Newfoundland & Labrador Energy Innovation Roadmap: Priority Identification (Phase 1)

Recommendations for Innovation Priorities

Final Report

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E4tech orioninnovations

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Contents

List of Figures

List of Tables

Glossary

ACOA – Atlantic Canada Opportunities Agency

AEA – An environmental consultancy, operating in the UK, Europe, the US and China

Aquafinca – (Honduras) One of the world's largest Tilapia Farms

Avista – (US) A regulated energy utility

CESI RICERCA - (Italy) Electrical systems research group

CIEMAT - (Spain) Public research agency for excellence in energy and environment

CNA - College of the North Atlantic (Newfoundland and Labrador)

CNG – Compressed Natural Gas – in this context marine transportation of natural gas in large vessels.

CREST – Centre for Renewable Energy System Technology, Loughborough, UK

DEWI – Deutsche Winderenergie Institut, Germany

DTU/RISO - Risø is the National Laboratory for Sustainable Energy at the Technical University of Denmark - DTU

EDF – Electricite de France, international energy utility

EPRI – (US) Electric Power Research Centre

Eskom - generates, transmits and distributes electricity primarily in South Africa and into other parts of the continent

GBS - concrete gravity base structure (as used in the Hibernia offshore platform)

GW or Gigawatts- One thousand million watts

ICE- Internal combustion engine

ICES - Integrated Community Energy Solutions

IEA- (France) International Energy Agency

LNG – Liquid natural gas

Minigrids – small scale grids with no external connection, serving a small number of loads (e.g. an outport)

MUN - Memorial University Newfoundland & Labrador

MW or Megawatts- One million Watts

NALCOR – Newfoundland & Labrador Energy Corporation

NaREC - (UK) New and Renewable Energy Centre

NGOs- Non-governmental organizations

NL - Newfoundland & Labrador

NMI - (UK) The National Microelectronics Institute is the premier trade association representing the semiconductor industry in the UK and Ireland.

NRC – National Research Council Canada

NREL- (US) National Renewable Energy Laboratory

NSERC - Natural Sciences and Engineering Research Council of Canada

R&D- Research and Development

RD&D - Research, Development and Deployment

Remote energy systems – system connecting loads to renewably generated energy (e.g. wind) in remote settings (see also Microgrids)

STRI AB - (Sweden) is an independent technology consulting company and accredited high voltage laboratory

SWRI – Southwest Research Institute

TUVSUD - (Germany) Provides services of consulting, testing, certification and training

UniSea Inc – (US) Located in Alaska, produces a variety of finished seafood products that are marketed and distributed throughout the world

US Seafoods - a seafood harvesting and marketing company based in Seattle, Washington and operating chiefly off the coast of Alaska

Vestas - Danish wind turbine manufacturer

VNIIE - (Russia) Electric Power Research Institute

VTT - (Finland) the biggest multi-technological applied research organization in Northern Europe

WEICan - Wind Energy Institute of Canada

WESNet - Wind Energy Strategic Network; Canada wide, multi-institutional and multi-disciplinary research network funded by industry and the Natural Sciences and Engineering Research Council of Canada (NSERC)

Executive summary

Project context

The Newfoundland and Labrador (NL) Energy Plan, published in September 2007, sets out a long term vision for the development of energy opportunities for the benefit of its people and the environment. It also commits to the development of a 'roadmap' to address the innovation needed to achieve this. The need for innovation arises where new ways of doing things are necessary to overcome barriers to the commercialization of energy.

Under the guidance of a cross-Government team (led by Department of Natural Resources and including representatives from Research & Development Corporation - Newfoundland and Labrador, Department of Innovation, Trade and Rural Development, Department of Business and Nalcor Energy), energy innovation needs and related development opportunities are being identified in two phases. In the first phase, the recommendations of which are summarized in this report, the priorities for innovation have been identified, based on a series of filters. Innovation roadmaps will be developed for priority areas in a second phase of work.

Project approach

The project took place between September 2009 and March 2010, following a structure that narrowed down 31 energy types to four innovation priority areas. The process reflected the difference between energy types and analyzed these types based on both resource potential and opportunities for innovation in Newfoundland and Labrador that could add value in overcoming barriers for local and/or external development.

The Energy Plan highlighted several key energy areas— onshore wind energy, hydroelectricity, transmission and oil and gas - each of which received detailed evaluation. A long list of other energy types was also assessed at a high level for their fit with local physical and human resources; consistency with the Energy Plan; and the need for technical innovation. Many were screened out as being of lower significance to the Province. Those energy types that emerged were subjected to more detailed evaluation that included an examination of:

- Barriers to determine where innovation may be required;
- Innovation opportunities to determine how valuable innovation would be and whether the innovation is well advanced outside Newfoundland and Labrador;
- Innovator competitiveness to determine whether Newfoundland and Labrador has a basis to be competitive for the required innovation; and
- Innovation priorities to determine the extent to which innovation may be a priority for local and/or external markets.

Overall recommendations

Four overall priority energy areas have been identified for Phase 2 development of innovation roadmaps: oil and gas, onshore wind, electricity transmission and remote energy systems.

- Several ***oil and gas*** innovation roadmaps are recommended in view of the importance of the sector to NL's economic future, and given the potential to exploit existing internationally competitive innovation capacity within the Province.
- The future development of ***onshore wind energy*** resources, particularly in Labrador, will require significant technology innovations, some of which are unlikely to be addressed by international innovators. A roadmap is recommended to cover a set of closely related innovation needs.
- Development of onshore wind, hydroelectricity and natural gas resources in Labrador may all require long-distance ***power transmission.*** This, in turn, would require an innovative solution to icing-related challenges, for which a roadmap is recommended.
- There is significant local and international need for ***remote energy systems*** and markets and technologies are still emerging. A high level innovation roadmap is recommended to build the basis for NL to exploit potential future opportunities.

Three main categories of innovation priority

Innovation priorities have been identified for each energy area and categorized as A, B, or C as follows:

A. Innovation opportunities with both a local and international value that may already be addressed by international innovators, but where NL has, or can acquire, an internationally competitive position. Opportunities in this category should be capitalized on through roadmapping exercises in Phase 2.

B. Innovation opportunities that have a significant local value and limited international value, where NL will have to lead the way if barriers are to be overcome and energy resources are to be exploited. Opportunities in this category should also be dealt with in Phase 2.

C. Opportunities that are being addressed by significant numbers of international innovators, where NL does not have an internationally competitive position, and is unlikely to acquire one in the foreseeable future. These should be built into NL's future energy plans, to ensure that NL is in a position to be an informed buyer.

In addition, numerous barriers to progress have been identified where the required innovation is not technological. These requirements have been noted during the project and will need to be addressed in NL's future energy plans, rather than as a roadmap or series of roadmaps.

Innovation opportunities to be addressed in the roadmaps

Oil and gas

Innovations that merit category A prioritization include opportunities related to technologies and techniques that enable operation in harsh ocean environments (such as personnel safety) and arctic conditions (such as subsea gas production), and solutions that deliver subsea protection for pipelines and other installations in ice-scoured regions.

Innovation opportunities in category B relate to enhanced recovery in reservoir structures prevalent in NL; far offshore logistics to deal with personnel and material supply along extended supply routes; and lightweight onshore seismic equipment to enable easier access of sensitive west coast areas.

Category C includes decommissioning which is a longer term requirement. This is summarized with other innovation opportunities in the table below.

Category		Barrier	Innovation Opportunity
A	Innovation opportunities with both a local and international value, that may be addressed by international innovators but where NL has, or can acquire an internationally competitive position.	Harsh environment	Develop technologies and techniques that can be applied in increasingly harsh environments. Covering exploration, project development and production phases (including gas export innovations).
		Arctic conditions	(See also Harsh environment) – Focused innovation program featuring the safety, subsea and unmanned techniques that will unlock known and potential Labrador gas and also other Arctic oil & gas.
		Subsea protection	Develop and demonstrate cost effective subsea pipeline and facility protection solutions that can reduce future project costs.
B	Innovation opportunities that have a significant local value and limited international value, where NL will have to lead the way if barriers are to be overcome and energy resources are to be exploited.	Enhanced recovery	Intensify research into reservoir structures prevalent in NL. Model and then trial techniques for enhanced recovery.
		Far offshore logistics	Research and model logistics solution(s) for offshore NL. Consider supporting shared facility for whole industry.
		Onshore seismic	Develop lighter seismic equipment and soft tire vehicles that can access sensitive areas when ground is not frozen.
C	Innovation opportunities that are being addressed by significant numbers of international innovators, where NL does not have an internationally competitive position, and is unlikely to acquire one.	Lack of decommissioning experience	Predict decommissioning needs of NL structures, identify where similar abilities will be required internationally, and understand technical requirements.

Prioritized oil and gas innovation opportunities

Onshore wind

Innovations that merit category A prioritization are related to the development, testing and operation of wind turbines in icy and cold conditions, and related to overcoming constraints associated with grid-integration.

Innovation that merits category B prioritization comprises resource mapping, particularly with regard to the interaction of wind and ice.

All other technological innovations fall into category C, as shown in the table below.

<table>
<tr><th colspan="2">Category</th><th>Barrier</th><th>Innovation Opportunity</th></tr>
<tr><td rowspan="3">A</td><td rowspan="3">Innovation opportunities with both a local and international value, that may be addressed by international innovators but where NL has, or can acquire an internationally competitive position.</td><td>Icing</td><td>Development and testing of anti-icing or de-icing solutions for medium and severe icing conditions.</td></tr>
<tr><td>Cold conditions</td><td>Development and testing of more reliable turbines capable of working in cold conditions. Development of new concepts for operation and maintenance of wind turbines in cold conditions.</td></tr>
<tr><td>Grid inflexibility</td><td>Development of new concepts for the techno-economic integration of high wind penetration systems featuring hydro and (possibly) gas and storage technologies.</td></tr>
<tr><td>B</td><td>Innovation opportunities that have a significant local value and limited international value, where NL will have to lead the way if barriers are to be overcome and energy resources are to be exploited.</td><td>Resource mapping</td><td>Development of high-resolution wind and ice maps, with long term predictability. Testing and optimization of wind turbine operation in combined wind and ice conditions.</td></tr>
<tr><td>C</td><td>Innovation opportunities that are being addressed by significant numbers of international innovators, where NL does not have an internationally competitive position, and is unlikely to acquire one.</td><td>All other technology barriers</td><td>Capital cost reduction, reliability improvement and gusting tolerance for turbines.</td></tr>
</table>

Prioritized onshore wind innovation opportunities

Transmission

The only area for which an innovation roadmap is recommended is in power line icing, where NL needs to build capability to manage high power transmission over long distances in harsh conditions. In view of the need for similar solutions internationally this would fall into category A, though it is likely that the solution will be developed with an extensive international partnership so NL may not end up with a unique competitive advantage, making it category B.

Category C comprises the techno-economic capabilities to integrate large scale power generation within an export-focused system. The opportunities are all summarized in the following table.

	Category	Barrier	Innovation Opportunity
A/B	Innovation opportunities with both a local and international value that may be addressed by international innovators but where NL may be able to acquire an internationally competitive position.	Power line icing conditions	Enhance power line icing capabilities (prediction, monitoring, control strategies, de-icing technologies) with a focus on specific Labrador conditions.
C	Innovation opportunities that are being addressed by significant numbers of international innovators, where NL does not have an internationally competitive position, and is unlikely to acquire one.	Wind/hydro/ gas to wire integration	Techno-economic system modelling leading to detailed understanding of most attractive options for integrating different NL energy sources and their export over long distances. Include: - Range of different electricity sources, uses, routes - careful examination of market needs - consideration the value of reliability

Prioritized transmission innovation opportunities

Hydroelectricity

A substantial opportunity exists to further develop hydro resources, particularly in Labrador. Careful discussion with Nalcor and Newfoundland Power confirmed that the barriers to development of hydro resources are not technical in nature and so do not require innovation roadmapping in the context of this project. However, transmission is a key enabler and innovation in this field is addressed.

Other opportunities

During the course of the project, a very wide range of other potentially relevant energy types were considered. These were initially assessed at a high level for their fit with local physical and human resources; consistency with the Energy Plan; and the need for technical innovation. Many were screened out as being of lower overall significance to the Province and those energy types that emerged for further analysis could be logically grouped under three themes, each of which is discussed with its recommendation below:

- ***Remote location power systems*** comprise the technologies that could be applied to smaller scale, off-grid settings such as outports, single dwellings and remote devices such as buoys. The markets and technologies associated with such systems (such as that being applied in Ramea and for other off-grid settings) are emerging worldwide. This represents an opportunity for NL to direct further development in these areas in order to develop options for exploitation in international markets. A roadmap should, therefore, be created for remote energy systems. However, in view of the earlier stage nature of many of these technologies, the roadmap should be broader-based and provide considerable flexibility in view of the uncertain development path that these technologies may take.
- ***Marine energy technologies*** chiefly comprise offshore wind, wave and tidal energy devices. NL has internationally competitive innovation services for these devices, however, it is not likely to be a suitable location for large scale deployment of this type of energy in the short

to medium term. These innovation resources should be actively promoted to innovators outside NL through, for example, an innovation services export plan.

- ***Energy efficiency*** is a policy priority for the Province, as laid out in the Energy Plan. An examination of the barriers to energy efficiency reveals that these are not technical, instead they relate mainly to behavioural factors which require public intervention, but not innovation roadmapping.

Several types of roadmap needed

Looking ahead to the roadmap development phase itself, it is instructive to consider what the roadmaps may comprise. Although this was not tackled in detail, the likely overall characteristics of the roadmaps were suggested, as shown in the table below. In general, the oil and gas and onshore wind roadmaps will probably require numerous stakeholders to engage in order to produce roadmaps that are complex in their specificity and coverage of the topics. Transmission is unlikely to involve as many stakeholders and the topic is a narrower one, making this less complex. Remote energy requires a roadmap that is flexible to likely changes whilst engaging a broad set of stakeholders.

<table>
<tr><th></th><th>Roadmap focus</th><th>No. of stakeholders</th><th>Likely complexity</th><th>Comment</th></tr>
<tr><td rowspan="6">Oil and Gas</td><td>Harsh environment</td><td>Many</td><td>High</td><td rowspan="6">• There is a need for coordination across oil and gas roadmaps. This is particularly true across the closely related opportunities of harsh environment, arctic conditions and subsea protection</td></tr>
<tr><td>Arctic conditions</td><td>Many</td><td>High</td></tr>
<tr><td>Subsea protection</td><td>Many</td><td>High</td></tr>
<tr><td>Enhanced recovery</td><td>Many</td><td>High</td></tr>
<tr><td>Far offshore logistics</td><td>Several</td><td>Medium</td></tr>
<tr><td>Onshore seismic</td><td>Several</td><td>Low</td></tr>
<tr><td>Transmission</td><td>Power line icing</td><td>Few</td><td>Low</td><td></td></tr>
<tr><td>Onshore wind</td><td>Icing, cold conditions, grid inflexibility, resource mapping</td><td>Several</td><td>High</td><td>• Needs to address all barriers to Labrador wind.
• Focus may change once engagement defined
• Links to hydro and transmission strategies</td></tr>
<tr><td>Remote energy</td><td>All remote energy</td><td>Several</td><td>Medium</td><td>• High level and flexible to changes in the market and technologies</td></tr>
</table>

Characteristics of innovation roadmaps to be developed

1 Project background

This document is structured into four main areas:

- Chapter 1 describes the background to the project;
- Chapter 2 explains the approach used to conduct the project;
- Chapter 3 provides an overview of the recommended innovation priorities across all energy areas; and
- Chapters 4 to 7 describe individual energy areas and the specific innovation opportunities and recommended priorities within them.

1.1 Context

The Energy Plan, published in September 2007, sets out a long term vision and key principles by which Newfoundland and Labrador (NL) will develop energy opportunities for the long term benefit of its people, while ensuring an appropriate environmental legacy for future generations. Abundant oil and gas, hydroelectricity and onshore wind resources, often referred to as the Province's 'Energy Warehouse', are obvious priority areas for development.

We have taken the Energy Warehouse areas as the initial guidance for our work. The Energy Plan does not provide specific details for how these resources will be developed, but future roadmaps will help address areas requiring innovation in order for the sector to grow and for development to occur.

The Energy Plan identified the need for innovation to unlock the potential of NL resources, meaning finding new ways of doing things to overcome challenges. Planning will be needed "to provide direction, focus, and priorities for our future energy technologies". The Energy Plan committed specifically to develop a strategic co-ordinated approach to energy innovation focusing on areas of competitive advantage – an 'Energy Innovation Roadmap' (or more accurately Roadmaps).

1.2 Objectives

The Energy Innovation Roadmaps introduced above are being developed under the guidance of the Department of Natural Resources in collaboration with the Department of Innovation, Trade & Rural Development, Department of Business, the Research & Development Corporation and Nalcor. The roadmaps are being developed in two phases. In this first phase, external consultants have been engaged in order to identify priority areas for energy innovation, as summarized in this report. The Consultants comprised E4tech (a UK and Swiss firm focused on sustainable energy technology innovation), Orion Innovations (a UK firm focused on cleantech innovation support) and Wade Locke Economic Consulting (Wade is Professor of Economics at Memorial University). In the next phase, specific plans for supporting the prioritized innovation areas will be created.

The overall objective of this report, therefore, is to identify areas of energy innovation which align with sector needs and resource development opportunities, and for which NL has a basis for competitive advantage and/or a significant need that is unlikely to be met by others.

2 Project approach

2.1 Project structure

The project took place between September 2009 and March 2010, following a structure that narrowed down 31 energy types to four main innovation priority areas (oil and gas, onshore wind, power transmission, and remote energy systems). The process reflected the difference between energy types and analyzed these types based on resource potential and opportunities for innovation in Newfoundland and Labrador that could add value in overcoming barriers for local and/or external development.

The Energy Plan introduced the concept of an 'Energy Warehouse,' which featured several key resource types— onshore wind energy, hydroelectricity, and oil and gas. Detailed evaluation has been applied to the areas of energy within the Energy Warehouse concept. In analysing these types of energy, it was found that long-distance electric power transmission is critical to their exploitation and merited separate examination as a potential innovation area in its own right. This evaluation process is represented in the upper green arrow in Figure 1 below.

The Energy Plan also refers to several other energy types that could offer opportunities for NL, though it is less specific about which are priorities. A long list of energy types was initially assessed at high level for their fit with local physical and human resources; consistency with the Energy Plan; and the need for technical innovation. Many were screened out as being of lower significance to the Province and those energy types that emerged for further analysis could be logically grouped under three themes. This process is represented in Figure 1 below – the lower green-tipped arrow shows areas that were carried forward, the grey-tipped arrow those that were set aside. The three themes carried forward were:

- Remote location power systems, which comprise the technologies that could be applied to smaller scale, off-grid settings such as outports, single dwellings and remote devices such as buoys. The technologies include small scale generation, energy storage and control systems;
- Marine energy technologies, chiefly comprised of offshore wind, wave and tidal energy devices; and
- Energy efficiency in buildings and industry.

A detailed evaluation framework was used to examine the energy types that reached this stage in the selection process. This evaluation framework is described in Section 2.3 below. The results of the evaluation are presented in this report which summarizes and discusses recommended innovation priorities.

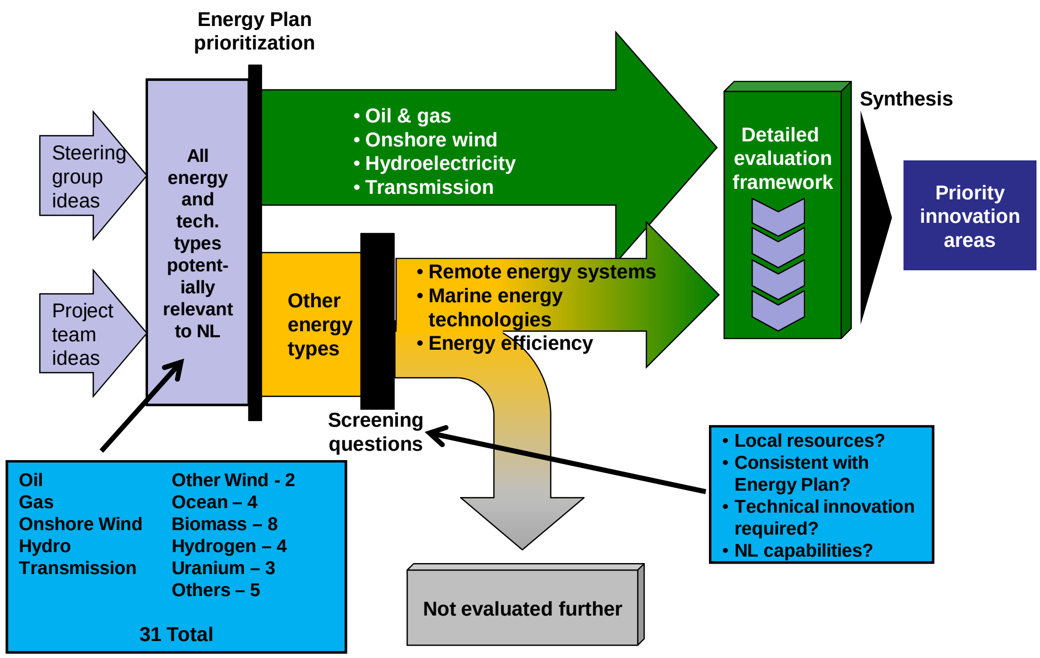

Figure 1: Energy Innovation Roadmap phase 1 process

2.2 Stakeholder inputs

The Energy Plan drew upon a vast range of inputs through public consultation. This project also used consultation to draw upon industry and sector experts from the NL energy and innovation communities. This allowed the consultants to further develop and refine their analyses.

Consultation took place at two points in time for largely different purposes. Consultations in Autumn 2009 concentrated upon validating barriers to the development of energy types identified as part of the Energy Warehouse as well as screening other energy types against high level questions. Consultations took the form of meetings, workshops and calls. A total of 86 individuals and organizations within NL were invited, 45 of whom participated, with some stakeholders in multiple sessions, taking the total participation count to 52.

Further meetings took place in January 2010, with a focus on identifying NL innovation capabilities and evaluating the other energy types. 17 meetings were held with various organizations across the NL energy and innovation communities (20 invitations having been sent).

In addition, the consultants drew upon their industry networks outside the Province to augment their knowledge of key technology issues, chiefly in the wind and marine energy areas.

There was a high level of consensus amongst most of the stakeholder views, though inevitably some disagreement arose. It is important to emphasize that the roadmapping process is intended to identify areas where NL should prioritize its allocation of limited innovation resources for the benefit of NL. Exclusion of a potential innovation opportunity from the priority list does not make it a ‘bad idea’, nor does it mean that no public support should ever be provided. However, prioritization does indicate where focus is recommended in future.

2.3 Detailed evaluation framework

2.3.1 Guiding logic

This work provides further direction in implementing the Energy Plan. Innovation may be the key to unlocking or enhancing the value of NL energy resources, as identified in the Energy Plan, but this project also considers value that can be attained by exporting innovation in the form of products, services or intellectual property.

The starting point was to first identify industry needs and development opportunities in the energy sector that require innovation and then to assess whether NL has, or could have, the necessary capabilities to meet them competitively. This approach was chosen rather than the inverse, since working forwards from existing capabilities would be a recipe for wishful thinking and may ignore chances to build capabilities upon latent skills. This approach recognizes the need to be strategic in building innovation capacity in order to optimize future investments in energy R&D and innovation within NL.

2.3.2 Analytical process

The overall approach taken to the analysis of each energy type is summarized in Figure 2 and discussed below. The analysis approach included an examination of:

- Barriers to determine where innovation may be required;
- Innovation opportunities to determine how valuable innovation would be and whether the innovation is well advanced outside Newfoundland and Labrador;
- Innovator competitiveness to determine whether Newfoundland and Labrador has a basis to be competitive for the required innovation; and
- Innovation priorities to determine the extent innovation may be a priority for local and/or external markets.

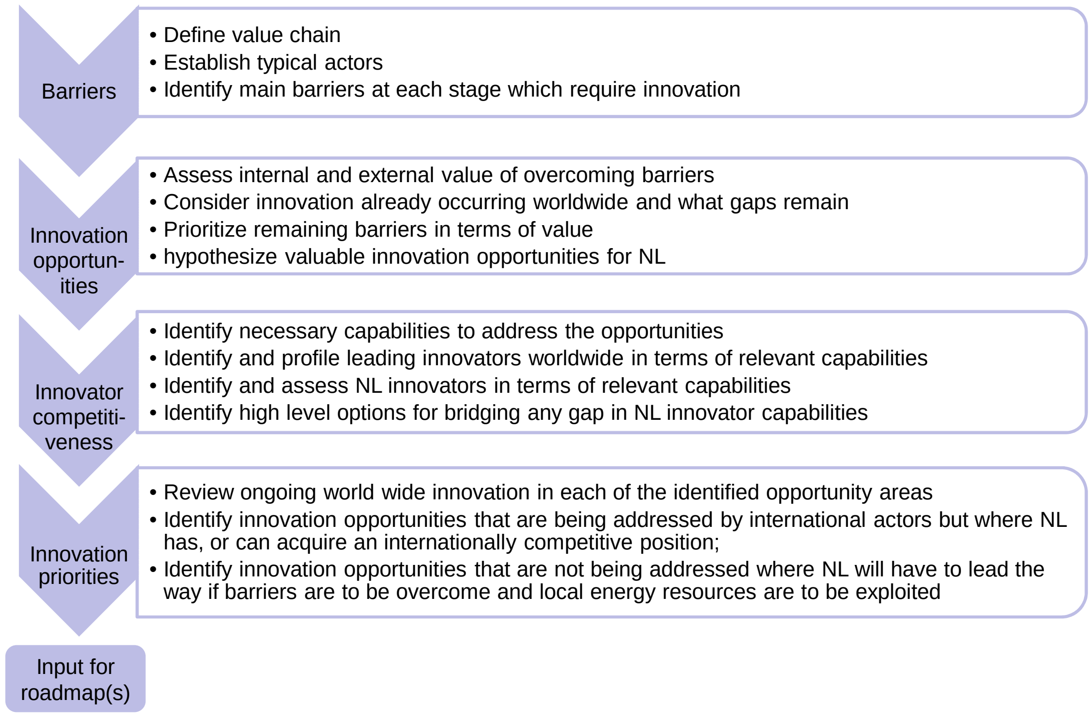

Figure 2: Detailed evaluation framework

Barriers

A key premise of this work is that innovation is the means by which barriers are overcome. Barriers are impediments to business operations, market development, or commercialization of an energy resource, technology or application, and which require things to be done for the first time in the sector as a whole. Barriers related to technology, company development, markets or regulation were identified, though only technological barriers have been considered for innovation prioritization purposes due to their greater inherent value creation potential (via intellectual property and job-creation) .

Innovation needs and opportunities

Once barriers have been identified, the next step is to consider whether overcoming them would provide significant *value*. This is a function of whether there is an industry need, resource development opportunity to be unlocked, and/or whether there would be an opportunity to export the innovation. This is achieved first by assessing the value of overcoming each barrier, based on NL's current capabilities and position in the value chain. Note that the value assessment is qualitative and relative within energy types. This assessment is based on the consultant team professional knowledge and expertise, project research and input obtained during the consultation sessions and numerous other project meetings. The value assessment is relative within each energy type – an absolute measure of value would result in some energy types being dwarfed by others, reducing the opportunity for long term options to be developed.

In the second step, consideration is given to whether the barrier is already being largely solved by others. This is a function of the scale of the barrier and the level of effort being applied by others. What remains at the end of this stage of the analysis are barriers for which it is judged that there is sufficient value in overcoming each of them and where there is still a global innovation gap.

Innovator competitiveness

NL's current strength and capacity to address the identified priority barriers and associated innovation opportunities were assessed relative to international players. The key types of international innovators are identified (e.g., technology providers/manufacturers, research institutions and academia) and profiled in terms of the nature and scale of their activities. NL innovators are assessed relative to these capabilities to understand where there are internationally competitive resources to be exploited, or gaps to be overcome in addressing priority innovation areas. High level options for building innovation capabilities or overcoming gaps are identified, along with their relative ease, time and cost of deployment.

Innovation priorities

The nature and scale of ongoing international innovation in each of the prioritized innovation areas were profiled in more detail. This involved profiling the types of innovators most active in the sector and an assessment of what it would take for NL to compete at this level. This, along with the other analysis in the second and third chevrons above, allows innovation opportunities to be separated into different categories, following the logical framework profiled in Figure 3 below:

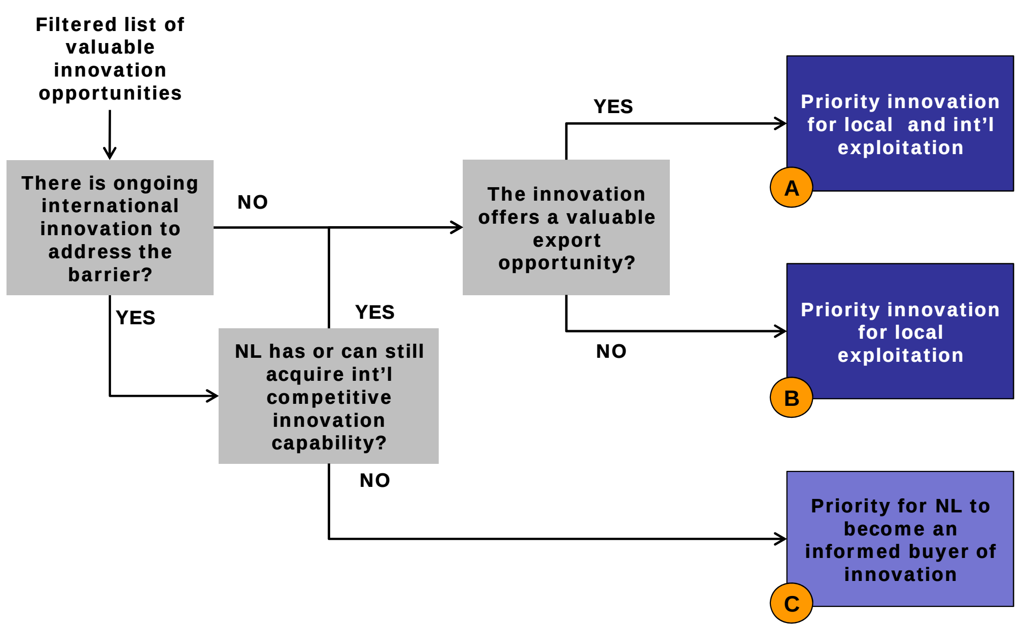

Figure 3: Logical framework for prioritization of innovation opportunities

2.3.3 Outputs

Three main categories of priority result from the analysis of each energy area, shown in Figure 3, and described in more detail below.

A. Innovation opportunities with both a local and international value that may already be addressed by international innovators, but where NL has, or can acquire, an internationally competitive position. Opportunities in this category should be dealt with in the roadmapping phase – Phase 2.

B. Innovation opportunities that have a significant local value and limited international value, where NL will have to lead the way if barriers are to be overcome and energy resources are to be exploited. Opportunities in this category should also be dealt with in the roadmapping phase.

C. Opportunities that are being addressed by significant numbers of international innovators, where NL does not have an internationally competitive position, and is unlikely to acquire one in the foreseeable future. These should be built into energy planning, to ensure that NL is in a position to be an informed buyer (an example is oil and gas facilities decommissioning).

In addition to the above categories, two other categories should be noted:

- Barriers which it would be valuable to overcome (locally or internationally), but where the required innovation is not technological. These barriers may include policy, regulatory, market, taxation and other challenges. This finding applied to all energy types, and in the case of energy efficiency, it was found that the barriers were exclusively of this type.
- Areas where NL has significant capabilities, but which are not innovation opportunities for local deployment. These should be priorities for international exploitation through offering innovative R&D, technologies and services to global markets, not innovation roadmapping. This applies only to marine energy technology services, where NL undoubtedly has skills and resources suited to marine energy innovation, but, for which, NL is not likely to be a primary location for their deployment due to the harsh conditions.

3 Recommended innovation priorities

The following energy areas have been identified as priorities for innovation roadmapping:

3.1 Oil and gas

Several oil and gas innovation roadmaps are recommended in view of the importance to NL's economic future and the wide variety of possible focus areas. Our analysis has identified three closely related areas that merit prioritization to allow them to be developed for local and international market opportunities ***(category A)***:

- **Harsh ocean environment:** NL and other oil and gas regions require technologies and techniques that can be applied in increasingly harsh environments as exploration, development and production go further, deeper and into colder operating environments, such as the Flemish Pass and Orphan Basin. These span exploration, project development and production phases of activity. Examples include gas monetization innovations which can be safely operated in rough conditions (floating LNG, LNG loading, and marine CNG).
- **Arctic conditions:** Moving north will require a focused innovation program featuring the safety, subsea and unmanned techniques that will enable operation in offshore Labrador and further north. This is particularly relevant for gas development, but could also be relevant to oil.
- **Subsea protection:** Ice scour will require development and demonstration of cost effective subsea pipeline and facility protection solutions that can reduce future project costs.

A further three areas require roadmapping to ensure that they are developed, regardless of the existing capability base ***(category B)***:

- **Enhanced recovery:** There is a critical need to intensify research into reservoir structures prevalent in NL. This requires modelling and then testing of techniques for enhanced recovery. It is possible that such innovation will be applicable outside NL, though it will, out of necessity, be focused on local reservoir types.
- **Far offshore logistics:** Research and modelling of logistics solution(s) for offshore NL could assist the whole sector, possibly in ways that no single company or field project would address. Solutions will, by definition, be NL-focused.
- **Onshore seismic:** Development of lighter seismic equipment that can access sensitive areas when ground is not frozen will increase exploration rates in western Newfoundland. Note that this opportunity has a lower value relative to oil and gas exploration in other areas of the Province, based on known resource sizes.

3.2 Onshore wind energy

Development of wind energy resources in Labrador will require significant technology innovation. With substantial potential for exploitation within the Province (over 5 Gigawatts of resource), it has been identified as one of the four primary elements of NL's Energy Warehouse. Development of these resources, along with transmission capacity, will open up the prospect for substantial and valuable export of renewable electricity.

Although international innovators are addressing most innovation needs, some NL-specific issues, such as wind and ice mapping, are unlikely to be addressed without active engagement by the local innovation community. Others innovation needs, such as the development and testing of anti-icing or de-icing solutions offer the opportunity for NL to acquire an internationally competitive position.

The roadmap will need to show how all innovation needs will be met, including those where NL will rely on international innovation (such as dealing with very gusty conditions compared with typical wind conditions internationally). In these instances, NL will need to acquire sufficient knowledge in order to make informed purchase decisions and deploy innovation solutions.

We recommend the following priority areas of innovation opportunity for local and international exploitation (***category A***):

- **Icing:** Development and testing of anti-icing or de-icing solutions for medium and severe icing conditions.
- **Cold conditions:** Development and testing of more reliable turbines capable of working in cold conditions. Development of new concepts for operation and maintenance of wind turbines in cold conditions.
- **Grid integration:** Development of new concepts for the technical and commercial integration of high wind penetration systems and storage technologies.

We also recommend that the roadmap should tackle one other NL-specific need, within ***category B***

- **Resource mapping:** Development of high-resolution wind and ice maps, with long term predictability. Testing and optimization of wind turbine operation in combined wind and ice conditions.

In addition, there are several other innovations that need to occur for which NL has limited basis to innovate. These include capital cost reduction, reliability improvement and gusting tolerance for turbines. These ***category C*** priorities should be built into the sector roadmap.

Onshore wind energy innovation activities are undertaken by wind turbine and component parts manufacturers, universities and institutes, and testing centres. The Province has no major manufacturers or researchers dedicated to the onshore wind energy sector today, meaning that strategic investments will be required to establish innovation capacity, probably including collaboration with national and international players.

3.3 Transmission

Although there are numerous barriers to be overcome to exploit generation opportunities, particularly in Labrador, we did not identify many that require specific technical innovations to overcome them. A limited roadmap is therefore appropriate for innovation relating to transmission.

The only area for which an innovation roadmap is recommended is in **power line icing**, where NL needs to build capability to manage high power transmission over long distances, in harsh conditions. In view of the need for similar solutions internationally this would fall into ***category A***, though it is likely that the solution will be developed with an extensive international partnership. As such, NL may not end up with a unique competitive advantage.

3.4 Hydroelectricity

A substantial opportunity exists to further develop hydro resources, particularly in Labrador. Discussions with Nalcor and Newfoundland Power confirmed that the barriers to development of hydro resources are not technical in nature and, as such, do not require innovation roadmapping in the context of this project. However, transmission is a key enabler and innovation in this field is addressed.

3.5 Remote location power systems

The remote power systems area globally, and NL's activities in particular, are too immature to allow us to be prescriptive about specific priority innovation opportunities. We recommend that an innovation roadmap be developed in this area, but that it should be flexible to the high level of uncertainty regarding the performance and availability of the relevant technologies, avoiding being overly prescriptive. This roadmap should allow for NL to plant seeds for the future (also known as 'taking options' within the sector) and for these options to be refined and prioritized as the sector and NL's activities mature. An illustration of an options approach is found in the technology development programs of many industrial companies, where a range of competing technology paths are followed in parallel until it becomes clear that some will not be successful and are closed off. The roadmap should cover the main technology areas and market applications to be focused on, but should build in considerable flexibility as information about these evolves.

3.6 Overall roadmap requirements

The individual roadmaps recommended above have different levels of stakeholder breadth and complexity.

- Those for oil and gas tackle one area each, mostly requiring considerable detail and input;
- For transmission, only one area is recommended for roadmapping and its scope and stakeholders are relatively well-defined;
- For onshore wind, a comprehensive sector-wide map is recommended to tackle all barriers; and
- Remote energy systems require a high level roadmap that will be highly flexible to changes in technology and markets.

In total, nine separate roadmaps are required to address the recommended areas, as summarized in Table 1 below.

	Roadmap focus	No. of stakeholders	Likely complexity	Comment
Oil and Gas	Harsh environment	Many	High	• There is a need for coordination across oil and gas roadmaps. This is particularly true across the closely related opportunities of harsh environment, arctic conditions and subsea protection
	Arctic conditions	Many	High	
	Subsea protection	Many	High	
	Enhanced recovery	Many	High	
	Far offshore logistics	Several	Medium	
	Onshore seismic	Several	Low	
Transmission	Power line icing	Few	Low	
Onshore wind	Icing, cold conditions, grid inflexibility, resource mapping	Several	High	• Needs to address all barriers to Labrador wind. • Focus may change once engagement defined • Links to hydro and transmission strategies
Remote energy	All remote energy	Several	Medium	• High level and flexible to changes in the market and technologies

Table 1: Characteristics of innovation roadmaps to be developed

It is important to note that, in addition to the recommended roadmap areas, this project has identified numerous barriers to energy development that do not merit innovation roadmapping, but which do need to be addressed through future plans and actions. Broadly speaking there are barriers which NL is not likely to influence, other than by being an informed buyer (category C areas such as oil and gas decommissioning), and there are also barriers which are non-technical in nature (for example, those in the area of energy efficiency). Each of these has the potential to impede energy development and deployment in the Province and so they require careful consideration in the energy policies and plans made by the relevant agencies.

4 Oil and gas

Oil and gas are primary contents of NL's 'Energy Warehouse' – 2.9 billion barrels of oil and 10.9 trillion cubic feet of gas have already been discovered, with much more anticipated. They represent the main source of energy revenue for the Province and several of the world's largest oil and gas companies have established offices in the Province. The opportunity in oil and gas goes beyond exploitation of the Province's own resources however. The development of oil and gas so far has resulted in a strong base of offshore supply and service companies, organizations, facilities and research organizations with capabilities suitable for oil and gas development, in particular, in harsh ocean environments and Arctic conditions. NL is well-placed to serve this market, potentially serving as a 'gateway to the Arctic', thanks to a growing offshore industry and geographic location.

Overall, there is an innovation opportunity for NL resulting from further oil and gas development within the Province, including opportunities to build upon existing strengths to serve the oil and gas industry internationally as it begins to face challenges that are already familiar to NL. This is consistent with several Energy Plan goals, notably energy security, sustainable economic development, and maximizing the long term value of oil and gas.

4.1 Innovation needs

There are a number of challenges to the further exploitation of oil and gas in NL. Some of these challenges are common to the oil and gas industry as a whole; others are specific to the Province. The areas where technical challenges lie include:

- Dealing with the harsh environment offshore Newfoundland and Labrador continues to be a challenge facing the sector, but it also provides the key to a potential competitive advantage internationally.
- Ice hazards are a fundamental challenge affecting project design and execution, which becomes very acute in northerly latitudes. Potential ice scour creates the need to protect subsea lines and installations, and surface level ice means that manned facilities must be built to withstand this and to operate safely. Ice also pushes design philosophy towards unmanned and subsurface operations.
- The geographic spread of oil and gas resources and early stage of overall development in the Province means that many projects have yet to reach critical mass. This is particularly the case offshore Labrador where gas finds have yet to be aggregated economically for export purposes and export options (pipeline, LNG, gas to wire) are interdependent with strategic plans for energy development in other areas (e.g., power export from Labrador).
- The types of oil and gas reservoir in NL present a tough challenge in some areas and improved subsurface knowledge and techniques for production are needed to improve the value of resources.
- Production in far offshore locations is challenging logistically, particularly in view of the weather, though this does not act as a showstopper by any means.
- Though still expected to be decades away, it should be noted that there is almost no experience worldwide with decommissioning of concrete GBS structures such as Hibernia.

The specific barriers associated with these challenges, and the resulting innovation needs, are summarized in Table 2.

Value chain	Barrier	Barrier detail	Potentially valuable innovation opportunities
Several stages	Harsh environment	The harsh environment is an impediment to activity in several areas of the value chain. The main challenge for offshore Newfoundland is the combination of wave, wind and (sometimes) ice which imposes costs on exploration, development and production phases. Further north the ice hazard becomes more significant and requires totally different approaches (see Arctic conditions).	Develop technologies and techniques that can be applied in increasingly harsh environments including freezing conditions. Covering exploration, project development and production phases (including innovative technologies for the monetization of NL offshore natural gas).
Exploration	Onshore seismic	Onshore explorers are obliged to shoot seismic in winter months when heavy tracked vehicles will not damage bogs and streams. Lighter equipment would avoid this, enhancing productivity.	Develop lighter seismic equipment and soft tire vehicles that can access sensitive areas when ground is not frozen.
Project development	Subsea protection	A key feature of project developments in iceberg-prone waters is the need to bury lines (in trenches) and well facilities (in glory holes). These are costly and hard to construct at depth.	Develop and demonstrate cost effective subsea pipeline and facility protection solutions that can reduce future project costs.
	Arctic conditions	The development of Labrador (and other Arctic) resources is currently prevented by a range of challenges associated with harsh, very icy conditions. This may require high degrees of subsea operation and extended tiebacks. There will also be a need to develop means of safe operation in ice-bound waters. Gas export from scattered sources also poses technical and economic challenges.	(See also Harsh environment and Subsea protection) – Focus innovation program featuring the techniques that will unlock known and potential Labrador gas and also other Arctic gas.
Production	Far offshore logistics	Many of the fields are far offshore and, in combination with very variable weather, this means that supply logistics are often stretched.	Research and model logistics solution(s) for offshore NL. Consider supporting shared facility for whole industry.
	Enhanced recovery	Improving recovery rates is a fundamental challenge across the industry. It is particularly relevant to some Newfoundland and Labrador reservoir types.	Intensify research into reservoir structures prevalent in NL. Model and then trial techniques for enhanced recovery.
Decomm-issioning	Lack of experience	Experience with decommissioning of steel structures is increasing rapidly worldwide, but for Hibernia-type large GBS structures there is much less experience.	Predict decommissioning needs of NL structures and identify where similar abilities will be required internationally, understand technical requirements (this is a long term requirement).

Table 2: Oil & gas technology-related barriers and associated innovation opportunities

4.2 International innovation landscape

Innovation in oil and gas is carried out by a vast number of players worldwide - we have sampled the activities of several innovators in the areas of opportunity identified in order to characterize the landscape. There are three broad categories of innovators:

- Oil and gas companies – many 'majors' make significant investments in R&D (e.g., ConocoPhillips invested $500 M in 2008 both in-house and via third parties); national oil companies are increasingly conducting R&D in-house rather than depending on others; whereas independent oil companies tend to be reliant upon R&D conducted by others.
- Service companies and other contractors – these cover a spectrum from very large firms with significant R&D facilities (e.g., Schlumberger has 25 R&D centres worldwide) to smaller firms who innovate in a specific product or service area.

- Research organizations – there are numerous dedicated oil and gas research institutes (e.g., Global Petroleum Institute in Texas), as well as oil and gas oriented departments of universities worldwide. These conduct research on behalf of oil and gas and service companies, as well as more exploratory and conceptual work.

The topics covered by the innovators above include, to varying extents, all of the innovation opportunities included in Table 2 above. In most cases, the location of the innovator determines the focus of the work. For example, the Norwegian University of Science and Technology is active in harsh environment research.

One of the most active companies in Arctic oil and gas R&D is ExxonMobil, whose research activities include: seismic acquisition in ice environments; year-round offshore production in heavy ice conditions; long-distance tiebacks and flow assurance; remote detection of oil spills under ice; craft for safer offshore platform evacuation in ice conditions; year-round and extended-season drilling; remote sensing of ice, permafrost and icebergs; subsea processing, including gas compression and power transmission; and high-strength steel for gas-transmission pipelines from remote locations. This work is conducted in many instances from central research facilities in Texas.

4.3 NL competitive position

Despite the presence of majors and independent oil companies and larger supply and services companies in NL, none have established R&D facilities in the Province.

There are several smaller NL technology-based companies that are now pursuing market opportunities in NL's offshore and globally. These tend to be in areas related to sonar, acoustic imaging, marine electronics, simulation, and ocean engineering.

There are also a number of academic researchers and institutes in NL, with significant R&D infrastructure and resources that are relevant to the offshore oil and gas sector. These include: NRC's Institute of Ocean Technology; MUN's Faculty of Engineering and Applied Science, Departments of Earth Sciences, Physics and Physical Oceanography, the Ocean Engineering Research Centre and 3-D Visualization Centre; College of the North Atlantic; Marine Institute; C-CORE; and Propel (formerly Centre for Marine CNG). These establishments have close ties with several of the oil companies and recently a number of research chairs have been sponsored – such as the Wood Group Chair in Arctic and Cold Region Engineering. The key resources and activities of four of these organizations are profiled in Table 3 and collectively, they represent an internationally competitive force for addressing the innovation challenges associated with the harsh environment, Arctic conditions and subsea protection challenges in oil and gas.

Institution	Resources	Ongoing Innovation
MUN	• Numerous researchers and specialists within the Faculty of Engineering and Applied Science, and Departments of Earth Sciences, Physics and Physical Oceanography, • Specialist Ocean Engineering Research Centre incl. 58 m long tow tank; process safety and risk engineering lab; cold room and AUV lab. • 3-D Visualization Centre, research vessel, marine and seismic equipment	• Primary and applied research , much of relevance to the oil and gas sector. For example: • Engineering and applied science research programs cover topics such as structures for operation in ice, underwater vehicles, marine safety and fluid-structure interaction. • Earth Sciences research encompasses areas such as geophysics,and petroleum geology,
Marine Institute	• ~400 faculty and staff. • Facilities incl. Offshore Safety & Survival Centre; Safety and Emergency Response Training Centre; and Centre for Marine Simulation.	• Applied research, much of it for organizations / companies outside Canada. Approx. $2million on research out of total $32 million budget.
C-CORE	• ~70 engineering and business experts. • Key facilities include: cold rooms and a refrigerated centrifuge infrastructure.	• Focused on engineering for offshore oil and gas prod. and transport, and on-land gas transmission • Areas of expertise include: intelligent sensors; geospatial systems; ice and geotechnical eng.
NRC's IOT	• Numerous specialist staff. • Major facilities include: a 200m towing tank; a 75m by 32m offshore engineering basin; a 90m ice tank, the longest in the world; cold room laboratories; and a cavitation tunnel.	• Canada's national centre for ocean technology research. Focus on: ocean observation; marine safety; arctic operations; and performance evaluation.

Table 3: Key NL research organizations addressing harsh environment, Arctic conditions and subsea protection challenges

NL has a number of options for engagement in innovation in oil and gas – at the level of oil and gas companies, service companies or research organizations. Options include establishing a brand new entity, acquiring or partnering with others.

In identifying priorities for innovation focus within NL, it is important to have an understanding of what is feasible. For this reason, an informed judgment has been made as to the current gap between NL innovation capabilities and international competitors, and the likely ease, time and cost to the Province associated with bridging these gaps. This subjective assessment, which is shown in Table 4 below, is based on the consultant's own in-house knowledge and has been validated with the Project Steering Committee. Further detailed review will be applied in Phase 2 of the Innovation Roadmap project.

Practicalities and costs would suggest that NL is likely to favour collaborative options for engagement with oil and gas companies, service companies and technology suppliers, based on existing academic and institutional strengths. This will be a key topic for Phase 2 of the project.

	Option for engagement	Current Gap	Ease of impl.	Time to impl.	Cost to impl.
Oil and Gas Companies	• Grow local oil and gas company and related innovation capability (Nalcor).	Medium	Difficult	Medium	High
	• Encourage / collaborate with national / international oil and gas co. to establish research/ innovation facility in NL.	Medium	Difficult	Short	Low
	• Oil and gas companies lead R&D investments in some priority areas	Medium	Easy	Short	Low
G&G Service, Equipment Suppliers, and Eng. and Construction Companies	• Establish / build local technology solutions provider(s) in NL.	Medium	Moderate	Medium	Medium
	• Acquire service/equipment/engineering or construction company and bring innovation activities to NL.	Medium	Moderate	Short	High
	• Encourage / collaborate with current supplier to establish research / innovation facility in NL.	Medium	Moderate	Short	Medium
Universities and Institutes	• Establish dedicated oil and gas-related research institute (Or build on existing institute).	Small	Moderate	Medium	Medium
	• Establish specialist oil and gas-related research department within existing university or institute (Or build on existing departments).	Small	Easy	Medium	Medium
	• Support individual researchers to collaborate with third parties.	Small	Easy	Short	Low

Table 4: Options for NL engagement in oil and gas innovation
(Current gap between NL innovation capabilities and international competitors, ease of implementation, time to implement, and cost to the Province associated with implementing measures to close gaps)

4.4 Priority NL innovation opportunities

As stated, there is significant innovation activity worldwide in all of the opportunity areas identified. It is important that NL selects as innovation priorities those areas where it has a basis for competitive advantage, or an interest in becoming an 'informed buyer' of other innovation. The exception is where NL-specific barriers will not be addressed by waiting for others to overcome them.

Combining the review of barriers, the assessment of the value that overcoming these barriers would provide, and a review of NL's competitive advantage, relative to each barrier, provides, in Table 5 below, a list of overall innovation priorities shown under three categories.

	Category	Barrier	Innovation Opportunity	Rationale
A	Innovation opportunities with both a local and international value, that may be addressed by international innovators but where NL has, or can acquire an internationally competitive position.	Harsh environment	Develop technologies and techniques that can be applied in increasingly harsh environments including freezing conditions. Covering exploration, project development and production phases (including innovative technologies for the monetization of NL offshore natural gas).	NL has a range of internationally competitive pure to applied R&D organizations with directly relevant skills. These already have close links with the industry and collaboration with industry and other research organizations is likely to be a promising way forward. Overcoming these barriers is key to NL oil and gas development, but is also highly applicable to other parts of the world.
		Arctic conditions	(See also Harsh environment and Arctic conditions) – Focused innovation program featuring the safety, subsea and unmanned techniques that will unlock known and potential Labrador gas and also other Arctic oil & gas.	
		Subsea protection	Develop and demonstrate cost effective subsea pipeline and facility protection solutions that can reduce future project costs.	
B	Innovation opportunities that have a significant local value but limited international value, where NL will have to lead the way if barriers are to be overcome and energy resources are to be exploited.	Enhanced recovery	Intensify research into reservoir structures prevalent in NL. Model and then trial techniques for enhanced recovery.	All of these barriers have aspects that are NL-specific and so careful attention needs to be paid to overcoming them in the most effective way. Enhanced recovery is a critical need, since local reservoir types need to be better understood by local personnel for the long term benefit of NL. NL has capabilities in several of these areas (e.g. offshore logistics, onshore seismic devices), so these should be built on.
		Onshore seismic	Develop lighter seismic equipment and soft tire vehicles that can access sensitive areas when ground is not frozen.	
		Far offshore logistics	Research and model logistics solution(s) for offshore NL. Consider supporting shared facility for whole industry.	
C	Innovation opportunities that are being addressed by significant numbers of international innovators, where NL does not have an internationally competitive position, and is unlikely to acquire one.	Lack of decommission-ing experience	Predict decommissioning needs of NL structures and identify where similar abilities will be required internationally, understand technical requirements.	NL should be mindful of this for the longer term, but it should not divert innovation resources towards this for the time being.

Table 5: Prioritized oil and gas innovation opportunities

5 Onshore wind energy

Onshore wind energy has been identified as one of the four primary elements of NL's 'Energy Warehouse', along with hydro, oil and gas. It is estimated that there is more that 5 Gigawatts of potential wind energy available within the Province, with much of the Province having average wind speeds of between seven and ten metres per second at 50 metres above the ground. A little over 50 MW is exploited today in wind farms at St Lawrence and Fermeuse in Newfoundland.[1]

Development of wind energy resources, linked to existing and proposed facilities, is a consideration for future development. Development of these resources, along with transmission capacity, will open up the prospect of very substantial export of valuable renewable electricity to markets in North America.

Exploitation of these onshore wind energy resources is intimately linked to the delivery of a number of Energy Plan goals, notably environmental leadership, energy security, sustainable economic development, and maximizing electricity export value.

5.1 Innovation needs

There are a number of challenges to the exploitation of wind energy resources in NL, including:

- Development of wind turbines that are robust in gusty wind conditions, reliable, efficient, and low cost. In Labrador, these turbines will also need to be suitable for operation in cold and icy conditions.
- Access to project sites with predictable and suitable wind conditions, appropriate grid infrastructure, planning and operating consents, and development finance.
- Enhanced manufacturing capacity capable of delivering increased volumes of component parts and products of consistent quality at lower cost.
- New concepts for transportation, installation, operation and maintenance of wind turbines, particularly in remote locations, cold or complex terrains.

The specific barriers associated with each of these challenges, and resulting innovation needs are summarized in Table 6 below. Any identified non-technology-related barriers were not considered when identifying priority areas for innovation roadmapping.

[1] Focusing our Energy; NL Energy Plan available at http://www.nr.gov.nl.ca/energyplan/EnergyReport.pdf

Value chain	Barrier	Barrier detail	Potentially valuable innovation opportunities
RD&D and engineering	Capital costs	Those countries that have high levels of wind power generation, such as Denmark (19%), Spain (13%) and Portugal (17%) continue to rely on large government subsidies for commercial viability. Key factors influencing economics are capital cost; reliability of technology, which is reflected in percentage of up-time, ease of operation and O&M costs; and failure rates, most commonly associated with wind gusting.	Development and testing of lightweight turbines that exploit new materials, and use fewer standardized component parts.
	Reliability		Development and testing of wind turbine designs with greater up-time, ease of operation and reduced and predictable maintenance.
	Gusting		Development and testing of turbines capable of withstanding very strong gusty wind conditions.
Project development	Grid connection	Wind resources are often in locations that are remote from centres of energy demand and so lack infrastructure. There is a need for cost-effective grid connection options.	Development and testing of intelligent solutions for grid integration, in particular for remote locations or power systems with large proportions of wind power [see Grid inflexibility below and separate section on Transmission].
	Resource mapping	Wind resource mapping is well understood as a discipline, but the combined effects of wind and ice for wind energy are not well understood or less well-mapped. This is needed for Labrador wind development.	Development of high-resolution wind and ice maps, with long term predictability. Testing and optimization of wind turbine operation in combined wind and ice conditions.
Mfg and fabrication	Key component bottlenecks	Most major wind turbine manufacturers are struggling to cope with the rapid increase in demand for technology, with typical back-logs in supply of 1.5 to 2.5 years.	Development of enhanced manufacturing capacity capable of delivering increased volumes of component parts and products of consistent quality and at lower cost.
	Cost of raw materials	The price of steel and concrete are asserted to be relatively high in NL due to limited competition. These have the potential to impact on the cost and economics of wind farm developments.	Some of these effects may be mitigated through competition policy. In addition, the relative proportion of steel and concrete in a wind turbine may be reduced by alternative designs
Install	High construct'n costs	The construction costs are believed to be relatively high in NL due to short summer construction periods, remote locations with poor access, and lack of skilled resources.	Development of new concepts for transportation, installation, operation and maintenance of wind turbines, particularly in remote locations, cold or complex terrains.
Operation and maintenance	Icing	There is a risk of the build-up of ice on turbine blades unbalancing and damaging turbines, and also that ice will be thrown from the blades. No commercial anti-icing or de-icing solutions currently exist for medium and severe icing conditions. Given current demand for standard turbines, there is little incentive for technology suppliers to address this issue. We believe that Enercon is the only large supplier investigating icing today.	Development and testing of anti-icing or de-icing solutions for medium and severe icing conditions.
	Cold conditions	Operation of wind turbines in cold conditions poses particular challenges due to factors such as metal contraction, the need for specialized lubricants, and slow operation.	Development and testing of more reliable turbines capable of working in cold conditions (See Reliability above). Development of new concepts for operation in cold conditions.
	Remote location	Lengthy and expensive repairs lower turbine availability and commercial viability. This is a particular challenge in remote locations.	Development and testing of more reliable turbines (See Reliability above). Development of new concepts for operation and maintenance of wind turbines, particularly in remote locations.
	Grid inflexibility	The ability of the grid to absorb higher penetrations of intermittent wind energy is a function of the flexibility of other generation supply, interconnection, customer loads, and the availability of electricity storage facilities. This is particularly challenging for NL given the absence of these features.	Development of new concepts for the techno-economic integration of high wind penetration systems featuring hydro and (possibly) gas and storage technologies.

Table 6: Onshore wind technology-related barriers and associated innovation opportunities

5.2 International innovation landscape

There are three principal types of players involved in wind energy innovation globally. These are wind turbine manufacturers, universities and institutes, and testing centres.

The wind turbine manufacturing sector is dominated by a few large companies. Six have 77% global market share. All make significant investment in in-house innovation. For example, Vestas has 11 technology centres which employ ~1500 people and spend >US$300 million per annum. They engage in a broad range of technology innovation, much focused on cost reduction and improved reliability of technology. Most collaborate with universities, research institutes and testing centres.

There are numerous dedicated research institutes and universities with specialist renewable energy departments. There has traditionally been a bias towards Europe within the wind energy sector. Denmark and Germany are of particular significance, with other important institutes in Norway, UK, Spain, Greece and the Netherlands. Non-European specialist centres can be found in the US, China, India and Japan.

There is a broad spectrum in terms of the size and focus of these research institutes, ranging from a few people (7 at CREST, UK) to many hundreds (750 at DTU, Denmark). They engage in a broad range of innovation that includes wind turbine technology; wind resource assessment; wind energy extraction; system integration; integration into the energy economy, and environmental and societal impacts.

Globally, there are a small number of specialized turbine test centres, often associated with certification against standards, which also collaborate in research. Well known testing and accreditation companies in Europe include DEWI, Germanischer Lloyd, TUVSUD, CIEMAT, and NaREC, and in North America, include WEICan, NREL and SWRI.

Other institutions of relevance to innovation within the wind energy sector include metrology institutes such as NMI (UK) and the Physikalisch-Technische Bundesanstalk (PTB) in Munich.

5.3 NL competitive position

All three types of innovation player are present in Canada, with a concentration on the east coast. However, there is nothing of significance in NL today.

None of the on-shore wind turbine technology 'majors' is based in Canada. There are a number of smaller wind turbine manufacturers in the country, including, for example, AAER Systems (Quebec); Americas Wind Energy Inc (Ontario), and; CWind (Ontario).

There is a concentration of universities and institutes conducting research into wind energy on the east coast of Canada, including the University of New Brunswick and the Université de Moncton in New Brunswick, the Corus Centre in Quebec (partnership of five colleges), and WEICan in PEI.

The Wind Energy Institute of Canada (WEICan) in PEI is the primary Canadian wind energy test centre. It comprises: a 38 acre site with IEC Class 1 winds, and a neighbouring wind farm that can be used for research and testing purposes. It employs a board of 12 and 5 members of staff, and is funded by NRC, ACOA and the PEI Energy Corp.

At a federal level, NRC's CanmetENERGY runs clean energy research centres in Devon, Alberta; Ottawa, Ontario; and Varennes, Quebec. In addition, NSERC funds WESnet (Wind Energy Strategic Network), a collaborative program involving 39 Canadian researchers from 16 universities, and 15 partners from industry, wind institutes and government. This program is focused on four themes: wind resource assessment and forecasting; wind energy extraction in a Nordic setting, including wind turbine performance assessment and wind turbine design; technologies for integration of wind power into the electrical grids; and simulation and optimization technologies to maximize the economic benefits of wind energy for Canada. The project is expected to run from 2007-2013 with a total of CAN$6.5 M comprised of CAN$5 M from NSERC and CAN$1.5 M from the partners.

NL has a number of options for future engagement in innovation in the onshore wind sector, either as a wind turbine manufacturer, component manufacturer, test facility or research institute. These include establishing new entities, purchasing established entities, or partnering with third parties with the relevant innovation capabilities. The definition and evaluation of these options will be a core part of the next phase of this Energy Innovation Roadmapping exercise. However, some options, such as the purchase of an established internationally competitive wind turbine manufacturer, are very obviously prohibitively expensive. Others, such as the set up and growth of an internationally competitive wind turbine manufacturer will almost certainly be very difficult and time-consuming to achieve.

In identifying priorities for innovation focus within NL, it is therefore important to have an understanding of what is feasible. For this reason, we have made an informed judgment as to the current gap between NL innovation capabilities and international competitors, and the likely ease, time and cost to bridge these gaps. This subjective assessment, which is shown in Table 7 below, is based on the consultant's own in-house knowledge and has been validated with the Project Steering Committee. Further detailed review will be applied in Phase 2 of the Innovation Roadmap project. Practicalities and costs would suggest that NL is likely to favour collaborative options, but for development to occur in Labrador a wind test site may be required for data collection as well as R&D and innovation related turbine operations in high winds and ice conditions.

	Option for engagement	Current Gap	Ease of impl.	Time to impl.	Cost to impl.
Turbine Manufacturer	• Establish local wind turbine / component manufacturer and related innovation capability.	Large	Difficult	Long	Medium
	• Acquire wind turbine manufacturer and bring innovation activities to NL.	Large	Medium	Short	High
	• Encourage / collaborate with international wind energy major to establish research/ innovation facility in NL.	Large	Moderate	Short	High
Universities and Institutes	• Establish dedicated wind energy research institute.	Large	Difficult	Long	High
	• Establish specialist RE department within existing university or institute.	Large	Moderate	Medium	Medium
	• Support individual researchers to collaborate with third parties.	Medium	Easy	Short	Low
Testing Centres	• Establish stand-alone testing centre.	Large	Difficult	Medium	Medium
	• Encourage / collaborate with established national / international testing centre(s) to build local facility focused on specific issues.	Large	Moderate	Short	Low

Table 7: Options for NL engagement in onshore wind energy innovation

(Current gap between NL innovation capabilities and international competitors, ease of implementation, time to implement, and cost to the Province associated with implementing measures to close gaps)

5.4 Priority NL innovation opportunities

Ongoing international innovation projects have been identified in each of the prioritized innovation areas identified in Table 6 above. However, some barriers are generic to all applications within the wind energy sector and will be fully addressed by ongoing international innovation. Others include aspects that are specific to NL. While ongoing international innovation will be relevant to overcoming these barriers, it is likely that further innovation will be needed specific to NL. As a result, innovation opportunities have been separated into three categories, as shown in Table 8 below.

	Category	Barrier	Innovation Opportunity	Rationale
A	Innovation opportunities with both a local and international value, that may be addressed by international innovators but where NL has, or can acquire an internationally competitive position.	Icing	Development and testing of anti-icing or de-icing solutions for medium and severe icing conditions.	Might merit prioritization by NL given modest ongoing international activity and potential to exploit related research at MUN, Nalcor and others. Ongoing global activity, including in Canada, suggests collaboration likely to be best way to implement.
		Cold conditions	Development and testing of more reliable turbines capable of working in cold conditions. Development of new concepts for operation and maintenance of wind turbines in cold conditions.	
		Grid inflexibility	Development of new concepts for the techno-economic integration of high wind penetration systems featuring hydro and (possibly) gas and storage technologies.	
B	Innovation opportunities that have a significant local value but limited international value, where NL will have to lead the way if barriers are to be overcome and energy resources are to be exploited.	Resource mapping	Development of high-resolution wind and ice maps, with long term predictability. Testing and optimization of wind turbine operation in combined wind and ice conditions.	Merits prioritization because conditions in NL are not well understood and this is needed for local exploitation. High level of ongoing global activity would suggest collaboration likely to be best way to implement.
C	Innovation opportunities that are being addressed by significant numbers of international innovators, where NL does not have an internationally competitive position, and is unlikely to acquire one	All other technology barriers	Capital cost reduction, reliability improvement and gusting tolerance for turbines.	Unlikely to merit prioritization by NL, given the significant ongoing activity in these areas by turbine manufacturers and institutions.

Table 8: Prioritized onshore wind innovation opportunities

6 Transmission

The Energy Plan identifies hydroelectricity, onshore wind and gas as major resources for further development. The first two of these are located in Labrador for the most part (11GW of unexploited reserves are estimated), and there are also significant gas resources offshore Labrador which may be exploited via conversion to electricity and exported along the same route. This represents a multi-gigawatt electricity opportunity, however, it is remote from any markets and, as such, requires long distance transmission. Even shorter distance options (e.g., large scale industrial use) also present transmission challenges.

Existing transmission corridors do not provide satisfactory capacity, and it is probable that economic value will be maximized by retaining maximum control over the export options. Overcoming the technical (and other) barriers to transmission is key to retaining control and maximizing this value, in line with Energy Plan goals.

6.1 Innovation needs

In our analysis of onshore wind energy, hydroelectricity and potentially natural gas, it became clear that several of the barriers impeding further development are associated with transmission. These relate, in particular, to the distances and climatic challenges associated with transmission of electricity generated in Labrador. We analysed the barriers to identify those where innovation could provide most value in NL and, potentially, in international markets.

- There is a complex multi-variable challenge associated with maximizing the value from NL's wind, hydro and potentially gas-fired electricity to be exported from Labrador. This is due to the intermittent nature of wind, the fluctuating (but predictable) nature of hydro and the fully variable nature of gas-fired electricity. These need to be integrated in a way that maximizes their value – typically by providing the buyer with the most predictability - and which minimizes the cost of transmission.
- Power line operation throughout NL is affected to some extent by icing. Tackling a large scale transmission project would require very careful technical measures for ice prediction, monitoring and control so that day to day operations are not interrupted by icing.

The specific barriers associated with each of these challenges, and resulting innovation needs are summarized in Table 9 below. As noted above for other energy sources, non-technology-related barriers are not considered further for innovation roadmapping purposes.

Value chain	Barrier	Barrier detail	Potentially valuable innovation opportunities
Planning and design	Wind/hydro/ gas to wire integration	Challenging integration issues of wind, hydro, and potentially GTW sources and operations.	Techno-economic system modelling leading to detailed understanding of most attractive options for integrating different NL energy sources and their export over long distances. Include: - Range of different electricity sources, uses, routes - careful examination of market needs - consideration the value of reliability
Operation	Icing conditions	Ice conditions act as constraint on system operation and can lead to outages.	Enhance power line icing capabilities (prediction, monitoring, and control strategies, de-icing technologies) with a focus on specific Labrador conditions.

Table 9: Transmission technology-related barriers and associated innovation opportunities

6.2 International innovation landscape

Innovation in transmission is carried out by numerous companies and organizations worldwide. There are three broad categories of innovator:

- Electric power utilities – Examples within Canada include BC Hydro and Hydro Quebec (the latter has 6 R&D laboratories, for example). Many Canadian utilities face challenges associated with icing in particular. Internationally, Vattenfall of Sweden invests about 1% of turnover in R&D, some of it towards icing.
- Technology solution providers – These provide services to utilities and vary in scale, but some are very large. For example Areva of France has R&D centres worldwide and has provided innovative de-icing solutions for companies such as Hydro Quebec.
- Research organizations – Leading examples include the Electric Power Research Institute in the US and numerous university departments worldwide. These work on behalf of utilities and solution providers, as well as conducting early stage research.

6.3 NL competitive position

Compared with oil and gas, there is a lower level of NL innovation activity in the two identified opportunity areas, with two main organizations being most active.

Renewable integration in grids

- Nalcor manages a system which is independent of systems outside the Province with substantial wind and hydro capacity so has good day-to-day experience of renewable integration, though not at the scale implied by Labrador resources. It is also currently leading a research and development project in the isolated community of Ramea to demonstrate the viability of wind-hydrogen-diesel technology.
- MUN Department of Engineering conducts a modest amount research into grid integration and reliability issues.

Power line icing

- Nalcor also has many years of specialist research and operating experience related to ice monitoring of overhead power lines.
- MUN Department of Engineering conducts research into icing issues in support of Nalcor.

Compared with international activities in similar areas, NL organizations play a smaller role:

- Research and innovation related to wind energy integration into the grid is the focus of numerous major utilities and academic organizations worldwide (VTT, EPRI, NREL, DTU/RISO and others). Investigation of technologies for integration of wind power into electrical grids is a theme of the NSERC-funded WESNet research programme. It is also the subject of research by utilities (such as Avista) and institutes (such as VTT in Finland) and the multi-party IEA Implementing Agreement for Cooperation in RDD of Wind Energy Systems.
- Research and innovation related to icing is the focus of a number of utilities and research institutes operating in northern environments. For example, contributors to the Sept 2009 international workshop on power line icing included Université du Québec à Chicoutimi; Landsnet (Iceland); College of Electrical Engineering of Chongqing University (China);

Technical University Braunschweig (Germany); Xi'an Polytechnic University (China); Electric Power Research Institute – VNIIE (Russia); CESI RICERCA (Italy); STRI AB (Sweden); and Hydro-Quebec Transenergie (Quebec).

NL has a number of options for future engagement in innovation in the transmission sector. These sensibly build on Nalcor, Newfoundland Power and MUN capabilities. The definition and evaluation of these options will be a core part of the next phase of this Energy Innovation Roadmapping exercise. However, in identifying priorities for innovation focus within NL, it is important to have an understanding of what is feasible. For this reason, we have made an informed judgment as to the current gap between NL innovation capabilities and international competitors, and the likely ease, time and cost to bridge these gaps. This subjective assessment is shown in Table 10 below.

	Option for engagement	Current Gap	Ease of impl.	Time to impl.	Cost to impl.
Electric Power Utilities	• Expand existing Nalcor research capacity.	Moderate	Moderate	Medium	Medium
	• Collaborate with other national/international power utilities with innovation capabilities in areas of interest.	Moderate	Moderate	Short	Low
Technology Solution Providers	• Establish local technology solutions provider in NL.	Large	Difficult	Long	Medium
	• Encourage / collaborate with international tech. solution provider to establish research / innovation facility in NL.	Large	Difficult	Medium	High
Universities and Institutes	• Establish dedicated electric power research institute.	Large	Difficult	Long	High
	• Establish specialist power technology research department within existing university or institute.	Large	Difficult	Medium	Medium
	• Support individual researchers to collaborate with third parties.	Moderate	Moderate	Short	Low

Table 10: Options for NL engagement in transmission innovation
(Current gap between NL innovation capabilities and international competitors, ease of implementation, time to implement, and cost to the Province associated with implementing measures to close gaps)

6.4 Priority NL innovation opportunities

The two main areas requiring innovation do not fall into areas of current strong international competitive advantage, despite some areas of proven NL capability. In the case of icing, no solution is yet available 'off the shelf' and partnership will be needed to develop solutions. It is possible that this would be exportable to other locations, though NL is unlikely to gain unique competitive advantage due to the level of collaboration required. It remains to be seen whether this will fall into ***Category A or B*** therefore.

In the case of renewable energy integration within the transmission system, there is significant expertise that can be drawn upon worldwide. Consequently, NL should prepare to become an informed buyer of such technical services (***Category C***).

The opportunities are summarized in Table 11 below.

	Category	Barrier	Innovation Opportunity	Rationale
A/B	Innovation opportunities that have a significant local value but limited international value, where NL will have to lead the way if barriers are to be overcome and energy resources are to be exploited.	Power line icing conditions	Enhance power line icing capabilities (prediction, monitoring, control strategies, de-icing technologies) with a focus on specific Labrador conditions.	Merits prioritization because conditions in NL (particularly Labrador) are not found elsewhere and this is needed for local exploitation. High level of ongoing global activity would suggest collaboration to build upon Nalcor skills likely to be best way to implement.
C	Innovation opportunities that are being addressed by significant numbers of international innovators, where NL does not have an internationally competitive position, and is unlikely to acquire one.	Wind/hydro/ gas to wire integration	Techno-economic system modelling leading to detailed understanding of most attractive options for integrating different NL energy sources and their export over long distances. Include: - Range of different electricity sources, uses, routes - careful examination of market needs - consideration the value of reliability	This capability is essential to maximize the value of NL resources, however it is a service offered by others, who offer the benefit of supplying similar services around the world. NL should be sufficiently informed to contract this service in, maximizing skills transfer as it does so.

Table 11: Prioritized transmission innovation opportunities

7 Remote location power systems

During the screening of energy types, several types of primary energy resource, energy conversion technology and energy system emerged which could be deployed in remote off-grid applications. In most instances, the distinguishing feature related to the system integration and its application, rather than to the energy source or conversion technology. It was therefore decided to address these in a technology-neutral fashion by evaluating remote location power systems as a whole, rather than any individual component. The one exception to this technology neutrality is the use of fish oil in gensets, where the resource and the application are key to one another[2].

The availability of reliable and durable power in settings where the electricity grid is unavailable is a constraint to economic and social development worldwide. By some estimates, over 2 billion people live without access to reliable grid supplies of electricity.

In general, there are few solutions to the need for power in remote settings. For low power applications (e.g., remote sensing devices, single lights) batteries are dominant, in some cases with renewable energy. For larger power applications (e.g., building power, outdoor power, minigrids) larger scale gensets are prevalent. In all cases, the functioning of the system is constrained by the availability of energy (fuel or battery charge), which, in turn, enhances the attraction of a system that can make use of the various forms of energy available in the vicinity, whether solar, kinetic (wind, marine) or chemical (fish oil).

NL has a wide variety of settings where grid power is unavailable and the alternative is expensive. Applications vary from a few milliwatts (marine condition monitoring devices) to watts (marker lights, communications towers) up to tens of kilowatts (off grid dwellings, fish processors and outport communities).

It would be grandiose to suggest that, in the context of satisfying its own needs, NL could develop technologies that could solve the world's remote energy problems. However, it is clear that systems which are applicable to even a small fraction of the global remote energy market could be a very valuable export opportunity for NL.

7.1 Innovation needs

There are a number of challenges to the development and deployment of cost-effective remote energy solutions. These include:

- Securing and harnessing energy sources which are predictable, consistent quality, and cost competitive with fossil fuel alternatives.
- Designing and engineering systems that integrate renewable energy sources and energy storage devices and cost-effectively satisfy remote energy needs.
- Designing and engineering systems that operate reliably and cost-effectively under a range of demand conditions.

[2] Fish oil is a by-product of fish processing. It can be cleaned and used in internal combustion engines as a diesel blend or substitute. It can also be processed to improve its combustion properties.

The specific barriers associated with each of these challenges, and resulting innovation needs are shown in Figure 4 below.

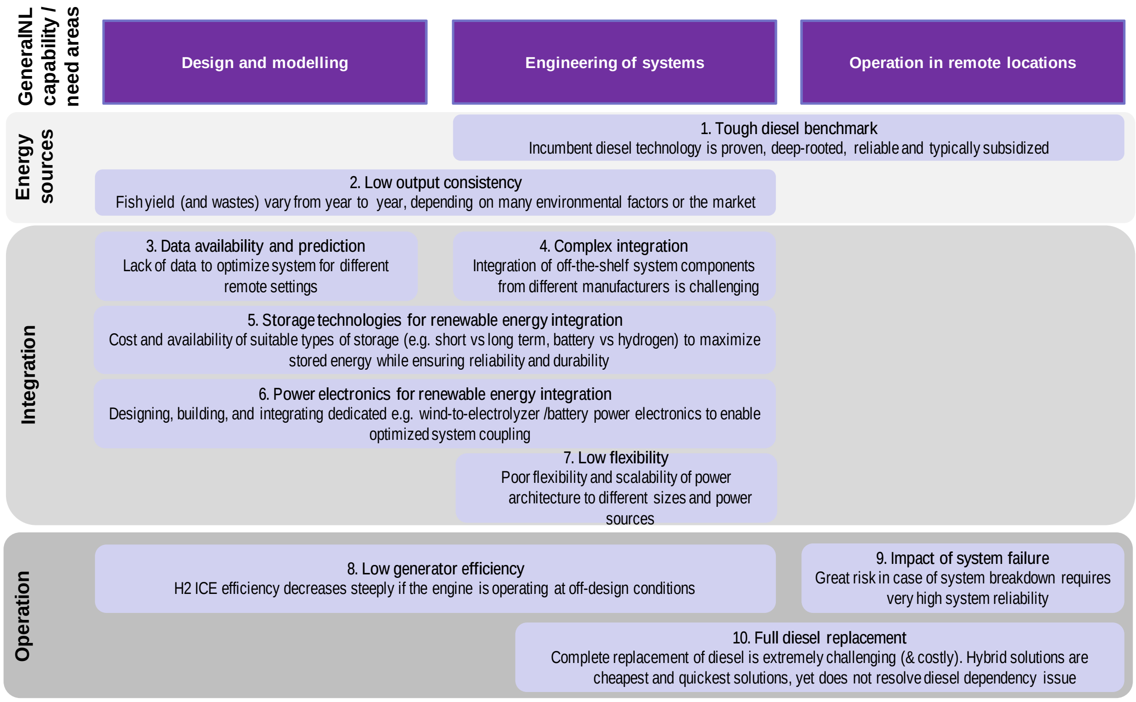

Figure 4: Remote energy systems – Key barriers matching general areas of NL capability

7.2 International innovation landscape

The principal players involved in innovation in remote energy systems are utilities, energy and telecommunications companies; research centres and universities; system design and installation businesses; and international aid agencies and NGOs. Fish oil and biodiesel innovation often involves the waste producers, such as fish processing companies.

7.2.1 Remote power

Most large utilities seeking to serve remote communities engage in innovation related to remote energy systems. This includes, for example, Eskom and EDF, the two largest utilities serving Africa.

A great many research centres and universities conduct research that has a bearing on remote energy solutions, often addressing parts of a complete system (e.g., hydrogen storage and electrolyser optimization at DTU/RISO in Denmark) or complete system integration, optimization and operation.

There are numerous businesses that have expertise in the bespoke design and installation of hybrid systems, using available technology. Many of these have a focus on a single primary power source, generally solar or wind, and the majority use battery storage.

Implementation of remote hybrid energy systems is considered a key factor in reducing poverty and improving the well-being of many rural communities in the developing world. As such, there are a number of aid agencies and NGOs that have considerable experience on the ground in supporting innovation in the deployment of such hybrid systems.

National and international large-scale collaborative programmes have been initiated in order to support innovation in remote energy systems. The IEA Wind to Hydrogen programmes is an example.

Within Canada, the Integrated Community Energy Solutions (ICES) 'roadmap for action' (2009)[3] contains a strong endorsement for the use of local renewable energy resource potential, district energy systems, decentralized energy systems, grid management initiatives and community thermal and electrical storage.

7.2.2 Fish waste to energy

A number of fish processing companies, such as UniSea Inc and US Seafood, use fish oil-diesel blends as a straight substitute for diesel fuel. There is also interest in converting fish-oil to biodiesel for use in power generation and transport applications. For example, the Aquafinca (Tilapia Farm) in Honduras[4] is fully sustainable, using bio-diesel made on site from fish oil

The efficient use of fish oil from fish waste in a diesel blend, or converted to bio-diesel, is the subject of research by a number of institutions around the world. The Alaska Energy Authority (AEA) has an entire biomass energy program[5], of which fish oil and biodiesel is an important part.

7.3 NL competitive position

NL has a wide variety of settings where grid power is unavailable and the alternative is expensive. An example is Flowers River Lodge in Labrador, which recently announced the intention to install a wind-solar-battery system to replace a diesel genset. At smaller scale, there are numerous marine applications for which small-scale power is needed. Interestingly, the Marine Institute is launching a project to evaluate subsea microgeneration systems. Even more ambitiously, MUN researchers are assessing the creation of a renewably-powered subsea recharging network for Autonomous Underwater Vessels. If successful, all of these could open up markets within NL, but more significantly beyond NL since the techniques would be widely applicable.

General areas of relevant NL capability and current innovation include the following:

- *Design and modelling*: Researchers at MUN, Marine Institute and CNA, for example, are active in identifying energy requirements and designing and simulating systems that meet these needs in concept.
- *Engineering of systems*: The Nalcor-led project to install a wind-hydrogen-diesel system at Ramea has required the development of bespoke control systems to integrate diverse components. At a more conventional level, Nalcor has developed a broad range of diesel genset systems for outport communities.
- *Operation in remote locations*: Nalcor has extensive experience in operating power systems in outport communities. In addition, fish oil production and genset operation in remote settings is well-understood across NL.

3 Council of Energy Ministers, Integrated Community Energy Solutions, A Roadmap for Action, Sept 2009.

4 http://aquaticbiofuel.files.wordpress.com/2009/08/fishwaste-biodiesel.pdf

5 http://www.akenergyauthority.org/programsalternativebiomass.html

7.4 Priority NL innovation opportunities

Although globally there are numerous businesses and research institutions focused on remote energy system research, the 'race' has only just begun. It is still possible to acquire a globally competitive position and there are numerous opportunities for national and international collaboration.

NL has a number of strategic advantages. It combines technical skills and operating experience with remote energy challenges that are widely found in the developing world. It also has some existing innovation activity on which to build. This is focused on the design, modelling, engineering and operation of remote energy systems, not on any specific technology.

The remote power systems area globally, and NL's activities in particular, are too immature to allow us to be prescriptive about specific priority innovation opportunities. We recommend that a high level innovation roadmap be developed in this area. This roadmap should allow for NL to plant seeds for the future (also known as 'taking options' within the sector) and for these options to be refined and prioritized as the sector and NL's activities mature. This will mean identifying a range of different areas in which to be active and then monitoring progress carefully, actively weeding out less successful options and encouraging those that show promise.