintaining a constant depth of indentation, as illustrated in the figure below. During this moving interaction the horizontal and vertical loads were measured to characterize the crushing properties of ice.

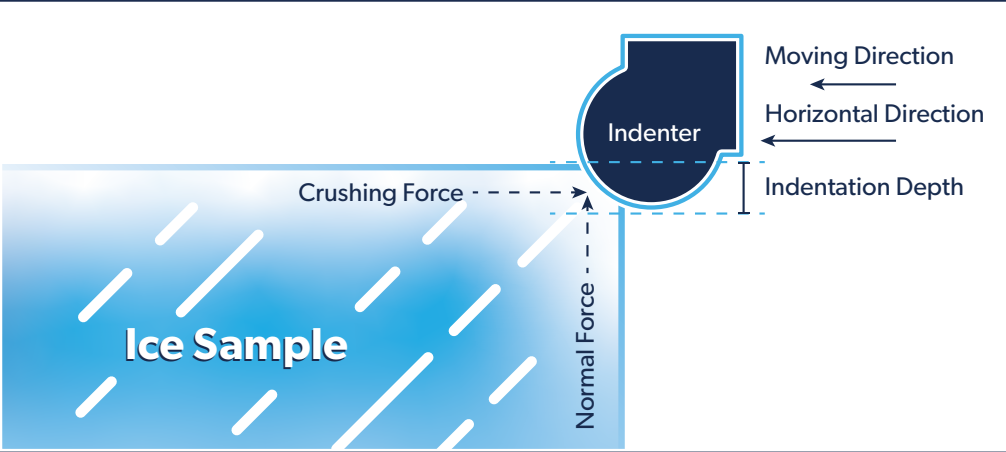


Figure 98. Schematic of the Ice Crushing Experiments

Given that the 10-15 kN/m rated sidewall strength of the cable samples were significantly lower than the expected ice crushing strength the cable samples were not used directly in the ice crushing experiments, but were side-loaded in an uniaxial hydraulic frame with 250 kN loading capacity (refer to the figure below).

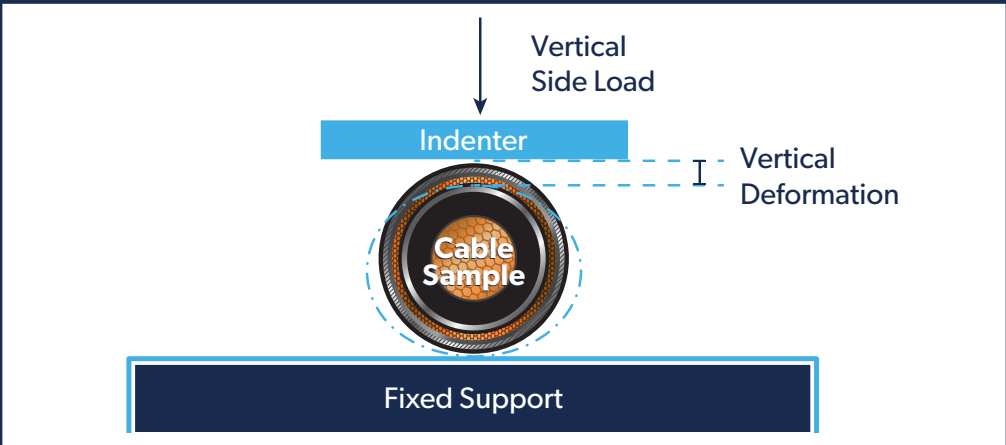


Figure 99. Schematic of Cable Side Loading Experiments

The vertical load and vertical deformation of the cables during the side loading were measured. Both 125 mm HVDC copper core cables and 225 mm HVAC aluminum core cables were tested, and in two experiments the cable samples were heated to resemble the interaction condition of electrically loaded subsea cables. Sections of the cables were cut after each test and investigated for visual signs of mechanical failure.

Cable Failure Criteria

The purpose of the crushing test is to verify that the cable can withstand loadings from installation and repair, so the loads are recommended to hold for at least 1 hour. Impact tests are performed to measure the impact capacity of a cable due to accidentally dropped objects.

Visual inspections were done on the cables after the test to assess their mechanical behavior. The ovality of the cable sections and thickness of the cable layers, were measured after each test, and separation of the cable layers during the tests were monitored.

Composition of Provided Cables

Two types of high voltage (HV) subsea cables produced by_____ were provided for the test program; a 123 mm single core HVDC copper cable and a 218 mm three core HVAC aluminum cable. At the core of each cable are high conductivity metals, copper for single core and aluminum for three core, which are responsible for transmitting high voltage power. The figures below show a schematic 3D CAD view of the internal structure of the cables used in this study.

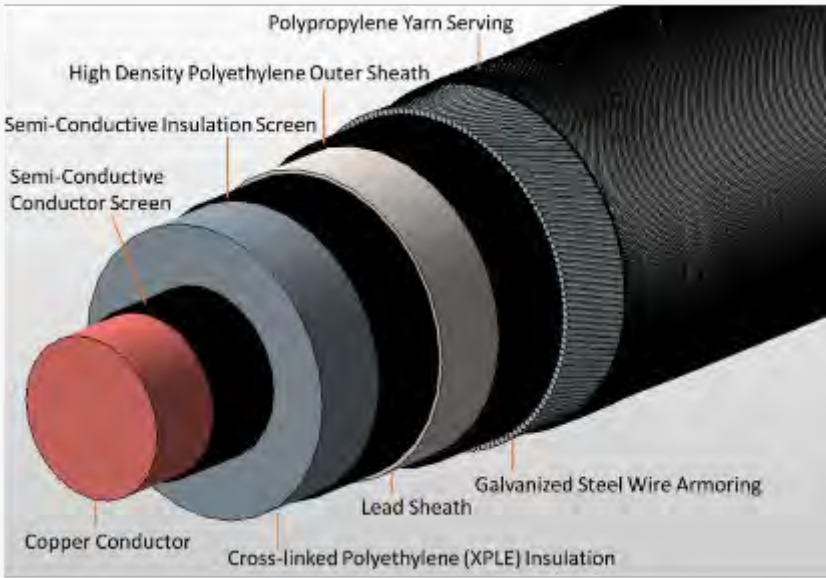


Figure 100. Schematic View of the Single Core HVDC Cable Internal Structure

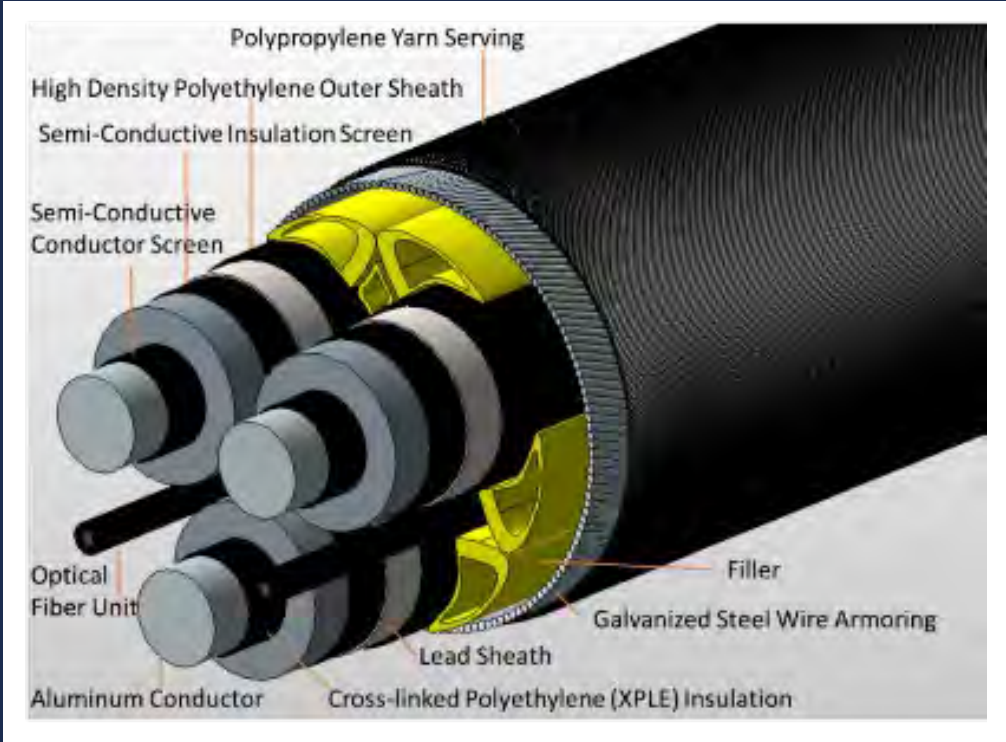


Figure 101. Schematic View of the Three Core HVAC Cable Internal Structure

Cable Test Setup

A total of six tests were performed, including two tests of room temperature single core HVDC cables, two tests of room temperature three core HVAC cables, and two tests at 50°C on the single core HVDC cables (refer to the table below).

Test #	Cable Type	Heated	Target Side Load Pressure [kN/m]
1	Single core	Yes	280
2	Single core	No	280
3	Three core	No	280
4	Single core	No	550
5	Three core	No	550
6	Single core	Yes	550

Table 36. Test Matrix Side Load Testing

The tests were conducted in a hydraulic test frame with vertical loading capacity of 250 kN. Cables were put on a supporting platform and fixed in the horizontal direction. A hydraulic moving arm on the top pushed a rectangular 39 X 77 X 2.5 cm flat steel indenter vertically downward until the plate contacted the cable sample and vertical forces reached 214 kN (85% of 250 kN load capacity), then moved vertically up to relieve the load. Refer to the figures below.

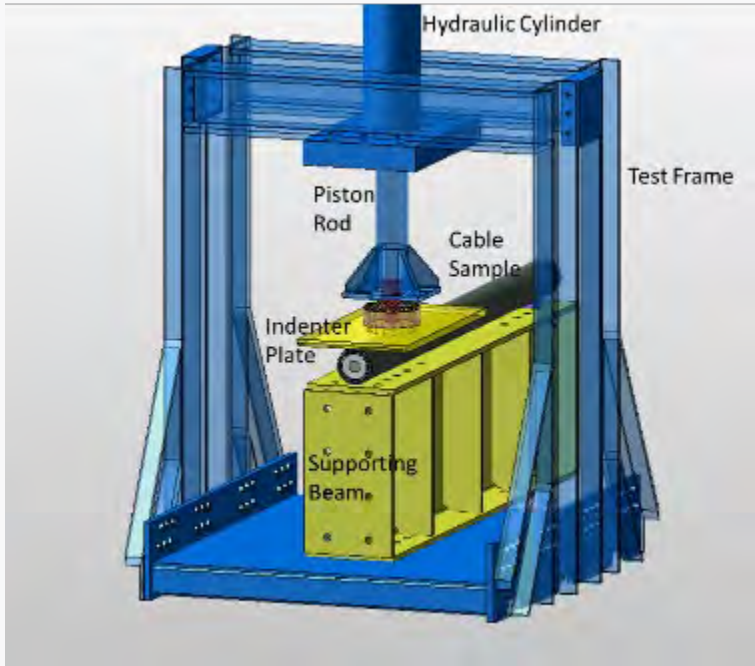


Figure 102. 3D CAD Model of the Cable Testing Apparatus



Figure 103. Front View of a Cable Side Loading Test at Maximum Deformation

The side loading testing program included both heated and non-heated (room temperature of 18 °C) cable samples. The cable samples for two of the HVDC tests were heated prior to the test to resemble the thermal condition of the electrified subsea cables. To heat the cables, two 300 W cartridge heaters were planted on drilled holes at two ends of the cable and heated to 90 °C for 24 hours using a temperature controller. Refer to the figure below.



Figure 104. Heating and Temperature Monitoring of the HVDC Cables

Cable Test Results

Stiffness

While the stiffness values achieved in this testing program, presented in the table below, provide an estimation of the radial stiffness of the cables, the exact values of the stiffness should be used with caution. As soon as the indenter contacts the cable, the deformation is related to cable deformation; however, because of the non-uniformity and distortion of the galvanized steel wiring layer, the starting point of contact of the cables varies between samples and this affects the stiffness readings.

Test #	Cable Type	Heated	Stiffness [kN/m]	Maximum Pressure [kN/m]	Maximum Deformation [mm]
1	Single core	Yes	3,394	289	10.7
2	Single core	No	4,982	289	7.3
3	Three core	No	2,445	283	26.0
4	Single core	No	5,372	556	13.0
5	Three core	No	3,732	537	32.4
6	Single core	Yes	3,903	554	17.9

Table 37. Stiffness Results from Side Load Testing

Elastic Deformation

Using slow-motion video footage of the tests, the approximate time of elastic failure for each test was noted. Comparing the failure time to the time-pressure curves from test results, the failure force for each experiment was calculated (refer to the table below). Although the estimated elastic failure forces might not be accurate, all of the visual failures happened in the range of 20-35 kN/m pressure. It should be noted that the video failure inspection only covers the tips of the cables and the actual failure may happen anywhere within the cable, so the elastic failure forces may over-estimate the actual failure pressure.

Test #	Cable Type	Initial Diameter (mm)	Heated	Approximate Failure Pressure [kN/m]
1	Single conductor	126	Yes	20-25
2	Single conductor	126	No	30-35
3	Triple conductor	225	No	25-30
4	Single conductor	126	No	25-30
5	Triple conductor	225	No	30-35
6	Single conductor	126	Yes	25-30

Table 38. Cable Elastic Deformation Tests

Approximate Elastic Failure Pressures

During the three core cables side loading experiments, no detectable deformation of the internal cables was observed. However, significant deformation in the overall structure of the cables, as shown in the figures below, was observed.



Figure 105. Displacement of the Internal Cable Components in Test 3



Figure 106. Displacement of the Internal Cable Components in Test 5

Plastic Strain Energy Dissipation

The dissipated plastic energy for the six tests are 11.04, 4.07, 12.80, 19.75, 36.08, and 33.75 kN/m respectively (refer to the table under Cable Test Setup section for test conditions). The plastic energy dissipation for the three core cables is higher than the single core cables, the heated cables have higher dissipated energy than the room temperature cables, and the amount of energy dissipation increases with the increase of stress.

Plastic Deformation

The visual inspection of the tested cable samples to identify signs of mechanical failure and/or plastic deformation is a critical step after mechanical testing. The cable samples that were tested at 550 kN/m side pressure were cut in short disk sections and inspected for plastic deformation. The figure below shows a cable sample prepared for cutting and samples of HVDC and HVAC disk sections.



Figure 107. Cable Sample Prepared for Cutting (left), Sample of HVDC Cable Section (middle), and Sample of the HVAC Cable Section (right)

After cutting, each cable section was thoroughly inspected on both sides with a 3.5x magnifying glass for signs of failure or deformation. More than 3,000 thickness measurements were taken to profile the plastic deformation and eccentricity of the cable samples after side load testing.

The figure below shows some examples of permanent damage to the cable after test 6.



Figure 108. Examples of Permanent Damage on the Three Core HVAC Cable After Test 6; Separation of the Lead Sheath and the Insulation Screen (Left), Deformation of the Lead Sheath and Polyethylene Sheath (Middle), and Plastic Deformation of the Filler Material (Right)

Ice Resistance

Ice Strength Review

During the interaction of an iceberg keel and subsea cable, the amount of force applied to the cable is limited by the ice failure force. The main purpose of this task was to estimate the loads applied to a rigid cylindrical indenter, as a representative of the subsea cable, during iceberg interaction.

Experiments conducted by Bailey et al. (2018) provides a valuable insight to the mechanism of failure of freshwater ice samples against the rigid cylindrical indenter. Local ice failure processes were investigated through scaled tests where an ice sample was indented vertically against a rigid, 4.5" diameter pipe laid on either a rigid surface or compliant soil bed (refer to the figure below). Confined and non-confined experiments were conducted on lab grown freshwater ice and iceberg ice. It was found that the failure force increases with the confinement (steel ring on the bottom in the figure below) and lab grown ice has a higher strength than the iceberg ice.



Figure 109. Medium Scale Ice-Pipe Indentation Setup by Bailey et al. (2018)

Iceberg ice generally has a higher number of flaws and cracks that contribute to weak points, stress concentration, and lower strength. Bailey concluded that, contrary to previous assumptions, a pipeline may survive interaction with a free-floating iceberg keel and iceberg keels fail locally when contacting rigid pipelines.

Ice Failure Test Setup

C-CORE designed a novel test apparatus for executing iceberg-cable impact experiments. Large ice samples are fabricated in the C-CORE cold room, installed onto the test apparatus, and impacted by a hydraulics driven indenter at realistic impact speeds. A 6" diameter steel cylinder moves forward at a constant velocity and a set indentation to crush through the ice in a 80" stroke. Refer to the test apparatus setup in the figure below. This scenario simulates an iceberg keel impact with subsea cable segments. Data is collected on ice strength and failure mechanisms, to compare to the results from the cable resistance experiments.

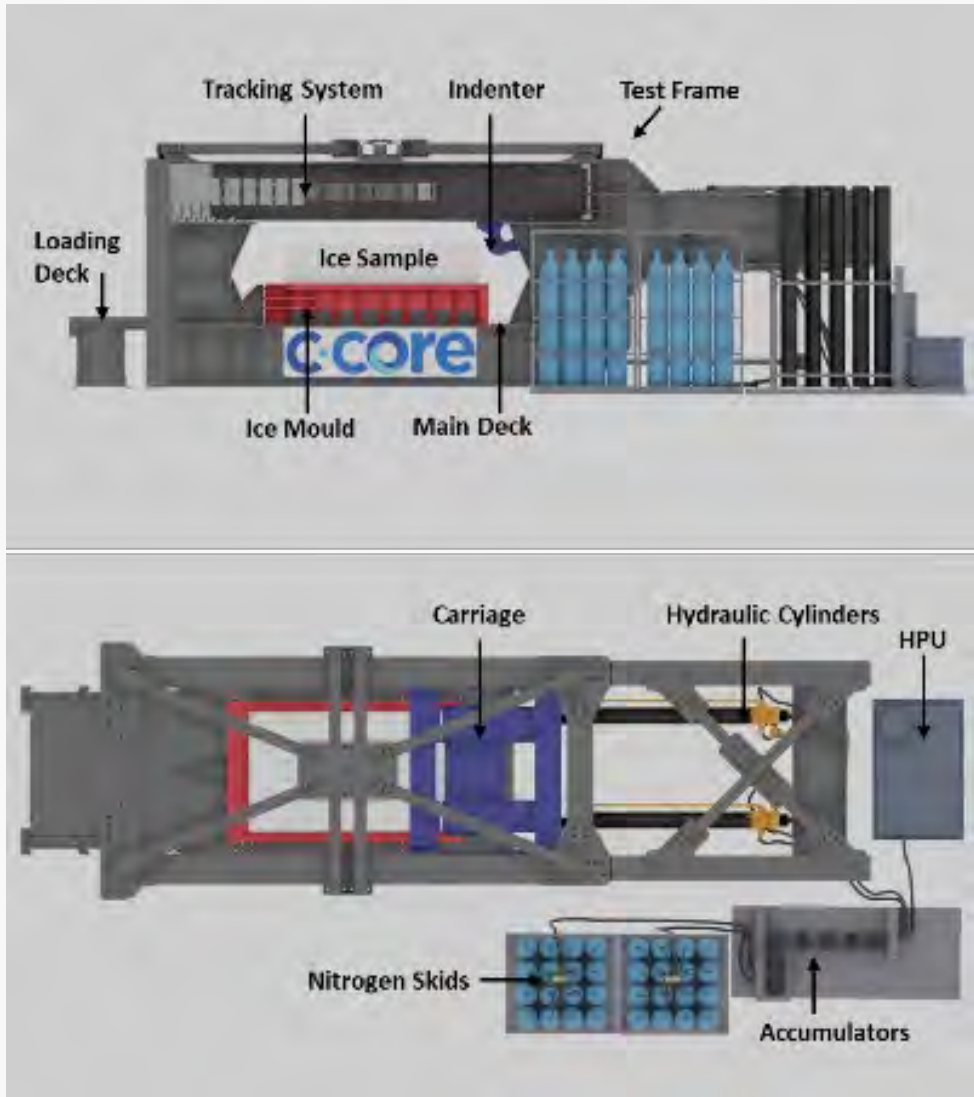
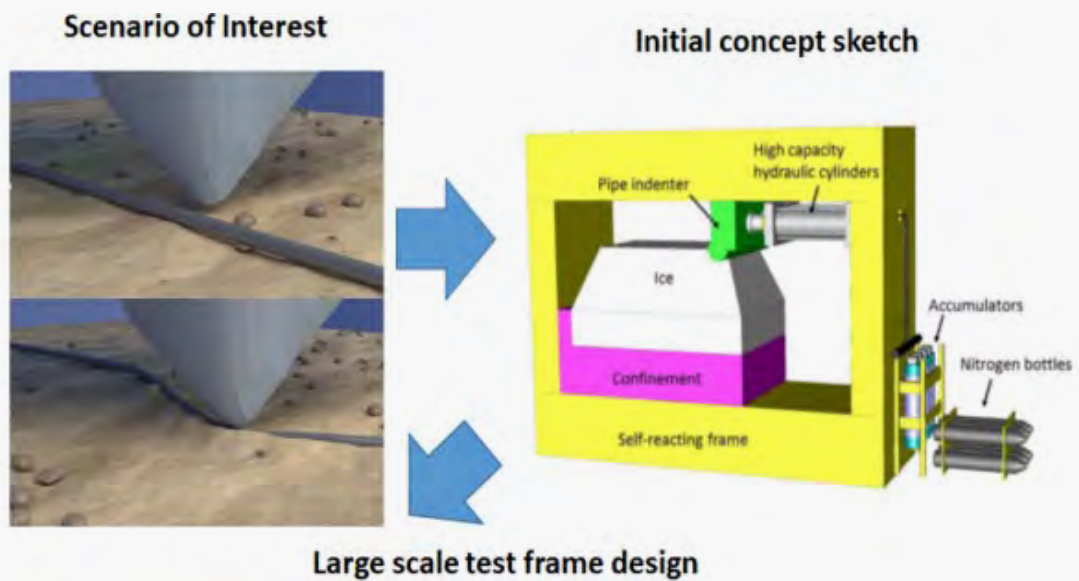


Figure 110. Design of the Rapid Interaction Test Apparatus

Ice Failure Test Results

The first test using the apparatus was for this project, executed on June 2, 2022, with an indenter diameter of 6", traversing velocity of 0.2 m/s, and indentation depth of 1.5 - 2".

By the time the mould was loaded into the test apparatus, about 2.5 hours passed, and the surface temperatures were close to melting. Given the self-insulating properties of ice, the core was still close to -10°C. This temperature gradient reflects natural iceberg ice, which is also at melting temperature near the surface, and has a very cold core.

The peak resultant force measured during the interaction was 357 kN, see in the figure 67, which is 238 kN/m line load. The ice interaction was a mixed mode failure, with crushing and spalling occurring intermittently. Spalling limited the total loads, as expected given the proximity of the free surfaces to the indenter contact interface. Figure 118 to Figure 123 show the progression of the test and the ice failure modes.

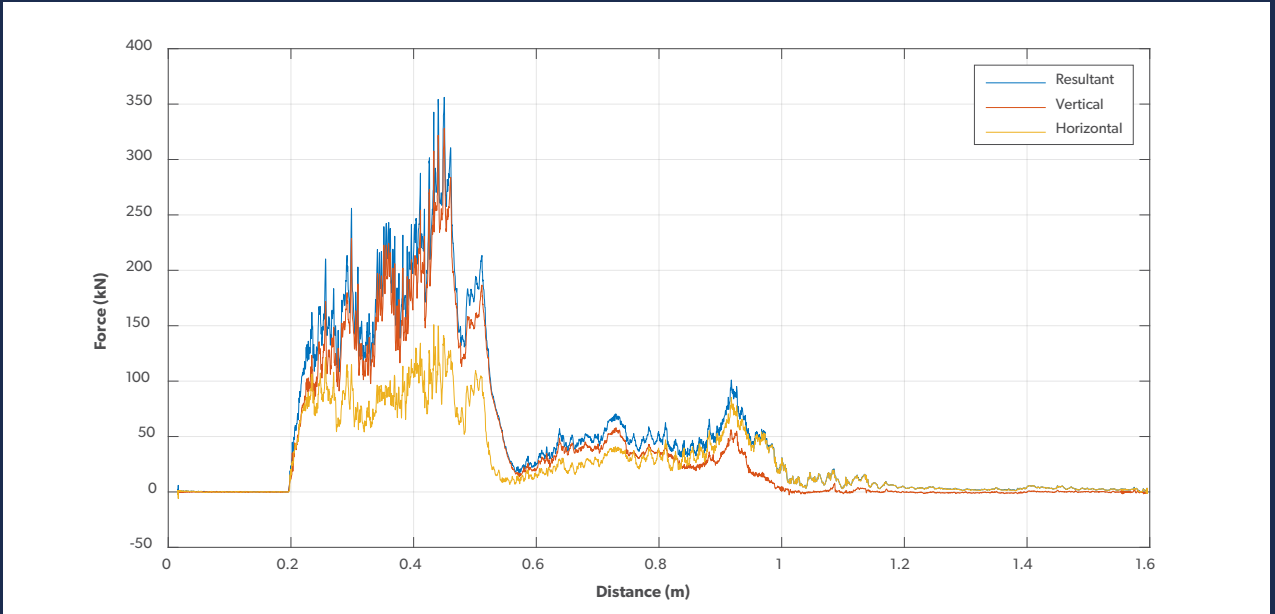


Figure 111. Test Results – Forces Collected by Loadcells



Figure 112. Initial Setup



Figure 113. Test Setup – First Contact



Figure 114. Test Setup – 2 Seconds Into Interaction



Figure 115. Test Setup – 3 Seconds Into Interaction



Figure 116. Test Setup – 4 Seconds Into Interaction



Figure 117. Test Setup – After Interaction

7.6 Finite Element Analysis (FEA) of Cable Response to Iceberg Keel Interaction

The Alternatives to Flowline Trenching (AFT) program developed a framework for analysis of flexible flowlines and rigid pipes subject to iceberg interaction. The approach was modified to accommodate much smaller diameter power cables. The cable response is evaluated considering sensitivity analysis to parameters including iceberg shape, iceberg clearance, soil strength, and assumed friction coefficient.

Basis for FEA

The FEA basis consists mainly of the cable, iceberg, and seabed conditions with appropriate interfaces between these three components. The cable properties are included in the table below.

	Single Core Cable	Three Core Cable
Outside Diameter (mm)	123	218
Mass (kg/m)	38	67
Minimum Bending Radius (m)	4.0	3.3

Table 39. Cable Properties

Refer to the figure below for illustrations and photos of the _____ cable samples.



Figure 118. Cable Illustrations and Single and Three Core Power Cable Samples

Based on literature review, the estimated acceptable cable parameters are shown in the table below.

Cable	1-core	3-core
Copper conductor area, mm ²	1*1400	3*650
Tensile limit (bending), kN	83	117
Tensile limit (axial), kN	84	155
Axial stiffness, MN	400	500
Bending stiffness, kN/m ²	24	16
Sidewall force limit, kN/m	21-59	15

Table 40. Assumed Cable Mechanical Parameters

FEA Sensitivities

Due to the complexity of the 3-core cable and uncertainty in the mechanical response, the focus of analysis was on the single core conductor. The aspect ratio between the sizes of iceberg to cable diameter is very large making it challenging to capture local and global behavior simultaneously, highlighted in the figure below.

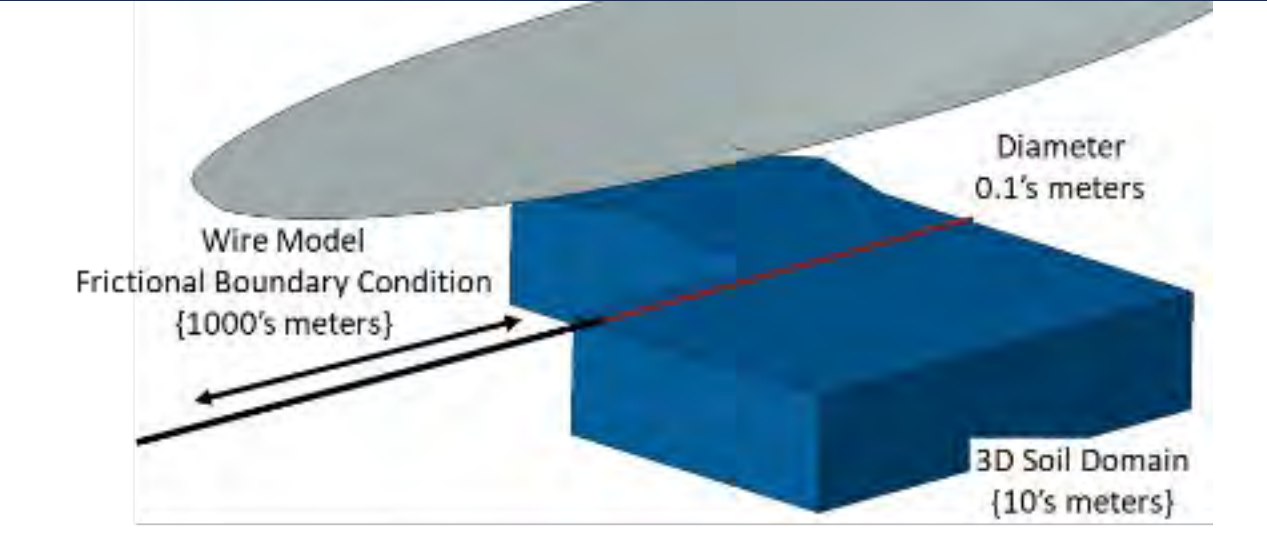


Figure 119. Typical Ice-Cable-Soil Finite Element Model

As shown in the comparison of strain contours in the following figure, and penetration force in the following graph, good correspondence is shown between the fine mesh analysis, which would be impractical to apply at larger scale analysis, and the coarse mesh, a probable lower bound limit of mesh density for larger scale analysis. A characteristic dimension of 20 mm (6 elements/diameter) was chosen to be a reasonable compromise of accuracy and scalability.

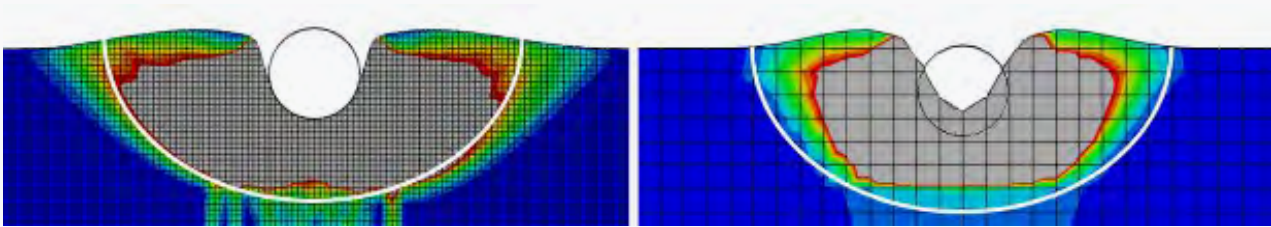


Figure 120. Strain Contours for Soil Failure

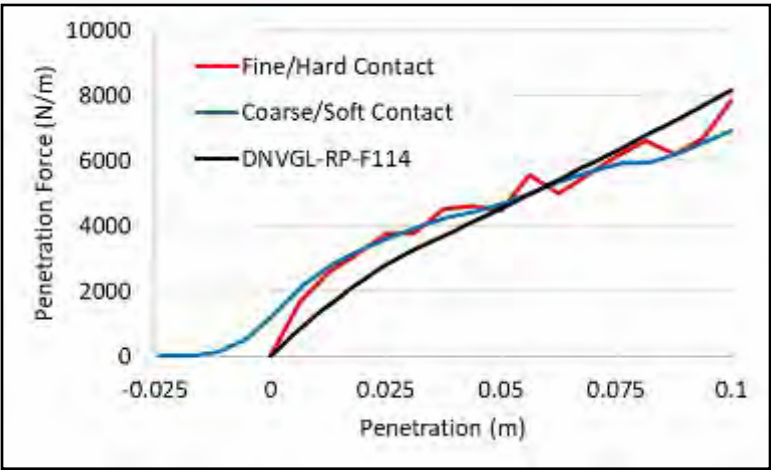


Figure 121. Penetration Force Comparison

After a few iterations on the size of the soil domain required, a relatively small soil domain, 3 m X 3 m X 2 m, was used, as shown in the figure below, where symmetry is assumed on the centerline of the iceberg. The rigid iceberg shape is assigned to be ellipsoidal and had characteristics similar to that used in AFT (C-CORE, 2020b). The analysis considered the narrow dimension, 2.8 m, parallel to the cable, with the long dimension, 8.7 m, intersecting perpendicularly. The initial position of the iceberg is positioned such that it is just touching the soil surface or, from the cable perspective, zero diameters (0.0D) from the bottom of the cable.

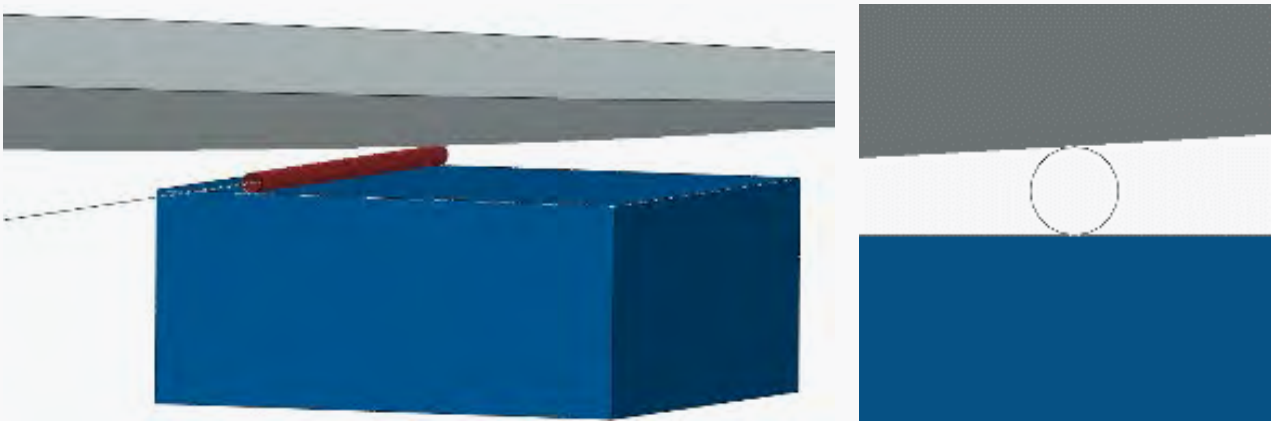


Figure 122. Free-floating Interaction Model with Power Cable

Ellipsoidal Iceberg: Slow versus Rapid Soil Response

This comparison is of slow (drained) soil behavior to an approximation of rapid (undrained) behavior. Rigid-circular cable displacement in the direction of keel movement is limited to about one meter, shown in the graph below, as the contact point between keel and cable is nearly vertical, shown in the figure below.

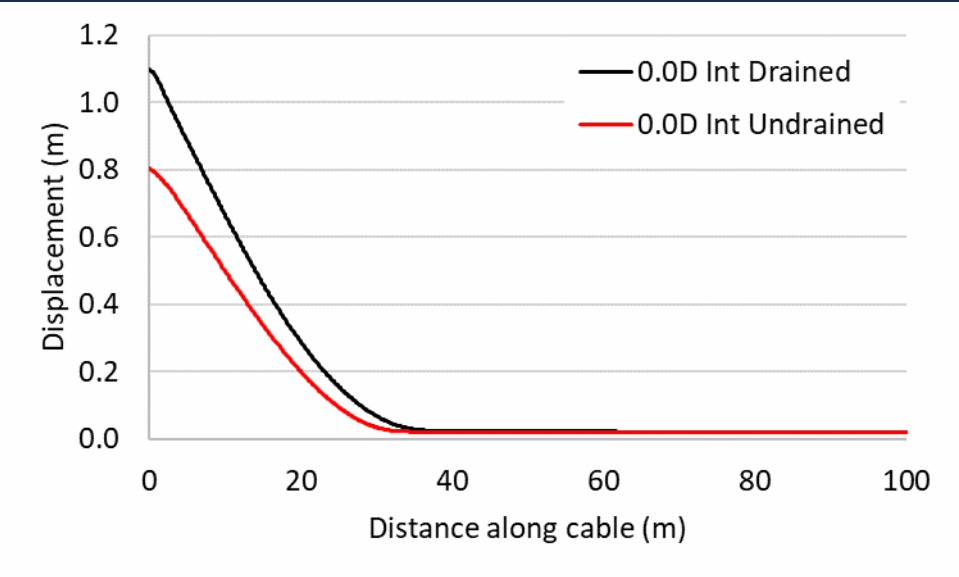


Figure 123. Cable Displacement Profile

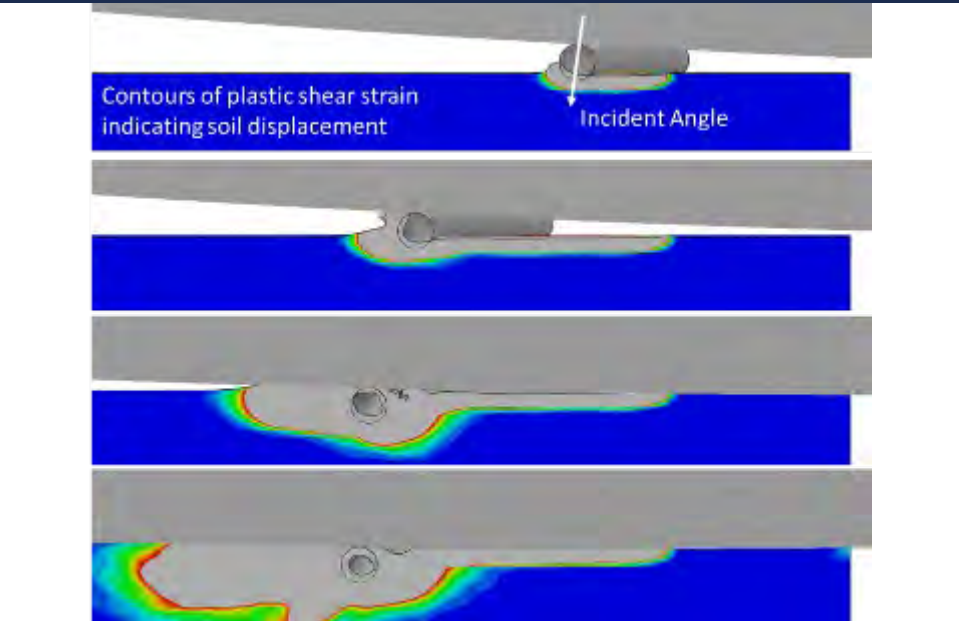


Figure 124. Plastic Strain Contours on Centerline of Interaction

With limited cable displacement, the tension developed in the cable is limited to 20 to 30 kN, as shown in the graph below.

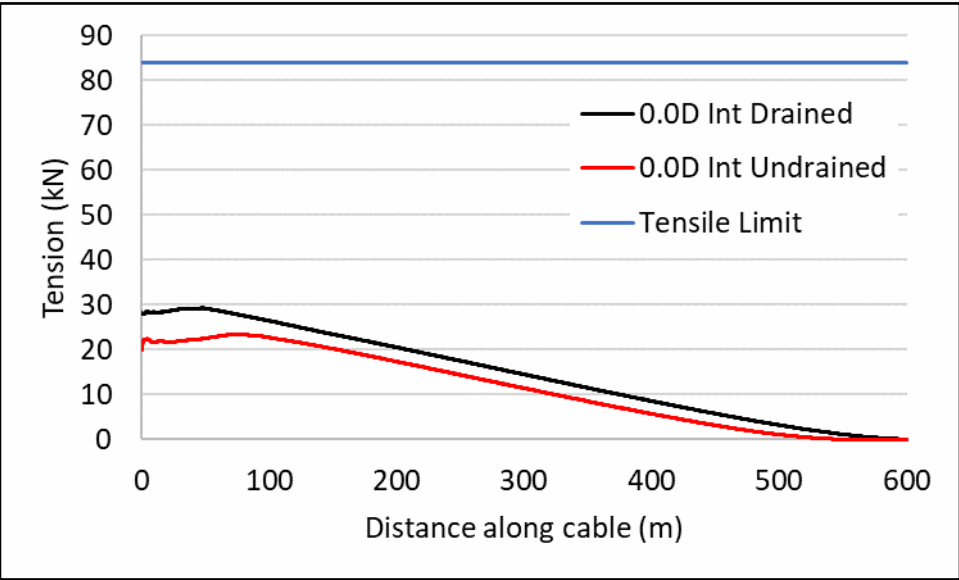


Figure 125. Tension Profile Along Cable

The iceberg driving force is compared between slow (drained) and rapid (undrained) soil parameters in the figure below. The 5 m keel displacement to peak force is consistent with the iceberg shape to override the 0.125 m diameter cable.

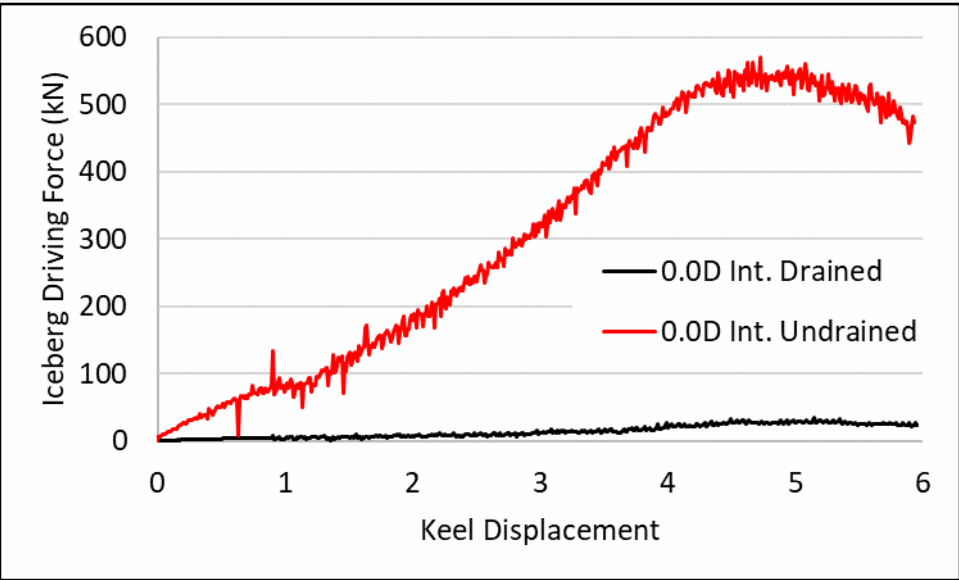


Figure 126. Iceberg Driving Force

It is apparent that under rapid loading conditions, significantly more force is required to penetrate the cable into the soil. Contact pressures within the interaction zone are processed to generate an estimate of global sidewall force per unit length of cable, as shown in the graph below. The drained soil interaction initially exceeds the sidewall limits, 40 kN/m over a length of 1 meter, before contact pressure becomes more distributed over a greater length and falls below the 15 kN/m limit. Under approximate rapid loading conditions, sidewall limits are immediately exceeded, indicating the cable would likely be crushed under this scenario. These sidewalls loads are less than the ice failure loads.

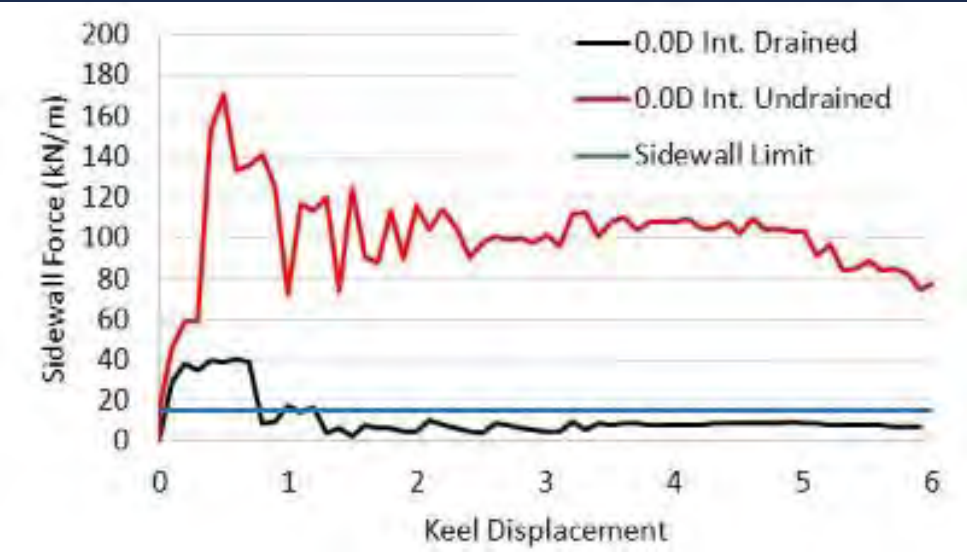


Figure 127. Cable Sidewall Force during Interaction

Simplified Local Iceberg Shape

The assumed local iceberg shape has a circular cross-section, and base widths considered include 5 and 10 m and the incident angles of 10, 30, and 60 degrees. Representative geometry is shown in the figure below for a base width of 10 m and incident angle of 10 degrees.

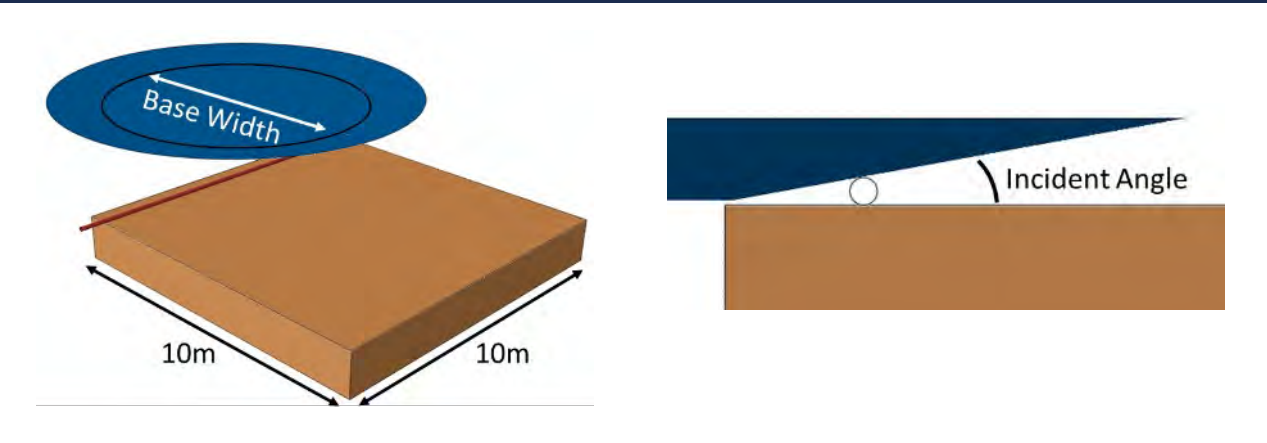


Figure 128. Local Geometry Sensitivity Analysis

For the 30 degree incident angle, the base width has an effect on the cable response. The narrower 5 m base width indicates the cable is dragged for some distance before being overridden at approximately 2 m displacement, whereas the 10 m base width case tended to push the cable in at relatively small iceberg displacement. This is highlighted in the figure below at 0.65 m iceberg displacement where plastic equivalent strain contours are an indicator for soil displacement.

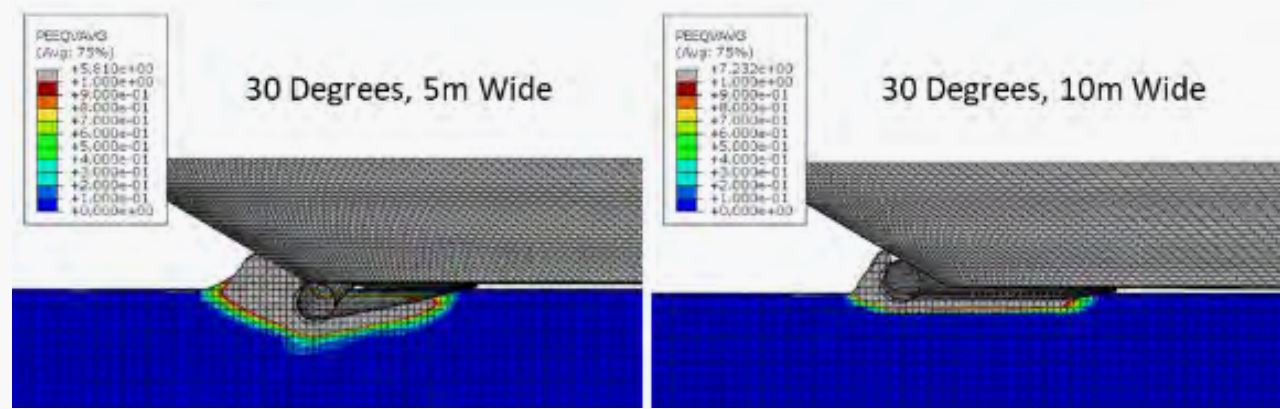


Figure 129. Soil Strain Contours at 0.65 m Iceberg Displacement

Average contact forces are calculated over the exterior of the cable during the interaction and plotted in the graph below. The 30 degree and 5 m wide case produced the highest average and localized contact pressure upon initial contact with the cable.

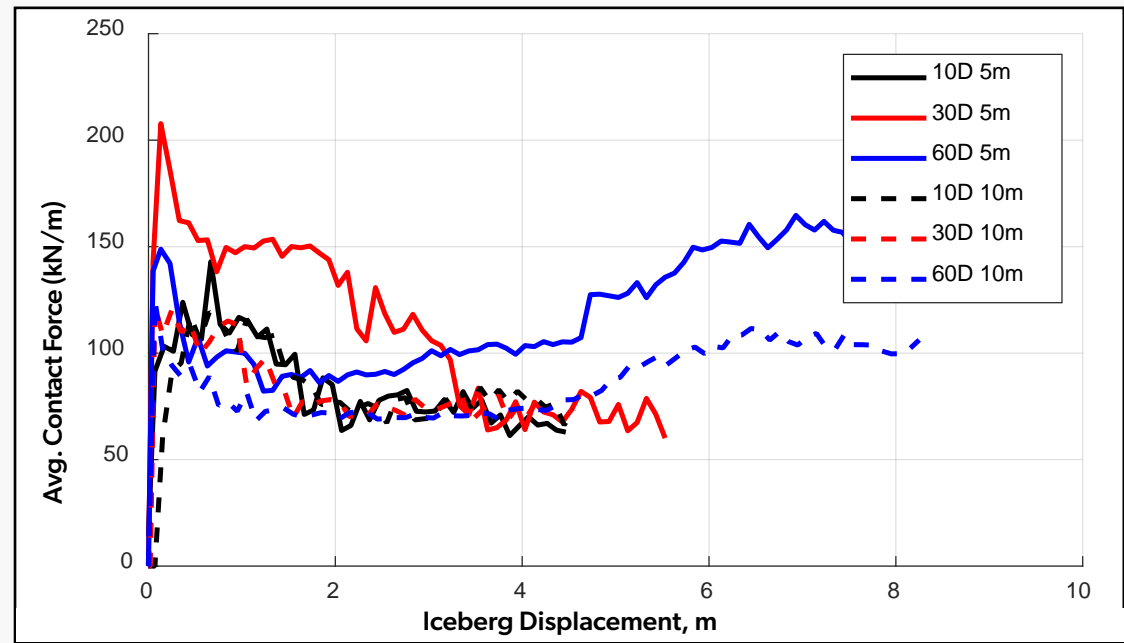


Figure 130. Average Contact Pressure versus Iceberg Displacement

Contact pressure contours, shown in the figure below, have limits between 0.1 and 10 MPa but a peak contact pressure of 34 MPa is predicted, which is excessive for natural ice without significant confinement. Considering a cable diameter of 0.12 m and sidewall force of at least 120 kN/m, bearing pressures are on the order of 1 MPa. This is well above accepted sidewall limits for standard single core power cables, but possibly below expected ice failure loads.

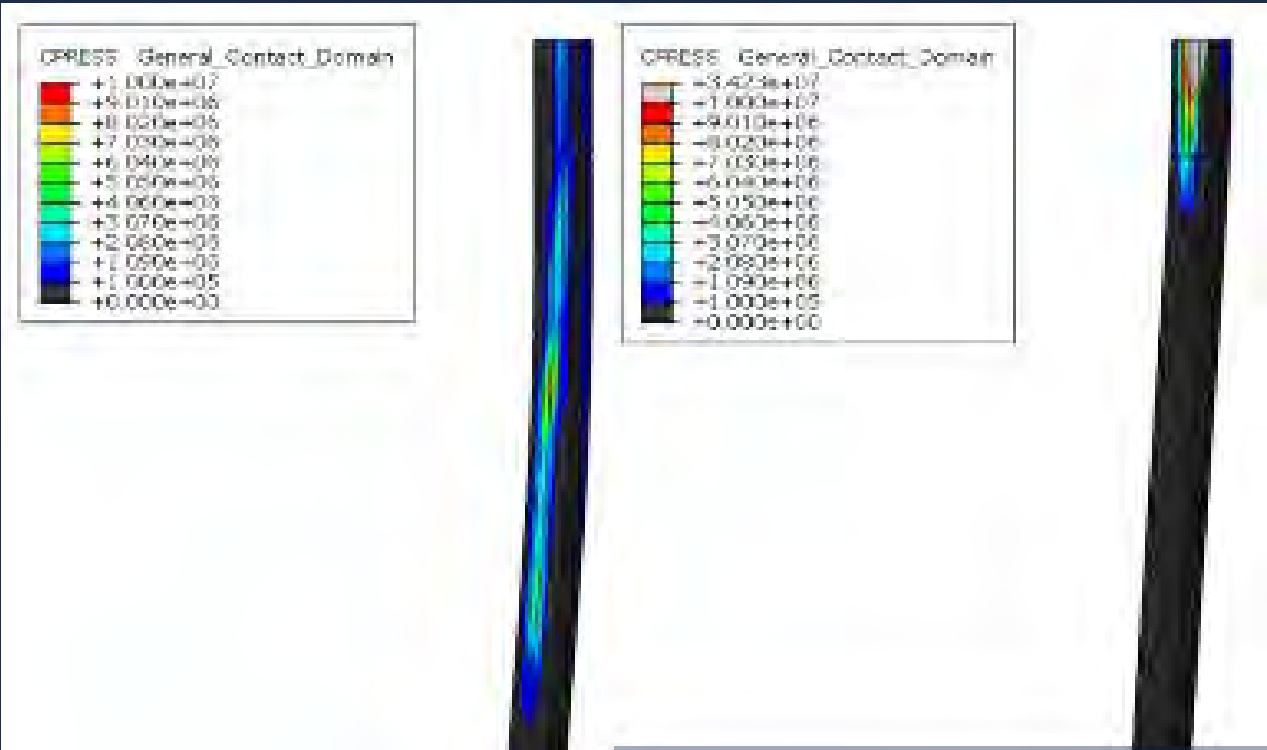


Figure 131. Contact Pressure Contours for 30 degree, 10 m (left) and 5 m (right) at 0.65 m Displacement

Summary of FEA Sensitivity Analysis

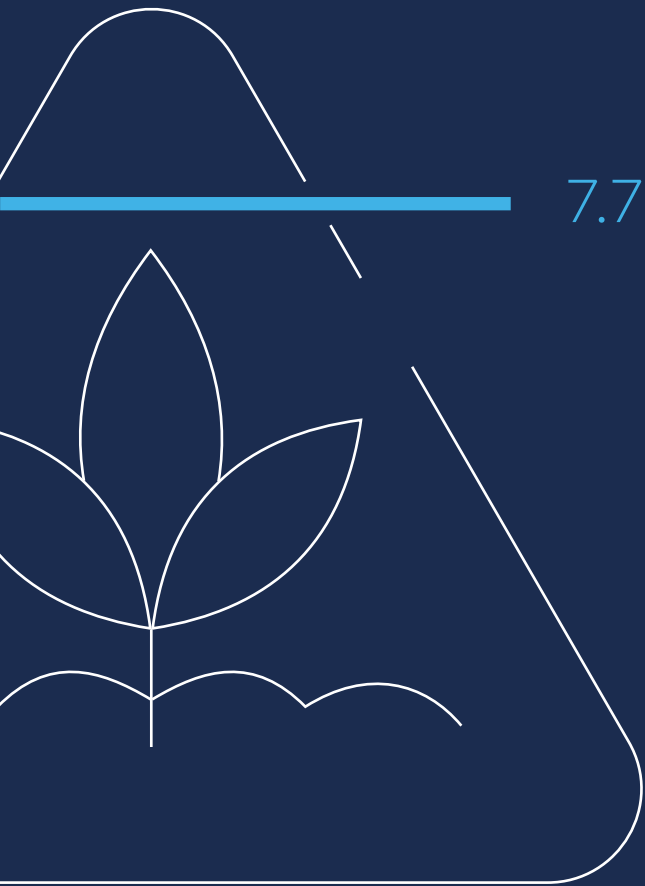
If soil response was drained, iceberg incident angle is low, and the radial robustness of the cable is slightly improved, there may be scenarios where the cable would be overridden and survive the encounter. However, as the soil is expected to behave approaching an undrained behaviour, the cable will most certainly be crushed in exceeding sidewall limits. If the local iceberg incident angle is steep, the most likely outcome is that the cable tension limits are exceeded. The analyses highlight that the cable response is sensitive to the assumed local shape of the iceberg.

It was also discovered that the HVDC cables tend to retract to their original shape after the force is removed and are capable of resisting forces several times their rated capacity without permanent deformation. However, since the elastic capacity of the cables are reached during most interaction scenarios, if the cables are electrified during the impact, burning of the insulation layer may be caused by short circuits between core and lead sheath. If cable routes that are prone to ice interaction are selected for electrification of future offshore developments, it is recommended to further investigate the sidewall and tensile strength of the specific selected cables since the loading situation and failure criteria of the conventional mechanical testing of subsea cables may differ from the requirements of the iceberg interaction.

Summary

Considering the results of the C-CORE work, the risk associated with subsea cables and glacial ice does now appear to be as severe as was assumed at the onset of this project.





7.7 Environmental and Regulatory Risk Identification

Compared to the proportions for Canada as a whole, total energy generation in NL is comprised of 34% more hydroelectricity (95% hydro)

There is significant potential for pursuing the conversion to renewables in NL and it has been well-established that NL boasts some of the best conditions in the country for wind power.

The Environmental and Regulatory Risk Identification process identified the regulatory and environmental considerations for potentially affected ecosystem components, including those in both the marine and terrestrial environments. This risk identification study is unique in that the project areas of West Orphan Basin and Labrador South would be farther from shore and in deeper water than most other electrification projects around the world.

The desktop study was comprised of several components, each of which had associated methodologies, including:

- a literature review;
- risk mapping;
- the development of a database;
- ranking the relative importance of environmental and regulatory barriers.

The Environmental and Regulatory Risk Identification process

The study area included the coastal environment from the coast of Labrador and Goose Bay to the Northern Peninsula of insular Newfoundland, and the north coast of the island to the Avalon Peninsula.

- The terrestrial environment component comprised the entire province, and the marine component was comprised of the entirety of the NL shelves region from the northern tip of Labrador to the southern Grand Banks.
- This bioregion is heavily influenced by the cold Labrador Current moving south from west Greenland and the warm Gulf Stream moving north from the eastern United States. The mixing of these currents at the Grand Banks creates productive waters for plankton and fish communities.
- Seasonal pack ice is also a notable defining characteristic of this bioregion (White, Edwards, & Dooley, 2018). This region covers a large latitudinal range and has a high seasonality with a mix of arctic and temperate species sharing the water at different times.

Spatial representation of the environmental and regulatory variables/barriers was necessary due to the immense amount of information involved. The figure below illustrates the process that was followed to create a map depicting environmental and regulatory risk. Risk was defined as “the probability that an environmental or regulatory variable would interact with the electrification options, and weighted for the size (i.e., magnitude) of the variable/barrier, and the consequences of interaction (e.g., insignificant to catastrophic).

The Process of Creating an Environmental and Regulatory Risk Map:

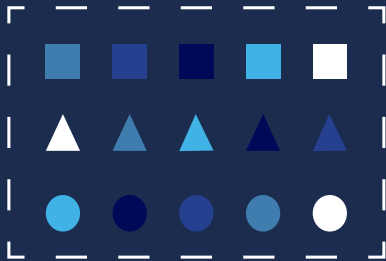
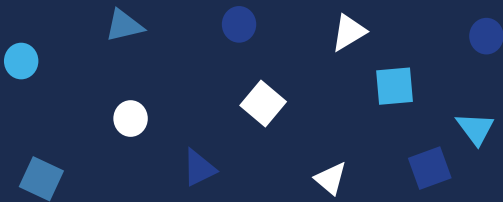
- 1

Research all public geospatial/GIS data
- 2

Create a centralized database

We’ve compiled a wealth of environmentally sensitive and culturally important areas to take into account.

Next, we gathered all data in a single place to compare risks.



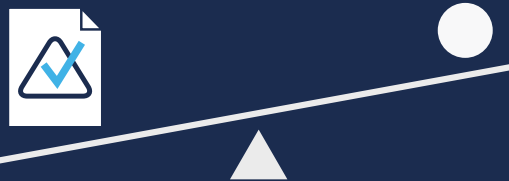
- 3

Standardize all data formats
- 4

Ranking inherent magnitude of barrier

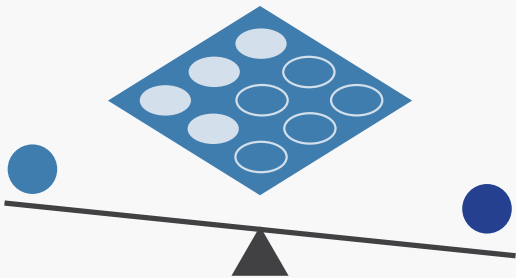
After gathering over 90 datasets we converted each into usable shapefiles, then trimmed to the area of interest.

Each dataset was ranked using multiple criteria including proximity risk and risk of regulatory and environmental consequences.



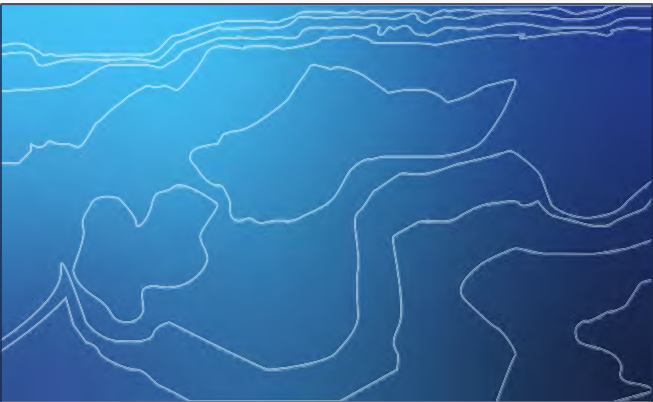
5 Ranking comparative importance

Once ranked on inherent risk, we categorized all datasets into 11 groups, then arranged them from high to low risk for this project.



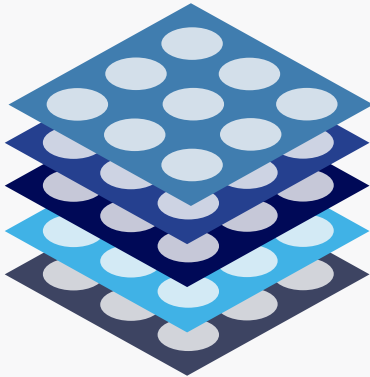
7 Create and compile final risk heatmap

Taking all dataset risk factors into account, we created an interactive “heatmap” based on the amount of risk in an area.



6 Calculation of overall risk

After all the datasets were ranked twice, we assigned an overall risk score for each layer.



Risk Map Constraint Groups and Overall Score

Overall Risk Score (IW/0.197) *MB		Importance Weight (High - Low)										
		Protected Habitat	Protected Park/ Reserve/ MBS	Environ- mentally Sensitive	Protected Water Resource	Protected River	Offshore Construc- tion	Culturally Significant Area	Industry/ Transporta- tion Infrastructure	Federal Land	Onshore Construc- tion	Land Ownership Consideration
		0.197	0.190	0.133	0.112	0.099	0.086	0.070	0.039	0.037	0.026	0.011
Magnitude of Barrier	100	100.0	96.4	67.5	56.9	50.3	43.7	35.5	19.8	18.8	13.2	5.6
	90	90.0	86.8	60.8	51.2	45.2	39.3	32.0	17.8	16.9	11.9	5.0
	80	80.0	77.2	54.0	45.5	40.2	34.9	28.4	15.8	15.0	10.6	4.5
	70	70.0	67.5	47.3	39.8	35.2	30.6	24.9	13.9	13.1	9.2	3.9
	60	60.0	57.9	40.5	34.1	30.2	26.2	21.3	11.9	11.3	7.9	3.4
	50	50.0	48.2	33.8	28.4	25.1	21.8	17.8	9.9	9.4	6.6	2.8
	40	40.0	38.6	27.0	22.7	20.1	17.5	14.2	7.9	7.5	5.3	2.2
	30	30.0	28.9	20.3	17.1	15.1	13.1	10.7	5.9	5.6	4.0	1.7
	20	20.0	19.3	13.5	11.4	10.1	8.7	7.1	4.0	3.8	2.6	1.1
	10	10.0	9.6	6.8	5.7	5.0	4.4	3.6	2.0	1.9	1.3	0.6
	4	4.0	3.9	2.7	2.3	2.0	1.7	1.4	0.8	0.8	0.5	0.2

Table 41. The Process of Creating an Environmental and Regulatory Risk Map

Extreme

High

Medium

Low

Note: The colours above represent the Magnitude of Barrier where:

The scoring is based on best judgement, and as such the depiction of risk is highly subjective. Areas which are mapped as higher risk should not be interpreted as “no-go” zones, the same as areas with lower risk should not be interpreted as “the path of least resistance.” For example, one limitation is simply the availability of spatial data; there is much more data that is available on the island of Newfoundland as compared to the Labrador portion of the province. Also, some types of data simply cannot be mapped, such as public receptiveness to new developments and new technologies, knowledge which would be gained from consultations with locals and Indigenous peoples, state of the economy, and changing regulations or environments.

Regulatory Framework

In 2019 the Canadian Energy Regulator Act (CER Act) came into effect to ensure that Offshore Renewable Energy (ORE) projects in Canada follow the highest safety and environmental protections. The CER Act provides the Canadian Energy Regulator (CER) complete authority over the entire life cycle of proposed ORE projects. Depending on the size and nature of the project the CER may call upon the Impact Assessment Agency of Canada to aid in the environmental review process (i.e., joint-review panel). Currently there are no regulations for ORE projects but there is an ongoing initiative led by Natural Resources Canada (NRCan) to fill this gap in the current Canadian legislation.

Regulatory Barriers to Offshore Renewables

1 Electrical Power Control Act

One of the largest barriers for any ORE project in Newfoundland and Labrador is Section 14.1 of the provincial Electrical Power Control Act, 1994 which gives Newfoundland and Labrador Hydro (NL Hydro) the exclusive right to supply, distribute, and sell electrical power or energy. This completely forbids any other industry from developing power (whether it be renewable or not) and from using it for its own operational purpose (Stapleton, 2017; Mercer, 2016). NL was the last province in Canada to implement a net-metering policy. As of July 2017, Newfoundland and Labrador electricity customers can generate power from renewable sources for their own use and supply surplus power to their electricity utility. The provincial cap on supplying surplus energy is 5 MW, which only permits small-scale non-commercial developments, thus guaranteeing continued demand for power from the Crown. This restriction makes it currently impossible for industry to develop clean energy resources to meet their emissions reductions objectives.

2 Moratorium on Wind Energy

Currently there is no legal avenue to pursue wind energy with a capacity over 1MW in Newfoundland. The moratorium on wind energy was established in 2006 through Order in Council OC2006-026 and included Labrador, until this portion of the province was removed in 2019. The motive to remove Labrador from the Order was to address the increasing age of isolated diesel generating facilities for small communities and provide alternative options for when those facilities were no longer operational.

3 Newfoundland and Labrador Renewable Energy Plan

On December 15th, 2021, the Newfoundland and Labrador Department of Industry, Energy and Technology (NLDIET) announced its Renewable Energy Plan. This plan outlines the long-term vision for renewable energy projects in Newfoundland and Labrador and its role in fighting climate change. The focus areas of the Renewable Energy Plan include energy uses and markets, regulatory framework, partnerships, innovation and industry support, training, and jobs.

In the plan NLDIET recognizes the current barriers for ORE projects in the province and has created a short-term goal to pursue opportunities to support industry in transitioning from fossil fuel-powered operations to renewable energy. Provincial regulatory framework actions include review of the wind moratorium policy on the Island Interconnected Electricity System and to review the provisions of the EPC act regarding the exclusive right to supply, transmit, distribute, and sell electrical power or energy. While it is important to draw attention to the province’s objectives to review these policies and regulations, there is currently no commitment to amend in favour of customer-owned generation and distribution.

Potential Project Interactions and Possible Mitigations

The following table presents a list of potential effects and mitigations for various project components. Other effects and mitigations may become apparent when specific siting, technologies, and scope of construction are defined.

Project Component	Habitat Type	Potential Effects	Potential Mitigations
Transmission line construction or other land-based construction and vegetation clearing	Onshore (forest/ shrubland/ meadow)	<ul style="list-style-type: none">Habitat alteration/lossIncreased access leading to direct mortalityChanges to migration routes and timingSensory disturbanceDirect mortalityPredator/prey availability changesDecreased foraging abilityExposure to herbicides	<ul style="list-style-type: none">Use existing roads or other already disturbed areasAvoid construction during the breeding seasons for wildlife species within the area (i.e., caribou calving season, bird breeding season)Use shortest path between generation to output site if possible
	Onshore (freshwater/ streams/rivers/ lakes)	<ul style="list-style-type: none">Harm to fish habitat in overland migratory corridors (i.e. salmon,eel) via increased turbidity, noise, and vibrationBlockages preventing upstream passages (such as by improperly installed culverts)	<ul style="list-style-type: none">Conduct activities outside of spawning timesConduct during low-flow periods or when waters are frozenMaintain appropriate buffer zonesRegularly test water quality (such as TSS, nutrients) and monitor for changes
Construction of components for subsea cables, including grounding facility construction, cable pulling, high density drilling, seabed trenching and cable laying	Nearshore and Offshore	<ul style="list-style-type: none">Increased trubidity from dredging, levelling, and trenching which harms fish and benthic organismsSensory disturbances from noise and lights (scares birds, underwater noise masks communication amongst whales)Accidental release of oils and other contaminants from vesselsMarine mammal- vessel collisionsLoss of benthic habitatDecline in water qualityBioaccumulation of contaminants	<ul style="list-style-type: none">A trained marine mammal observer (MMO) should be on board to record marine mammal and sea turtle sightings, and to help with navigation to avoid themRouting must be planned to avoid/coordinate with other ocean users Avoid construction during the breeding season for wildlife species within the area (i.e., bird breeding season)Ensure all vessels are equipped with pollution control materials and personnel follow appropriate procedures

Project Component	Habitat Type	Potential Effects	Potential Mitigations
Electrification and operation phase for subsea cables	Nearshore and Offshore	<ul style="list-style-type: none">Depending on proximity to cables, magnetic field that is generated can be detected by salmon, eels, and whales causing them to avoid the area (50-100 m for bipolar mode of operation, 500m for monopolar)Electric field that is generated can be detected locally by sharks/skates/rays, which has small effect on their prey detection and navigation abilitiesMaintenance inspections of the cable by ROVs may disturb wildlife nearby to a small degree	<ul style="list-style-type: none">Sheathing must be designed to block electromagnetic fieldsUse small/quiet ROVs for under-water inspections if possible
Construction and operation of wind turbines	Onshore	<ul style="list-style-type: none">Habitat loss or fragmentation of terrestrial habitatFragmentation of migratory pathwaysAvoidance behavior for certain wildlife speciesAvian or bat collisions with turbinesPossible siting along the Atlantic Migratory Bird Flyway or a bat migratory pathPossible impacts to marine protected areasPossible fragmentation of migratory pathways of listed species such as Northern Right WhaleLoss of benthic habitatAvoidance behavior for certain wildlife species (e.g., noise-sensitive whales, seabirds)Impacts to nearshore and offshore fisheries	<ul style="list-style-type: none">Conduct pre-siting surveys to determine presence of birds and batsAvoid construction near sensitive breeding habitat (e.g. caribou calving areas, raptor nesting areas) to minimize disruptionsConsider design elements such as minimal lighting to avoid attracting birds and batsAdhere to industry standards limiting noise levelsAvoid construction near sensitive breeding habitat (e.g. seabird colonies) to minimize disruptionsConsider design elements such as minimal lighting to avoid attracting birdsAdhere to industry standards limiting noise levels
Construction and operation of new hydroelectricity generating facilities	Onshore	<ul style="list-style-type: none">Habitat loss or fragmentation of terrestrial habitatFragmentation of migratory pathwaysAvoidance behavior (displacement) for certain wildlife speciesMethylmercury contamination through food web modifications	<ul style="list-style-type: none">Use existing hydro facilities and infrastructure as much as possibleMinimize the size of previously un-flooded terrestrial habitatAvoid sensitive wildlife habitats (e.g. caribou calving areas, pine marten critical habitat)

Project Component	Habitat Type	Potential Effects	Potential Mitigations
Construction and operation of reservoir pumped storage facilities	Onshore	<ul style="list-style-type: none">Habitat loss or fragmentation of terrestrial habitatFragmentation of migratory pathwaysAvoidance behavior (displacement) for certain wildlife speciesDecreased water quality	<ul style="list-style-type: none">Use existing water bodies rather than creating new man-made reservoirsEnsure appropriate measures are in place to prevent entrapment of migratory aquatic speciesMaintain appropriate buffers around waterways during construction activities
	Onshore	<ul style="list-style-type: none">Habitat loss or fragmentation of terrestrial habitatFragmentation of migratory pathwaysAvoidance behavior (displacement) for certain wildlife species	<ul style="list-style-type: none">Avoid construction during the breeding season for wildlife species within the area (i.e., caribou calving season, bird breeding season)Ensure proper pollution control procedures and equipment are in place
Construction and operation of hydrogen storage facilities	Nearshore	<ul style="list-style-type: none">Possible impacts to marine protected areasPossible fragmentation of migratory pathways of listed speciesImpacts to nearshore fisheries	<ul style="list-style-type: none">Avoid construction during the breeding season for wildlife species within the area (i.e., seabird breeding season)Minimize noise wherever possibleEnsure proper pollution control procedures and equipment are in place

Table 42. Potential Effects and Mitigations of Various Project Components

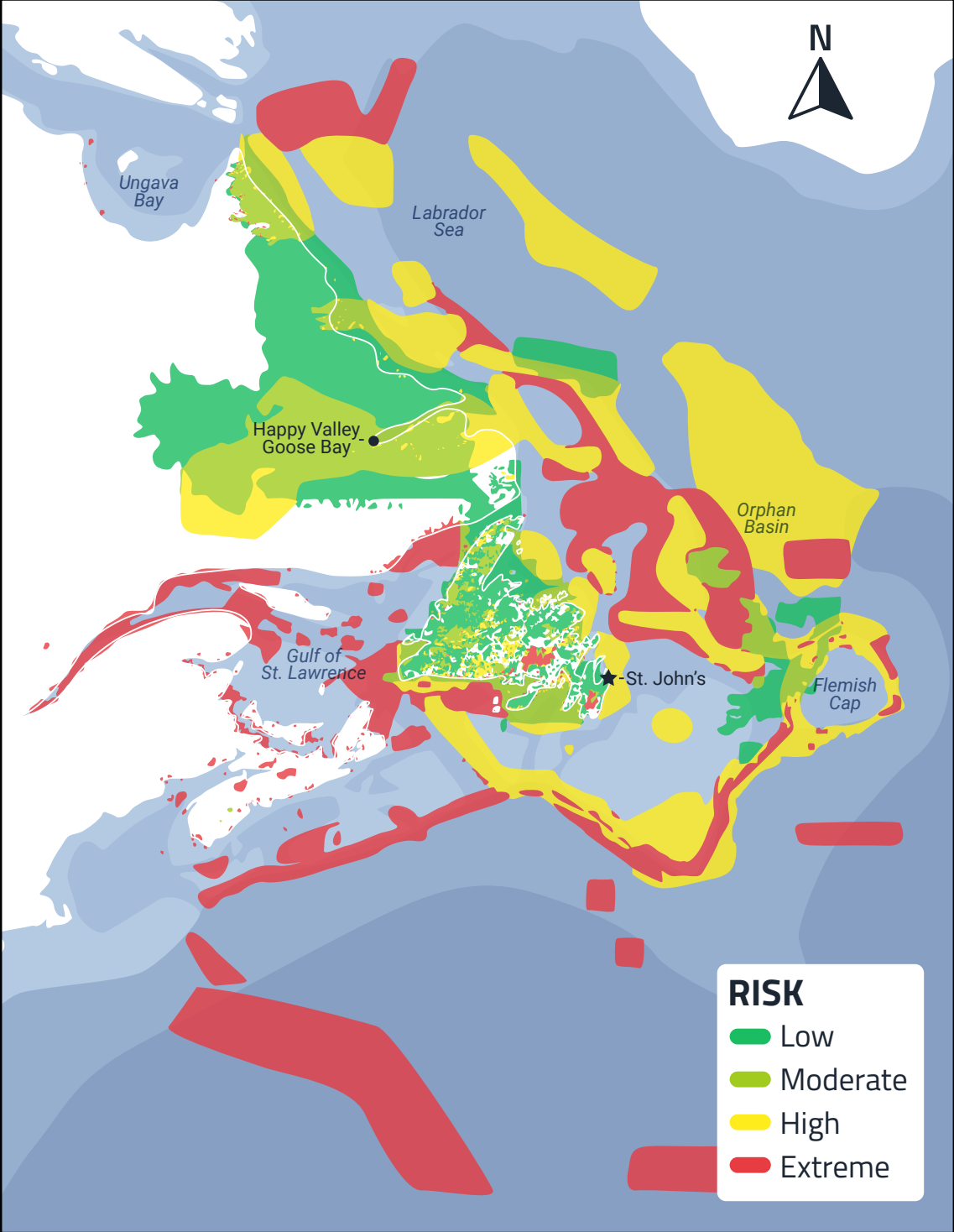


Figure 132. Risk Assessment Map

Summary

There are some areas of the province where renewable energy projects would be more favorable from a regulatory perspective, as is shown in the figure above. The regulation for renewable energy development is under review, but at the time of writing this report the regulations did not allow for private industry to develop renewable energy projects.



7.8 GHG Emissions Opportunity Assessment

The magnitude of GHG emission reduction is highly dependent on the renewable energy source used to electrify the FPSO for production operations.

Electrifying FPSOs with renewable energy (RE) reduces dependence on fossil fuels, hence reducing greenhouse gas (GHG) emissions, carbon tax payment obligations, and releases of airborne pollutants that are potentially harmful to human and environmental health.

As such, six RE systems (i.e., generation, storage, and/or transmission) have been evaluated and assessed for new FPSO developments in NL's offshore. Refer to the Table and Figure below.

Generation	Storage	Transmission
Onshore Wind	Pumped Hydro	Subsea Cable
Onshore Wind	Hydrogen (cryogenic to fuel cell)	Shipping
Hydroelectric	Integrated Reservoir	Subsea Cable
Hydroelectric	Hydrogen (cryogenic to fuel cell)	Shipping
Utility Supply	Integrated Reservoir	Subsea Cable
Offshore Wind Displacement	- ¹	Subsea Cable

-¹ No storage required.

Table 43. Renewable Energy Technologies Assessed



Figure 133. Renewable Energy Technology Roadmap

Methodology

The GHG emissions opportunity assessment was conducted using life cycle assessments (LCAs) of RE technologies. LCAs are used to help qualify environmental burdens and enhance the consistency of RE technology comparisons. This method is particularly useful for technologies that do not emit significant GHGs while in operation as it accounts for emissions from the cradle to the grave.

In terms of emissions, LCAs evaluate emissions from one-time upstream, ongoing, and one-time downstream sources. One-time upstream emissions arise from extraction, manufacture, and transportation of materials as well as on-site construction. Ongoing emissions are associated with operation and maintenance activities. One-time downstream emissions arise from activities associated with decommissioning, disassembly, and ultimate disposal of equipment and materials.

Life cycle GHG Emission Factors (EFs) in the table below are provided in units of grams (g) of carbon dioxide equivalents (CO₂e) per kilowatt-hour (kWh). CO₂e is a metric commonly used to compare emissions across various GHGs, by converting emissions to their global warming potentials (GWPs) (i.e., the amount of energy a GHG will absorb relative to carbon dioxide (CO₂)).

Technology		Total Life Cycle EF (g CO ₂ e · kWh ⁻¹)
Generation	Onshore Wind	12
	Offshore Wind	
	Hydroelectric ¹	13
	Utility Supply ²	
Storage	Pumped Hydro	7.4
	Hydrogen ³	
Transmission	Subsea Cable	NA ⁴
	Shipping ⁵	

¹ Includes life cycle emissions associated with integrated reservoir storage.
² Utility supply assumed to be entirely fed by hydroelectricity.
³ Derived from Spath and Mann (2004).
⁴ NA=value not established as it is anticipated that GHG emissions generated from these transmission technologies will be negligible as LCAs will sufficiently account for such emissions.
⁵ Cryogenic storage to fuel cell shipping.

Table 44. Life Cycle GHG Emission Factors

Emissions Assessment

To facilitate GHG emission calculations for RE technologies, the following inputs were required:

- Energy density of liquid hydrogen is 33 kWh per kg of H² produced;
- Conversion factors for energy (kWh to GWh) and mass (grams to kilograms to tonnes);
- Life cycle GHG EFs for RE technologies (Ref. Nicholson, S.; Heath, G. Life Cycle Emissions Factors for Electricity Generation Technologies. Natl. Renew. Energy Lab. 2021, 1–4);
- National Inventory Report EF for fossil fuel-based electricity generation in NL(Ref. Environment and Climate Change Canada. National Inventory Report 2019-2021: Greenhouse Gas Sources and Sinks in Canada; Ottawa, ON, 2021);
- Technical project details.

GHG emissions generated by RE technologies to power a new FPSO unit are provided in the table adjacent. In all instances, 438 GWh per FPSO per year was used. It should be noted that 438 GWh is equivalent to 50 MW per year (i.e., 50 MW over the course of 8,760 hours).

RE Technology	Emission Factor (g CO ₂ e·kWh-1)	Activity (GWh)	GHG Emissions (tonnes CO ₂ e)
Onshore Wind, Pumped Hydro & Subsea Cable			
Generation	12	438	5,256
Storage	7.4	438	3,241
Annual GHG Emissions			8,497
Onshore Wind, Hydrogen & Shipping			
Generation	12	438	5,256
Storage	6.5	438	2,847
Annual GHG Emissions			8,103
Hydroelectric, Integrated Reservoir & Subsea Cable			
Generation ¹	13	438	5,694
Annual GHG Emissions			5,694
Hydroelectric, Hydrogen & Shipping			
Generation	13	438	5,694
Storage	6.5	438	2,854
Annual GHG Emissions			8,548
Utility Supply, Integrated Reservoir & Subsea Cable			
Generation (hydropower) ¹	13	438	5,694
Generation (2019 mix) ²	28	438	12,264
Annual GHG Emissions [hydropower]			5,695
Annual GHG Emissions [2019 mix]			12,264
Offshore Wind Displacement & Subsea Cable			
Generation - Offshore Wind	19	313	5,947
Generation - Fossil Fuel	863	125	107,875
Annual GHG Emissions			113,822

¹ Includes integrated reservoir storage.
² Includes combustion, renewables, unallocated energy, and sulfur hexafluoride emissions

Table 45. GHG Emission from RE Technologies

Generation Technology Switch Reducation Assessment

- Of the evaluated RE technologies, the hydroelectric power option with integrated reservoir and subsea cable yielded the lowest GHG emissions. It should be noted that these emissions were calculated based on the assumption that the hydropower life cycle EF would sufficiently account for emissions associated with this RE technology.
- GHG emissions from utility supply were equivalent to the hydroelectric power option with integrated reservoir and subsea cable since the technologies are essentially the same. This is based on the assumption that the NL utility supply will be solely powered by hydroelectricity at the time of FPSO development. The highest GHG emissions were associated with the offshore wind displacement and subsea cable option due to the requirement for fossil fuels to supplement RE technology.

To evaluate GHG emissions mitigated by implementing RE technologies, annual GHG emissions from RE technologies were compared to those from traditional energy sources. For context, annual GHG emissions associated with generating 438 GWh using fossil fuels contributes 377,994 tonnes of CO₂e. Emissions associated with fossil fuels were calculated using the fossil fuel EF for the offshore wind displacement scenario. GHG emission reductions (expressed as percentages) associated with switching from fossil fuel dependence to RE technologies are provided in the table below.

RE Technology	GHG Emissions (tonnes CO ₂ e)	Fossil Fuel to RE Reduction
Onshore Wind, Pumped Hydro & Subsea Cable Emissions	8,497	97.75%
Onshore Wind, Hydrogen & Shipping Emissions	8,103	97.86%
Hydroelectric, Integrated Reservoir & Subsea Cable Emissions	5,694	98.49%
Hydroelectric, Hydrogen & Shipping Emissions	8,548	97.74%
Utility Supply, Integrated Reservoir & Subsea Cable Emissions [100% hydropower]	5,694	98.49%
Utility Supply, Integrated Reservoir & Subsea Cable Emissions [2019 Mix]	12,264	96.76%
Offshore Wind Displacement & Subsea Cable Emissions	113,822	69.88%

Table 46. Generation Technology Switch Reduction Assessment

- Implementing RE technologies on new FPSO developments has the potential to reduce GHG emissions significantly. The use of life cycle GHG EFs throughout this assessment ensures emissions for all life stages of RE technologies are included. Estimates used to generate life cycle EFs are based on literature and modelling outputs available during the generation of this assessment and are anticipated to change as technology evolves and more studies are conducted.
- GHG emissions provided in this assessment are subject to change as life cycle EFs for other components (e.g., overland transmission, subsea cable placement, hydrogen production facilities) become available.
- The switch from fossil fuel reliance to RE technologies on new FPSO developments has the potential to reduce power generation GHG emissions between 69.88 and 98.49%.
- Of the RE technologies evaluated in this assessment, it was determined that hydropower (and utility supply when NL has sole reliance on hydropower) annual GHG emissions were the lowest, and offshore wind displacement GHG emissions were the highest.
- The requirement of fossil fuels to supplement offshore wind power generation capacity was the driver of GHG emissions, accounting for approximately 95% of annual emissions. Emissions associated with offshore wind displacement could be significantly reduced if supplemental energy was provided by an alternative source.

The implementation of RE technologies could also be considered for existing FPSO developments. As such, GHG emission data was used to determine the impact of switching power generation from fossil fuels to RE technologies.

GHG reductions from the RE technology transition were only considered for power generation, although it is anticipated that as technology advances, more functions will be amenable to electrification. Emission data from two existing FPSO developments are provided in the table below. The data used to evaluate reductions was from the 2020 operational year.

Emission Source	GHG Emissions (tonnes CO ₂ e)	% of GHG Emissions
FPSO #1		
Power generation (fuel gas)	251,878	15.0%
Power generation (diesel)	12,803	0.8%
Other combustion (gas compressors)	383,717	22.9%
Other combustion (diesel)	3,700	0.2%
Other combustion ¹	1,025,512	61.1%
Total GHG Emissions	1,677,610	100.0%
FPSO #2		
Combustion (power generation)	124,683	68.1%
Combustion (diesel)	2,512	1.4%
Other emissions ¹	56,024	30.6%
Total GHG Emissions	183,219	100.0%
¹ Includes flaring, venting, and fugitive emissions.		

Table 47. Existing FPSO Emission Data for 2020

The existing infrastructure and power requirements have a significant effect on the magnitude of GHG emissions of FPSOs. For FPSO #1, 15.8% of emissions could be negated if RE technologies were implemented whereas 68.1% of emissions could be negated in FPSO #2. While GHG emissions associated with power generation vary widely between FPSOs, there is an opportunity to achieve measurable GHG emission reductions by transitioning away from traditional energy sources (i.e., fossil fuels) for power generation.



8. Economics

Why Economics is a Barrier to Offshore Electrification

Like most business decisions, the decision to electrify offshore assets is one that is based on both technical and economic merit. In the absence of regulations or constraints, the decision to electrify offshore will only be made if it is determined economically feasible to do so (in the traditional sense of economics). Because of this, it was determined that economics of offshore electrification with renewable energy is one of the most significant barriers to implementing electrification solutions for offshore Newfoundland and Labrador.

This section discusses some of the economic factors that are contributing the overall economic barrier, explores the shifting economic/market landscapes in which tomorrow's offshore assets will operate, investigates steps to remove the economic barrier, and provides recommendations on further works to advance the future implementation of offshore electrification solutions.

Contributing Economic Factors – Fortifying the Barrier

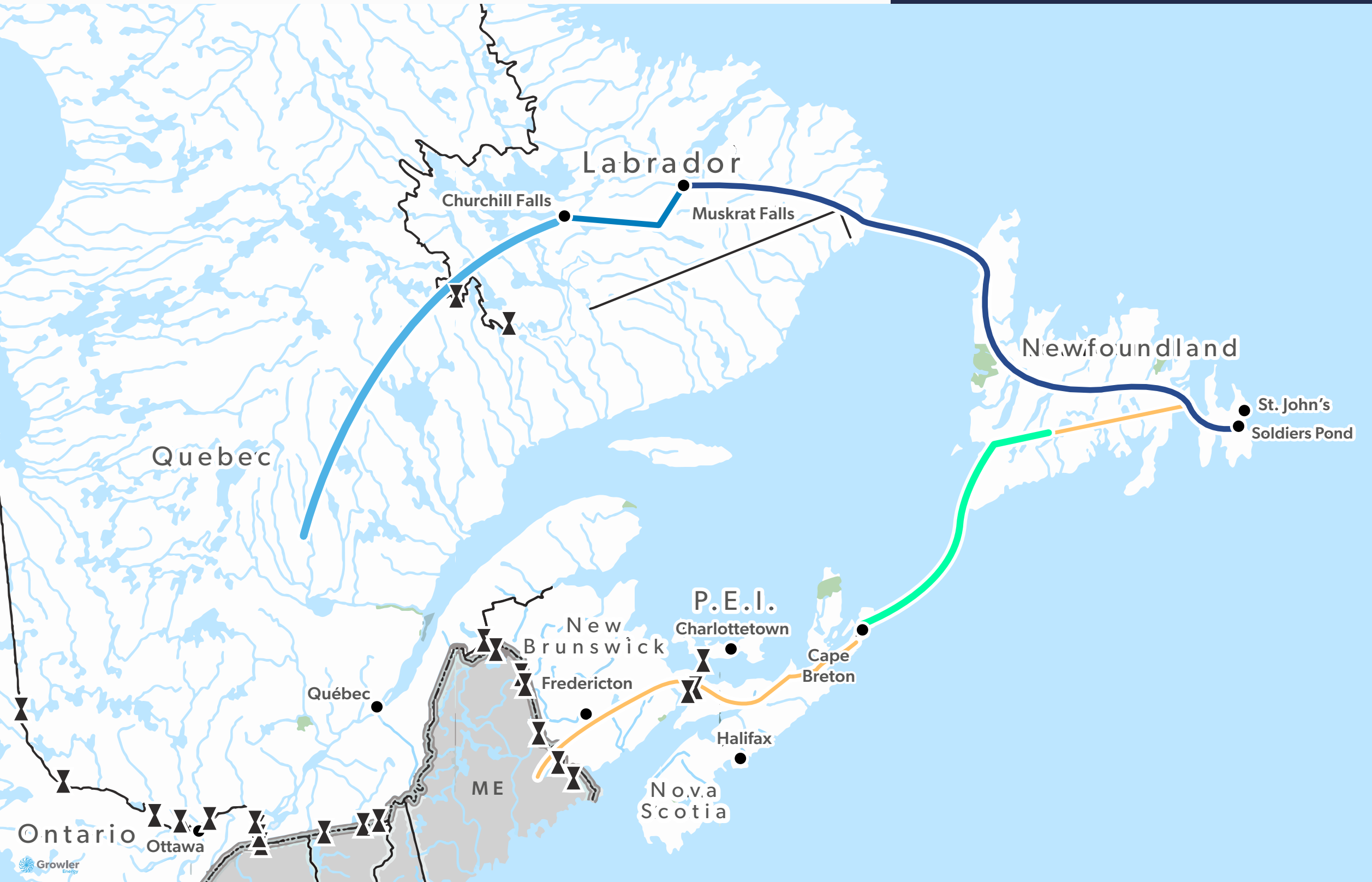
Throughout the course of the Barriers to Offshore Electrification study, it was determined that economics is one of the most significant barriers to the electrification of offshore Newfoundland and Labrador for several reasons including:

1. Market Competition for Renewable Electricity
2. Levelized Cost of Electrification Alternatives
3. Availability of Natural Gas as a Zero-Cost Alternative
4. Micro-Myopia – Exploring Electrification Independent of Overall Asset Economics

Market Competition for Renewable Electricity

Major Electricity Transmission Lines in Atlantic Canada

Newfoundland and Labrador renewable electricity is likely to be in demand as the North American grid phases out carbon intensive generation sources such as coal. Offshore electrification uses will face market competition that could influence energy costs.



Atlantic Canada Powerlines

- Transmission Power Lines**
- Churchill Falls to Quebec
 - Existing Infrastructure
 - Labrador-Island Transmission Link
 - Maritime Transmission Link
 - Muskrat Falls to Churchill Falls

- Existing Interconnections
 - Parks
 - Rivers
 - Water Bodies
- 0 100 200 400 km
- N

Source for Map on Major Electricity Transmission Lines in Atlantic Canada:

<https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2018/market-snapshot-newfoundland-joins-interconnected-north-american-electricity-grid.html>

Map produced by NEB, April 2018. The map is a graphical representation intended for the general informational purposes only.

Natural Gas as a Zero-Cost Alternative

Currently, natural gas is available to operators as a by-product of crude oil production. A small percentage of the natural gas produced is used for onboard generation/powering equipment and most of the natural gas is reinjected for pressure maintenance, enhanced recovery, or stored for future use. The natural gas feedstock used in generation is therefore considered a zero-cost alternative when used for onboard generation (excluding capital cost of generators).

There are challenges associated with the reinjection (reservoir capacity) and flaring (regulations and emissions) of natural gas. If the gas is not used for onboard generation, there are operational safety considerations and associated costs with managing the natural gas in the absence of an off-taker market to facilitate its sale.

Since the natural gas is effectively a zero-cost alternative for onboard power generation, it is a major economic barrier for the development of offshore electrification scenarios that have large capital costs.

Levelized Cost of Electrification Alternatives

The levelized cost of energy (LCOE) for electrification alternatives is a considerable barrier in the traditional sense of economics. In competition with natural gas as a zero-cost alternative, it is challenging to justify the installation of renewable energy electrification infrastructure.

The LCOE for the various alternatives considered in the economics section under the current maximum carbon tax scenario (\$170/tonne) of this study are presented in the figure below. In-situ renewables were previously screened in the concept selection phase as they were determined to be more expensive than the power from shore scenario. Future work should consider a more detailed economic comparison between power from shore and in-situ renewable alternatives. It is evident that the natural gas for onboard generation scenario is more cost-effective than renewable energy electrification alternatives, even under the maximum carbon tax scenario. Given the low carbon intensity of natural gas (when compared to other fossil fuel alternatives), the carbon tax would need to be approximately \$420/tonne to make the LCOE of renewable energy electrification alternatives comparable to that of natural gas for onboard generation.

In the absence of an off-taker market for the produced natural gas or additional constraints/regulations regarding the use of natural gas offshore, it is challenging to justify the implementation of offshore electrification solutions from a traditional economics view.

Micro-Myopia – Exploring Electrification Discretely from Overall Asset Economics

Under current circumstances, electrification/power generation opportunities are being evaluated as discrete projects for which the zero-cost natural gas alternative is more attractive. As the perception of economics changes, it will be increasingly important to consider electrification scenarios in the context of overall asset economics (i.e. is the asset still economic with the implementation of renewable energy electrification solutions?). While it may be slightly less economical overall, it may help protect the long-term viability of assets and hedge against future environmental, regulatory, and financial risks associated with increased emissions.

This view is currently a barrier to the implementation of renewable energy electrification scenarios as it resigns the argument for renewable electrification scenarios to a simple comparison of LCOE.

Turning of the Tides – Shifting Economic Landscapes

One thing is for certain, the view of economics is shifting from the traditional origins of viewing economics as a consideration of monetary value.

A new view of economics is emerging. The new view includes consideration of critically important topics such as social license to operate, environmental impact, and other topics that were ignored/neglected in the most traditional sense of economics.

Some key areas where there are ongoing changes that influence the future economics of offshore electrification are discussed below.

Brand Image and Social License to Operate

As public perception around the climate crisis and carbon intensive industries changes, it will be increasingly important for operators to consider actions to minimize their carbon footprint to maintain social license to operate and promote positive brand image in the global marketplace. This means that reducing carbon emissions will become increasingly important in maintaining public support for ongoing activities. This may eventually be favourable for the implementation of renewable energy electrification alternatives.

Availability of Investment Capital & Focus on Sustainable Assets

Over the last few years, there is an increasing shift in the behaviour of investment banking and financial investment firms towards sustainable investments. It is possible that in the future, there will be challenges associated with raising capital for investments associated with high levels of carbon emissions.

It is possible that renewable energy electrification alternatives can help secure the future supply of capital or maintain preferred interest rates by helping reduce the overall carbon footprint of offshore assets.

Possible Monetization of Natural Gas

As the world transitions from carbon intensive energy sources, there is an increasing demand for natural gas and lower carbon intensity fossil fuels. It is possible that the market for natural gas will expand to the point where there will exist a viable opportunity to monetize the natural gas through export sales.

Under the possible natural gas monetization scenario, the effective cost of natural gas for electricity generation then becomes the opportunity cost of the lost export sales. It is possible that under this scenario, renewable energy electrification will be more attractive than the continued use of natural gas for onboard generation.

Removing Barriers to Electrification

The following immediate steps can be taken to help remove the barriers to implementing renewable energy electrification alternatives for offshore Newfoundland and Labrador:

- 1. Continue Research and Development – While the technical solutions exist for offshore electrification scenarios, continued research and development can help reduce the costs and risks associated with the implementation of innovative alternatives in the harsh offshore Newfoundland and Labrador environment.
- 2. Refine Cost Estimates and Cost-Benefit Analysis for Offshore Electrification Alternatives – The economic analysis within this study is based on several high-level assumptions. It would be beneficial to pursue a more in-depth analysis of the different energy alternatives for powering offshore Newfoundland and Labrador assets. This will facilitate a better understanding of the gap that exists between natural gas onboard generation and renewable energy electrification scenarios.
- 3. Assess the Additional Benefits to Offshore Oil and Gas Producers from Offshore Electrification – It would be beneficial to undertake a broader analysis of the exogenous or by-product benefits that will be received by producers from the implementation of renewable energy electrification alternatives. The analysis within this study focused on the traditional sense of economics and didn’t consider the exogenous or by-product benefits that could bring significant value to producers.
- 4. Increase Confidence in the Availability of Low-Cost Renewable Energy – This study assumed that energy would be available from the Newfoundland and Labrador grid under the power from shore scenario. Further work should focus on identifying the amount of energy available under the power from shore scenario as well as the potential addition of generation that will be seen over the life of an offshore asset. Long term supply commitments will be critical to the implementation of a power from shore scenario.



9. Roadmap

SHORT TERM

TECHNICAL

Assess grid interconnection options based on reliability requirements, operational philosophy, cable economics and the levelized cost of energy. Investigate integrity of existing onshore transmission infrastructure, and future installations in detail to ensure capacity to support development of identified renewable energy generating resources.

In order to provide preliminary cable designs as a basis for accurate economic and technical comparisons of system alternatives, undertake Detailed system studies that better define:

- reactive compensation systems for AC systems
- converter configurations and controls for DC systems
- suitable turret system to accommodate FPSO rotation and disconnection

More detailed project specific requirements for each generating scenario are recommended as energy storage requirements are governed by daily and seasonal variations.

The capture of waste heat associated with the utilization of fuel cells in electricity production is an optimization area to explore.

A low emissions / low footprint strategy to explore further is pumped storage.

Near-shore wind developments have potential and additional investigation into these opportunities could be warranted.

The risks and opportunities of overcoming the offshore transmission challenges of subsea cables and hydrogen transmission should be explored further.

Industry and operators should explore what changes are required on their platforms to electrify their systems.

TECHNICAL & ECONOMICAL

Industry should advocate for continued development in a hydrogen economy, the development of H₂ bulk transport and storage options, and eventual use for offshore, as there are significant challenges to overcome to consider H₂ utilization offshore.

ECONOMICAL

It is recommended to conduct further research and analysis into the potential benefits of offshore electrification towards improving oil and gas recovery offshore NL.

ECONOMICAL & REGULATORY

A sensitivity and risk analysis of utility supply and market conditions, i.e. energy regulation and utility supply pricing, is warranted.

REGULATORY

Provincial and federal legislation for offshore wind needs to be developed.

Provincial and federal regulations for hydrogen transshipment needs to be developed.

If permits are required for altering bodies of water, then operators should apply early as the process is quite onerous and lengthy.

MID TERM

TECHNICAL

During the early stages of the electrified FPSO design, studies should be conducted concurrently with the NLSO customer application process to ensure engineering synergies and resources are best utilized. The following technical studies may include:

- Charging Current for the HVAC Transmission System
- Effective Grounding Study
- EMTP (Electro-magnetic Transient Program)
- NERC/CIP requirements

To complete a detailed risk analysis of cable routes, seabed surveys of cable routes and landfalls should be conducted to acquire detailed geotechnical data (furrows and pits) and higher resolution iceberg drift modelling should be done.

As the projects advance, additional landfall studies and activities, i.e. marine surveys, ice risk assessments, site visits, and trenching feasibility, will be necessary to optimize the design and better understand the risks.

Estimates used to generate life cycle EFs are anticipated to change as technology evolves and more studies are conducted. Thus, GHG emissions provided are subject to change as life cycle EFs for other components (e.g., on-land transmission, subsea cable placement, hydrogen production facilities) become available.

Further analysis into the use of electrolyzers offshore, for making gas turbines that are able to combust hydrogen / natural gas mixtures, is required.

Offshore transfer of hydrogen gas from ship to platform is a technical barrier to be developed.

ECONOMICAL

The cost of subsea cables should be explored further as it is likely that multiple facilities will be required to make a subsea cable cost competitive.

TECHNICAL

If cable routes that are prone to ice interaction are selected, further investigation into the sidewall and tensile strength of the specific cable is required since the loading situation and failure criteria of the conventional mechanical testing of subsea cables may differ from the requirements of the iceberg interaction.

Qualifying dynamic cables from an offshore wind facility to the FPSO is a technical barrier to overcome.

Qualifying deepwater dynamic cables for the North Atlantic, i.e. connection types, fatigue, ice interaction, etc. is a technical barrier to overcome.

For offshore wind significant storage capability would need to be developed to improved grid stability issues on the platform.

TECHNICAL & REGULATORY

Rigorous site-specific assessments are required for progressing onshore wind and pumped storage hydro systems.

REGULATORY & ENVIRONMENTAL

The potential effects and mitigations for various project components may change when specific siting, technologies, and scope of construction are defined. Thus, a more detailed environmental and regulatory risk assessment, including stakeholder consultations, should be conducted prior to project initiation.

ENVIRONMENTAL

The footprint of onshore wind facilities needs to be closely considered from an environmental and cultural perspective.

The footprint of offshore wind facilities needs to be closely considered from an environmental and cultural perspective.

Appendix

Appendix A: Acronym Legend

- **A-CAES** - Adiabatic ('no thermal losses') Compressed Air Energy Storage
- **AC** - Alternating current
- **AFT** - Alternatives to Flowline Trenching
- **BMH** - Beach Manhole
- **Bbl** - Barrel of crude oil
- **C-CAES** - Conventional Compressed Air Energy Storage
- **C-CORE** - Centre for Cold Oceans Resources Engineering
- **CAD** - Computer Aided Design
- **CAES** - Compressed Air Energy Storage
- **CANTAT-1** - Canada TransAtlantic Telecommunications
- **CANTAT-2** - Second Canadian transatlantic telephone cable
- **CAPEX** - Capital Expenditures
- **CCS** - Carbon capture and storage
- **CER** - Canadian Energy Regulator (CER)
- **CER Act** - Canadian Energy Regulator Act
- **CIP** - Clean-in-place
- **CO2** - Carbon dioxide
- **CO2e** - Carbon dioxide equivalents
- **C-NLOPB** - Canada-Newfoundland and Labrador Offshore Petroleum Board
- **Cm** - Centimeter
- **DC** - Direct Current
- **EF** - Environmental footprint
- **EFs** - Emission factors
- **EMTP** - Electro-magnetic transient program
- **EPC** - European patent convention
- **ERF** - Emissions reduction fund
- **ESG** - Environmental, social & governance
- **FACTS** - Flexible Alternating Current Transmission
- **FEA** - Finite Element Analysis
- **FPSO** - Floating Production Storage and Offloading
- **GHG** - Greenhouse gas
- **GW** - Gigawatt
- **GWPs** - Global warming potentials
- **GWh** - Gigawatt-hour
- **HDD** - Horizontal Directional Drilling
- **HDPE** - High-density polyethylene
- **HPTE** - Hydroxychlor
- **HV** - High Voltage
- **HVAC** - High Voltage Alternating Current
- **HVDC** - High Voltage Direct Current
- **HVGB** - Happy Valley Goose Bay
- **IPCC** - Intergovernmental Panel on Climate Change
- **IPPs** - Independent Power Producers
- **IRC** - Integrated Return Cable
- **KV** - Kilovolt
- **Km** - Kilometer
- **kN** - Kilonewton
- **kWH** - Kilowatt hour
- **LCAs** - Life cycle assessments
- **LCOE** - Levelized cost of electricity
- **LFAC** - Low Frequency Alternating Current
- **LH₂** - Liquefied hydrogen
- **LIL** - Labrador-Island Link
- **LNG** - Liquefied natural gas
- **M** - Meter
- **MMBtu** - Metric million british thermal unit
- **MMO** - Marine Mammal Observer
- **MPa** - Megapascal
- **MVDC** - Medium Voltage Direct Current
- **MW** - Megawatt
- **MWh** - Megawatt-hour
- **Mm** - Millimeter
- **NERC** - North American Electric Reliability Corporation
- **NG/H** - Natural gas/ hydrogen
- **NH₃** - Ammonia
- **NIMBY** - Not In My Backyard
- **NL** - Newfoundland and Labrador
- **NLDIET** - Newfoundland and Labrador Department of Industry, Energy and Technology
- **NLH** - Newfoundland Labrador Hydro
- **NLSO** - Newfoundland and Labrador System Operator
- **NPV** - Net present value
- **NRCan** - Natural Resources Canada (NRCan)
- **NS** - Nova Scotia
- **NUGs** - Non-Utility Generators
- **O&M** - Operations & maintenance
- **OPEX** - Operating Expenses
- **ORE** - Offshore Renewable Energy
- **ORER** - Offshore renewable energy regulations
- **PEM** - Polymer Electrolyte Membrane
- **PFS** - Power from Shore
- **PMS** - Power Management System
- **POI** - Point of Interconnection
- **PSH** - Pumped Storage Hydro
- **R&D** - Research & Development
- **R&D - Research & development**
- **RD&D** - Research, Development & Demonstration
- **RE** - Renewable Energy
- **ROV** - Remotely operated underwater vehicle
- **ROW** - Right of Way
- **SWOT** - Strengths, weaknesses, opportunities & threats
- **TJ** - Terajoules
- **TLP** - Tension leg platform
- **TRL** - Technology readiness level
- **TWh** - Terawatt-hour
- **V** - Voltage
- **VSC** - Voltage Source Converter
- **WTG** - Wind Turbine Generator
- **XLPE** - Cross linked polyethylene
- **XLPE** - Cross-Linked Polyethylene

Appendix B: References

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