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

Analysis Document:

‘Energy Warehouse’ areas (Onshore Wind Energy, Hydroelectricity, Transmission, Upstream Oil & Gas, Midstream Gas)

Final Report

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Glossary

AC – Alternating current

ACOA - Atlantic Canada Opportunities Agency

AUV – Autonomous Underwater Vehicle

Boundary layer- where wind behavior is directly influenced by the land or water surface

CANMET Energy Technology Centre - (Canada) the largest energy science and technology organization working on clean energy research, development, demonstration and deployment in Canada.

Cavitation erosion (hydropower) - A type of erosion caused by air bubbles in fast moving liquid, which can erode metals, particularly in propellers and pumps.

CHP – combined heat and power

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

DC – Direct current

DEWI - German wind energy institute

DHI – (Denmark) research and technological development and competence within the fields of water, environment and health

EAWE - European Academy of Wind Energy

EU – European Union

FACTS – Flexible Alternating Current Transmission System; enhances controllability and increases power transfer capability of the electricity network

G & G service companies – Geology and Geophysics service companies

GBS - concrete gravity base structure for the Hibernia offshore platform

GTL – gas to liquids

GTW – gas to wire

H2S – Hydrogen sulphide

HPHT – high pressure high temperature

HSE – health, safety and environment

HVDC – High Voltage Direct current

IEA- (France) International Energy Agency

IP – Intellectual property

IREQ – (Quebec, CA) Institut de recherche d'Hydro-Québec

kV – kilovolts, one thousand volts

kW- Kilowatts, one-thousand Watts

LC (hydropower) - Lower Churchill [project] in Newfoundland & Labrador

LNG – liquid natural gas

Low-head (hydropower) – Head is the height of the reservoir relative to the height of the turbine (point of discharge). Power generated is a function of head and water flow.

LPG – liquefied petroleum gas

MUN – Memorial University Newfoundland & Labrador

Nalcor Energy – (Canada) generation and transmission of electrical power

NaREC – (UK) New and Renewable Energy Centre

NMI - (UK) National Microelectronics Institute

Nord Pool spot market - the largest physical power market and exchange in the world, offering both day-ahead and intra-day markets

NRC – National Research Council

NRCan – Natural Resources Canada

NREL– (USA) National renewable energy laboratory

NSERC - Natural Sciences and Engineering Research Council of Canada

NTUA – (Greece) The National Technical University

O&G – oil and gas

O&M – Operations and management

PEI - Prince Edward Islands

PSP – Private Sector Participation

R&D – Research and development

RE – renewable energy

SCADA – Supervisory Control and Data Acquisition; controlling and monitoring process

SMEs – Small and medium enterprises

SWRI – Southwest Research Institute

The Corus Centre – (Quebec, CA) Collaborative wind energy research involving several Québec universities closely connected to the wind energy industry

TUVSUD - (German) Provide services of consulting, testing, certification and training

US DOE- US Department of Energy

VTT - (Finland) the biggest multi-technological applied research organisation 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)

WindREN AB – (Sweden) Wind Renewable energy consultant Göran Ronsten

1 Context

This study forms the first phase of a Newfoundland and Labrador energy innovation roadmapping exercise, guided by the Steering Committee which was led by the Department of Natural Resources and included representatives from Research & Development Corporation - Newfoundland and Labrador, Department of Innovation, Trade and Rural Development, Department of Business and Nalcor Energy. The purpose of this study is to identify priority innovation opportunities for Newfoundland and Labrador (NL) that merit detailed roadmapping in a subsequent phase of work.

The analysis, conclusions and recommendations from this phase of work are contained in four separate reports, illustrated, in the context of the overall project, through Figure 1 below. Our conclusions and recommendations are presented in the Innovation Priorities Report which, in turn, draws upon the detailed analysis contained within three other supporting documents:

1. Analysis document: 'Energy Warehouse' areas (Oil & gas, Onshore wind, Hydroelectricity, Transmission)
2. Screening document: Other energy types (All other potentially relevant energy types)
3. Analysis document: Other energy themes identified through screening (Remote energy systems, Marine energy technologies, Energy efficiency)

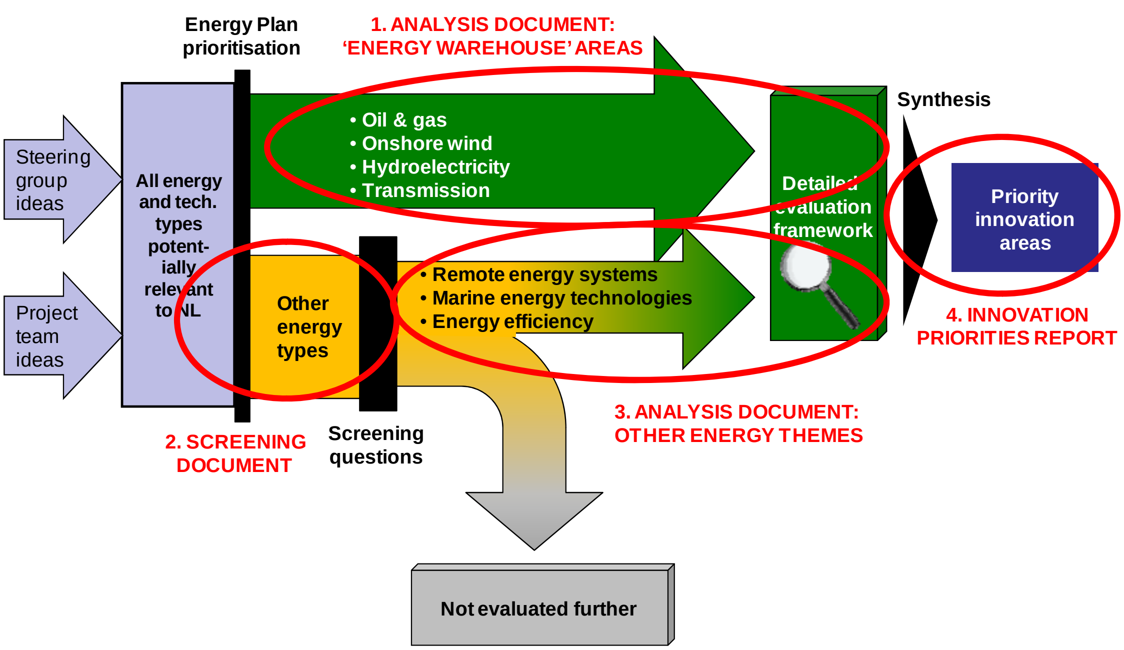


Figure 1: Overall project process and outputs

The Energy Plan, introduced the concept of an 'Energy Warehouse' featuring several key resource types, namely onshore wind energy, hydroelectricity, oil and gas. This Analysis document (1 above) describes the detailed evaluation that has been applied to areas of energy within the Energy Warehouse. 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. Note that mid and downstream oil, although referred to in the Energy Plan, in practice do not represent a significant energy innovation area for the province due to their relative maturity and corresponding lower innovation component. The focus of oil and gas is therefore upstream, in this context.

Analytical framework

The overall analytical approach taken to each energy type is summarised below and discussed in the following four sections, which correspond to the four vertical chevrons.

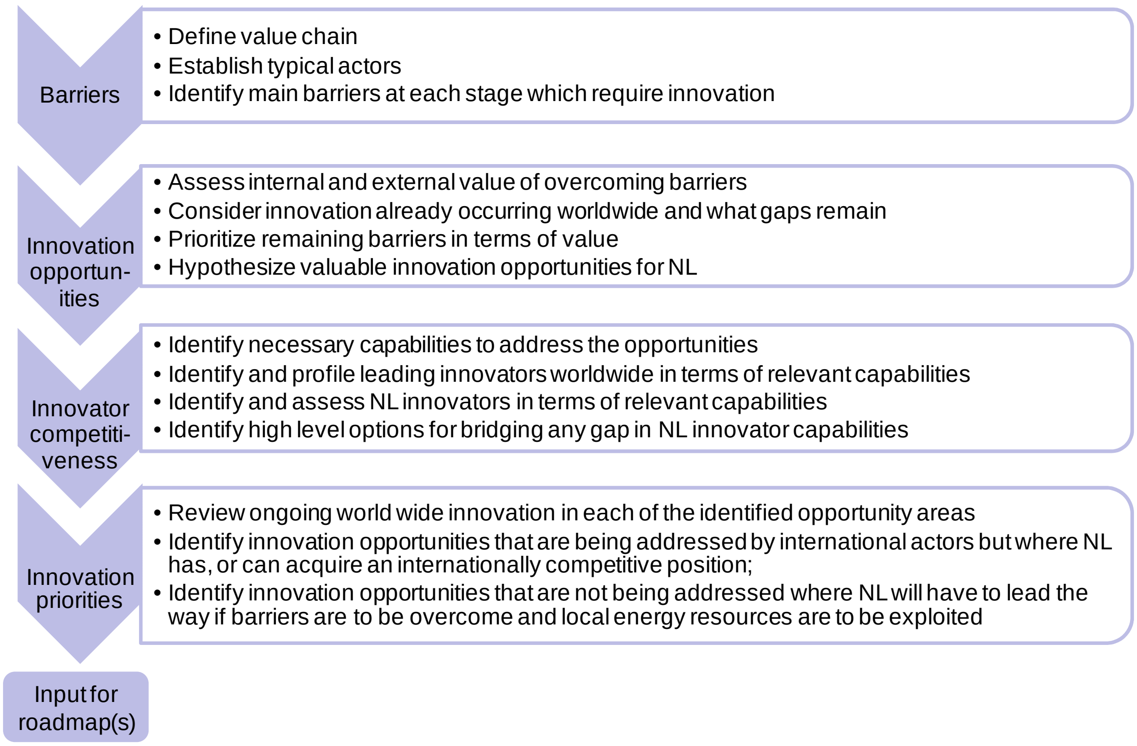


Figure 2: Detailed evaluation framework

1.1 Identifying barriers requiring innovation

A key premise of this work is that innovation is the means by which barriers are overcome. Barriers are impediments to the commercialization of an energy resource, technology or application. Barriers require things to be done for the first time in the sector as a whole and may impede commercialization along one of four parallel journeys[1]:

- **Technological barriers:** These are common in energy and require a new technical approach for their resolution. The innovation to overcome them may be the application of an existing technology to an energy setting, or the development and application of an entirely new technology.
- **Company barriers:** These are associated with the formation and development of firms to apply innovations. Barriers vary as the company matures, but are often related to the attraction of staff, finance and other resources.

[1] For more information refer to the UK Carbon Trust 'Four Journeys' framework: http://www.carbontrust.co.uk/emerging-technologies/Pages/innovation-journey.aspx

- **Market barriers:** These impair the scale of opportunities and speed of their development. They may be overcome through improved information, reduced uncertainty and/or lower prices for consumers.

- **Regulatory barriers:** These may be a significant consideration in the energy sector, due to the nature of the industry. They may manifest themselves as market or company barriers, but their resolution often requires a new regulatory approach.

Although barriers have been identified along all of these journeys, the main focus for innovation prioritization is the presence of technological barriers. Consequently, while the other barriers have been noted as relevant for the development of energy as a whole, they are not addressed or prioritized within this study. Barriers are initially mapped onto the industry value chain, and then segregated into technological and other barriers.

1.2 Identifying valuable innovation opportunities

Once barriers have been identified, the next step is to consider whether overcoming them would provide significant value to the local economy. This is a function of whether there is a local resource opportunity to be unlocked ('local value'), and/or whether there would be an opportunity to export the innovation ('external market value'). This identification procedure involves two steps.

Firstly, the theoretical value of overcoming each barrier is assessed. This is based on both NL's current capabilities and position in the value chain. Those barriers that are taken forward for further analysis are the ones in which NL would gain significantly, either domestically or as an exporter, from overcoming the barrier in question.

In the second step, consideration is given to whether the barrier is already being effectively 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 for NL in tackling them — they unlock a local puzzle with a potentially large prize and/or they offer export opportunities for NL-based innovators.

1.3 Assessing competitiveness of Newfoundland & Labrador for innovation

NL's current strength and capacity to address the identified priority barriers and associated innovation opportunities are assessed relative to international players. The key types of international innovators are identified (e.g., 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 for NL. High level options for building innovation capabilities or overcoming gaps are identified, along with their relative ease, time and cost of deployment.

The specific manner in which innovation opportunities should be exploited will be the subject of subsequent road-mapping activities (Phase 2). The purpose of this high-level overview is to inform a review of which innovation opportunities NL might sensibly address with existing innovation capabilities or those that could be competitively developed within NL (See Section 2.4 below).

1.4 Prioritizing innovation opportunities

The nature and scale of ongoing international innovation in each of the prioritized innovation areas are profiled in more detail in this section than in section 2.2. This, corroborated by the analysis in sections 2.2 and 2.3, allows innovation opportunities to be separated into the following three categories following the logic map in Figure 3:

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;

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; and

C. Innovation areas 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.

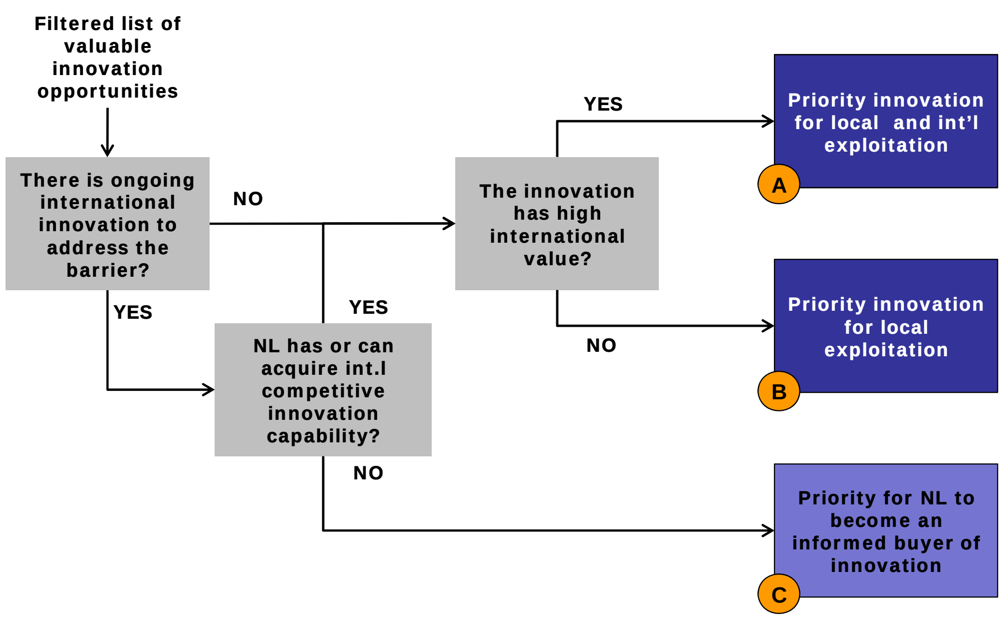


Figure 3: Logical framework for prioritization of innovation opportunities

In every instance, NL will need to understand and deploy innovation in order to overcome barriers to the exploitation of valuable energy resources. Even in those situations where NL will remain dependent upon international innovation (i.e., category C above), it will need to acquire sufficient knowledge to become an informed buyer of this innovation.

The competitiveness of current NL innovators (2.3 above) and prioritized innovation opportunities (2.4 above) provide the basis for the conclusions and priority recommendations for NL energy innovation roadmapping contained in the Innovation Priorities Report.

2 Onshore wind energy

2.1 Barriers

Onshore wind is defined here as the development and application of large scale wind turbines of over 100kW. The onshore wind industry has evolved rapidly in the past decade and the market has increased from its early beginnings in the late 1980s to one which was worth CAN$57bn globally in 2008[2]. The value chain has become well-defined, with typical actors as shown in Figures 4 and 5 below.

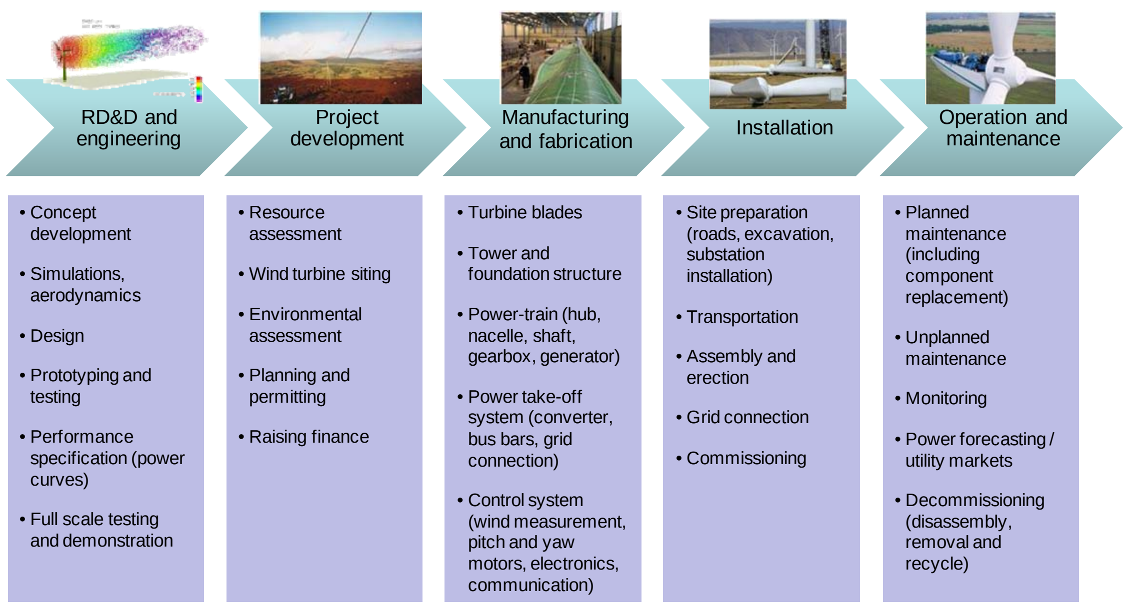
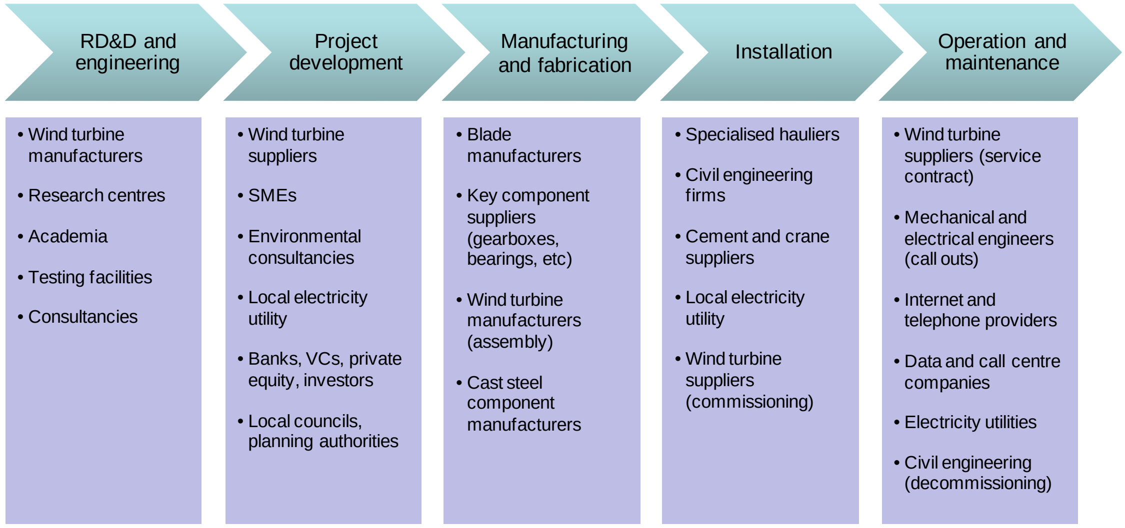


Figure 4: Onshore wind - industry value chain

[2] World Wind Energy Association



Note: many wind energy companies are vertically integrated, and cover several (or all) of these value chain steps

Figure 5: Onshore wind - typical actors along the value chain

We have drawn upon our knowledge of and contacts in the wind industry and have also held discussions with stakeholders within the province to identify the following barriers to the exploitation of onshore wind energy internationally. Key barriers for the exploitation of wind in NL, particularly Labrador, are highlighted.

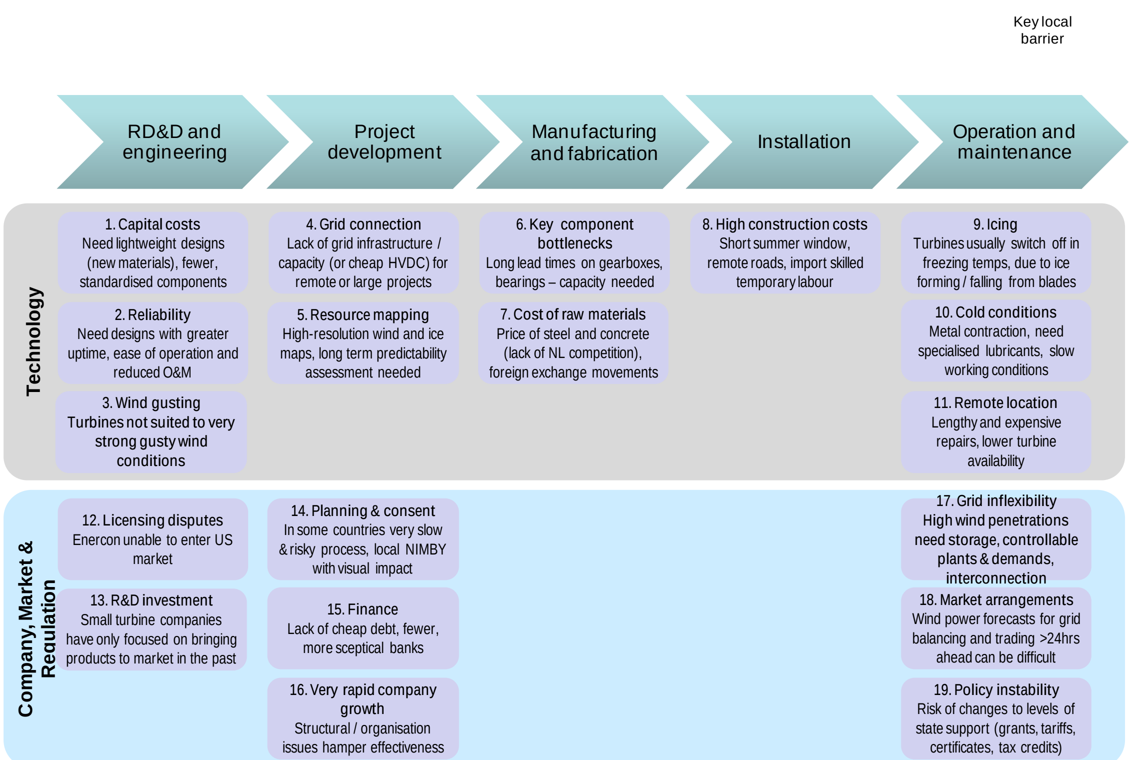


Figure 6: Onshore wind - main barriers worldwide

Additional information about each of these barriers is provided in the table below.

Barrier #	Additional information
1	The capital cost of turbines is fundamentally linked to materials and design choices. Need lighter designs which are made from fewer, standardised components
2	Turbine reliability is important for economics. Need to design machines with greater uptime, ease of operation and reduced O&M
3	Turbines are designed for strong winds, but few are able to withstand and utilise extremely gusty conditions (without shutting down), as found in NL.
4	NL project development is hampered in part by the lack of grid infrastructure or spare capacity (or low cost HVDC) for remote or large projects [see also barrier #2 in Transmission (section 4 of this report)]
5	Wind resource mapping is well understood as a discipline, but the combined effects of wind and ice for wind energy are not well understood and even less so well-mapped. This is a necessity for Labrador wind development in particular.
6	Project developments can be held up by shortages of key components such gearboxes and bearings, caused by supply chain imbalances
7	The prices of steel and concrete are key determinants of project costs and these are susceptible to a shortage of competition and foreign exchange movements
8	Labrador installation costs are likely to be particularly influenced by a short summer window for turbine installation, remote roads, and the need to import skilled temporary labour
9	There is a risk of the build-up of ice on turbine blades imbalancing and damaging turbines, and also that ice will be thrown from the blades. To avoid this, the turbine blades may be heated, and in any case, turbines are controlled to shut down before damage from imbalancing or vibrations.
10	Extreme cold conditions such as Labrador impair O&M activities due to e.g. metal contraction, embrittlement, the need for specialised lubricants and slow working conditions
11	Although the wind industry is increasingly familiar with operating in remote locations, the extreme isolation of potential project locations in Labrador mean that repairs would potentially be lengthy and expensive resulting in lower turbine availability
12	Enercon, a major EU supplier, is locked out of the US market due to a patent held by GE
13	The emergence of wind turbine 'majors' is a relatively recent event. Smaller companies have not had the luxury of significant research budgets and so the focus has historically been on product development, not earlier stage research
14	In some countries planning & consent is a very slow and risky process, subject to a strong local 'not in my back yard' factor due mostly to visual impact of turbines
15	A feature in recent years has been the lack of low cost debt for wind energy projects due to fewer, more sceptical banks who are in a position to lend
16	Several companies within the wind industry have grown extremely fast and exhibit structural / organisation issues which hamper effectiveness
17	The ability of the grid to absorb higher penetrations of intermittent wind energy is a function of the flexibility of other generation, interconnection, customer loads, and the availability of electricity storage in the form of e.g. pumped hydro facilities. This is a particularly challenging for Newfoundland and Labrador given the absence of these features, implying a strong need for export options.
18	In some energy trading markets the requirement for accurate wind power forecasts for grid balancing and trading over 24hrs ahead can be difficult
19	In some jurisdictions there is a risk of changes to levels of state support (grants, tariffs, certificates, tax credits) which significantly alters the 'bankability' of wind projects

Figure 7: Onshore wind - additional information about barriers

2.2 Valuable innovation opportunities

Each of the barriers identified in the previous section was examined in terms of the value that would be available to NL from overcoming it. This is expressed in qualitative terms for the export market outside NL ('external market value') and for the local resource development opportunity ('local market value'); see Figure 8 below.

The valuation of overcoming barriers through innovation was based upon judgement of the consulting team, informed by numerous consultations, and was also validated by steering group members. It was agreed that qualitative valuation would be suited to the purposes of the project, which requires sufficient evidence to justify prioritization, but not, for example, an econometric forecast of benefits. A one to four scale was chosen with a break point between scores of two and three.

Note: in interpreting the significance of these barriers, it is important to appreciate that the assigned values are relative to one another within the context of onshore wind, but are not relative to opportunities in other areas of energy such as hydro, oil and gas. More detail on the overall approach and the prioritization of opportunities across all energy areas is tackled in report 4 'Recommended Innovation Priorities'.

Type	Value chain	Barrier	Value of overcoming barrier (O = lowest, OOOO = highest)	
			External Market Value	Local Market Value
	RD&D and engineering	1. Capital costs	Potential value in IP generation for low capex turbines OO	Greater new project profitability, cheaper power OOO
		2. Reliability	Could open up further markets where high reliability needed OO	Maximise energy output, possibility of developing expertise OOO
		3. Gusting	No local manufacturers O	Necessary for Labrador wind development OOOO
	Project development	4. Grid connection	High potential to export expertise, and IP, but many actors involved OO	Precondition to deployment in Labrador, and possibly Newfoundland, plus employment benefits OOOO
		5. Resource mapping	Limited export value, since usually left to local organisations, but ice+wind is novel OO	Given excellent resource, identify best sites for maximum profit. Only few sites though OOO
	Manufacturing and fabrication	6. Key component bottlenecks	Limited value due to lack of component export manufacturers in NL O	Greater certainty regarding project timeframes / costs OO
		7. Cost of raw materials	Greater certainty regarding project costs OO	Greater certainty regarding project costs OO
	Installation	8. High construction costs	Some potential to export expertise to similar climates OO	Greater new project profitability, cheaper power OO
	Operation and maintenance	9. Icing	Some potential to export IP and expertise to similar climates OO	Maximise energy output, possibility of developing expertise OOOO
		10. Cold conditions	Some potential to export expertise to similar climates OO	Temperatures very regularly drop well below freezing – minimise operating costs OOO
		11. Remote location	Some potential to export IP and expertise since good wind sites usually remote, but limited since site specific OO	Isolated communities and low population, large distances OOO

Type	Value chain	Barrier	Value of overcoming barrier (O =lowest, OOOO = highest) External Market Value	Local Market Value
	RD&D and engineering	12. Licensing disputes	No role for NL	No patent disputes known about in Canada
			O	O
		13. R&D investment	None	No large wind turbine companies based in NL
			O	O
	Project development	14. Planning & consent	No role for NL since local regulations	Reduce uncertainty on likelihood of approval, streamlined project development
			O	OO
		15. Finance	Avoid postponed or cancelled projects, but limited since projects financed individually, and NL investment in overseas projects unlikely	Increased project profitability, streamlined project development
			OO	OOO
		16. Very rapid company growth	None	No wind turbine companies based in NL
			O	O
	Operation and maintenance	17. Grid inflexibility	*In the future*, some countries will have high wind – grid management know-how is of value	Local grid can only currently support 80MW of wind
			OOO	OOOO
		18. Market arrangements	No role for NL to influence other market structures	Not applicable to NL
			O	O
		19. Policy instability	No role for NL to influence other regulators	Would accelerate deployment and investment climate
			O	OOOO

Figure 8: Onshore wind - value of overcoming barriers

The outputs of the tables above are represented graphically in Figure 9, below.

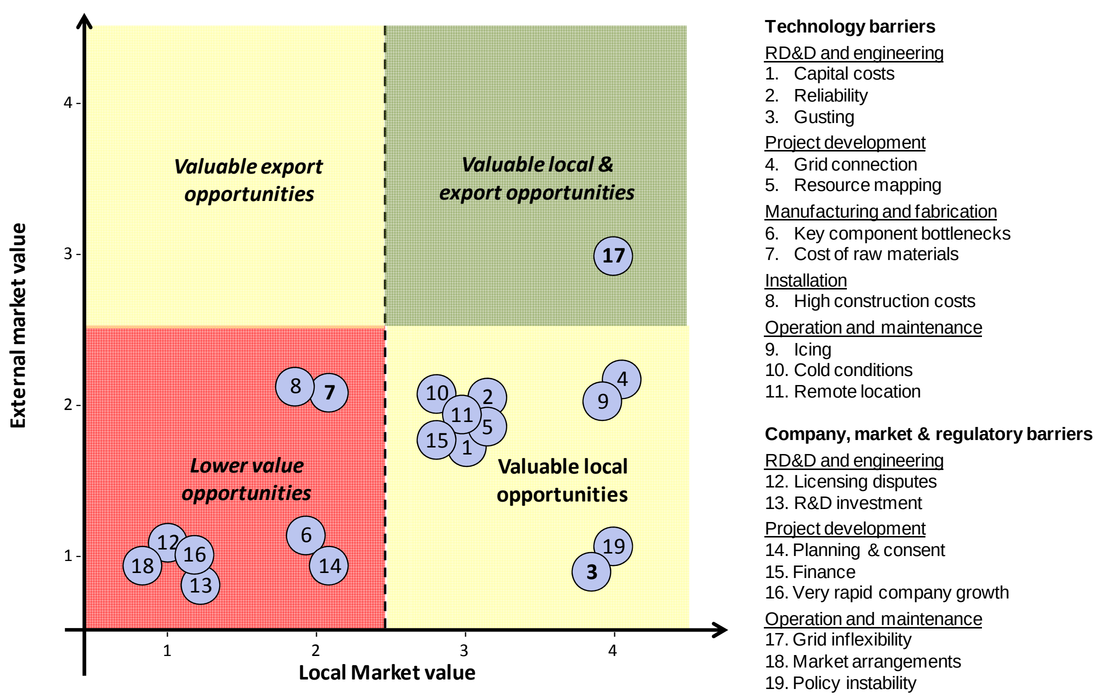


Figure 9: Onshore wind - theoretical value of overcoming barriers (summary)

The following observations can be made about the assessment of value:

- Ten innovation opportunities are valuable locally but not externally ('valuable local opportunities'). They relate to things that have a high potential value through unlocking wind resources in Labrador in particular. However, the absence of a strong NL wind energy turbine or development company which could also export products and services limits their position on the export value dimension. The value of overcoming policy instability (#19) is inherently local and would therefore have no export value.

- Eight barriers do not offer opportunities for either external or local value ('lower value opportunities') because, in most cases, they are things that do not apply to wind energy in the NL context and/or their resolution is not of significant value to the province.
- One barrier, grid inflexibility, could provide a valuable opportunity for NL to offer similar solutions to other parts of the world where similar conditions prevail. NL serves as a fairly extreme example of an electricity system with potentially very high renewable energy penetration (including wind), which is a common direction in many other markets.

Each of the barriers where the value in the external and/or local market value is high was considered further. Current innovation activities of leading innovators were assessed to determine whether there is a valuable innovation gap that NL might be able to address. These are presented in Figure 10 and Figure 11 respectively.

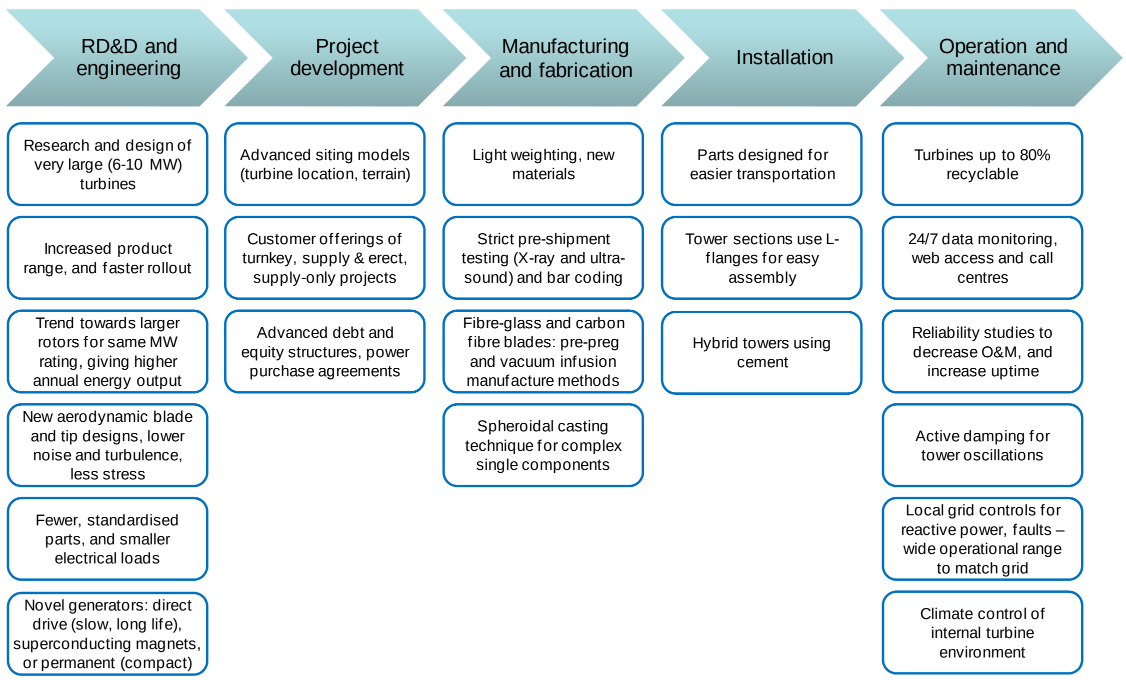


Figure 10: Onshore wind - main innovation currently occurring worldwide

There is evidence of activity in all value chain stages, addressing many of the challenges previously described (this is expanded in section 2.3). However, the wind industry is relatively young and so much of this work has yet to deliver fully proven solutions. These findings are matched to the specific barriers below to identify any significant gaps which NL may be able to address.

Type	Value chain	Barrier	Innovation to address the barrier	
			Innovation currently occurring	Remaining gaps
	RD&D and engineering	1.Capital costs	Very large turbines, lower cost materials	Still a key challenge
		2. Reliability	More data monitoring, reliability modelling, pre-delivery testing and inspection	Still a key challenge
		3. Gusting	Advanced materials, lower stress rotor design	More work needed
	Project development	4. Grid connection	[see separate Transmission section]	[see separate Transmission section]
		5. Resource mapping	Wind resource mapping well understood, but interaction with ice less so	Integrated wind/ice resource mapping
	Manufacturing and fabrication	6.Key component bottlenecks	Design for ease of manufacture	Not as big a challenge as in recent past
		7. Cost of raw materials	Lightweighting and new materials	Still a key challenge
	Installation	8. High construction costs	Design for ease of erection	NL may present specific challenges due to remoteness. May be opportunity for local assembly
	Operation and maintenance	9. Icing	Heating elements in blades, reducing tip speed	Requires further work for very cold weather
		10. Cold conditions	New lubricants and materials in research, climate control for turbine interior	Requires further work for very cold weather
		11. Remote location	Reliability work to improve uptime	Still a key challenge
Other	Operation and maintenance	17. Grid inflexibility	Modelling and growing experience with high wind penetration systems	Limited knowledge of systems resembling NL

Figure 11: Onshore wind - worldwide innovation gaps

The implications of this assessment are that several major challenges remain for the wind industry as a whole, particularly with regard to reducing capital and operating costs (e.g. #1, 2, and 7). There are also challenges which result from the particular conditions in NL which the industry is not likely to resolve without dedicated efforts (e.g. #3, 5, 8, 9, 10, 11, and 17). Note that transmission is a recurrent theme in wind energy, hydroelectrity and, potentially, electricity from gas. It is therefore treated separately in section 4 of this report where it cuts across all of these energy types.

Combining these findings with the earlier analysis of innovation value leads to the following summary of valuable innovation opportunities for NL (Figure 12). Hypotheses for how NL may be able to capture this value were also generated as an input to the next section of the analysis and are detailed in Figure 12 below.

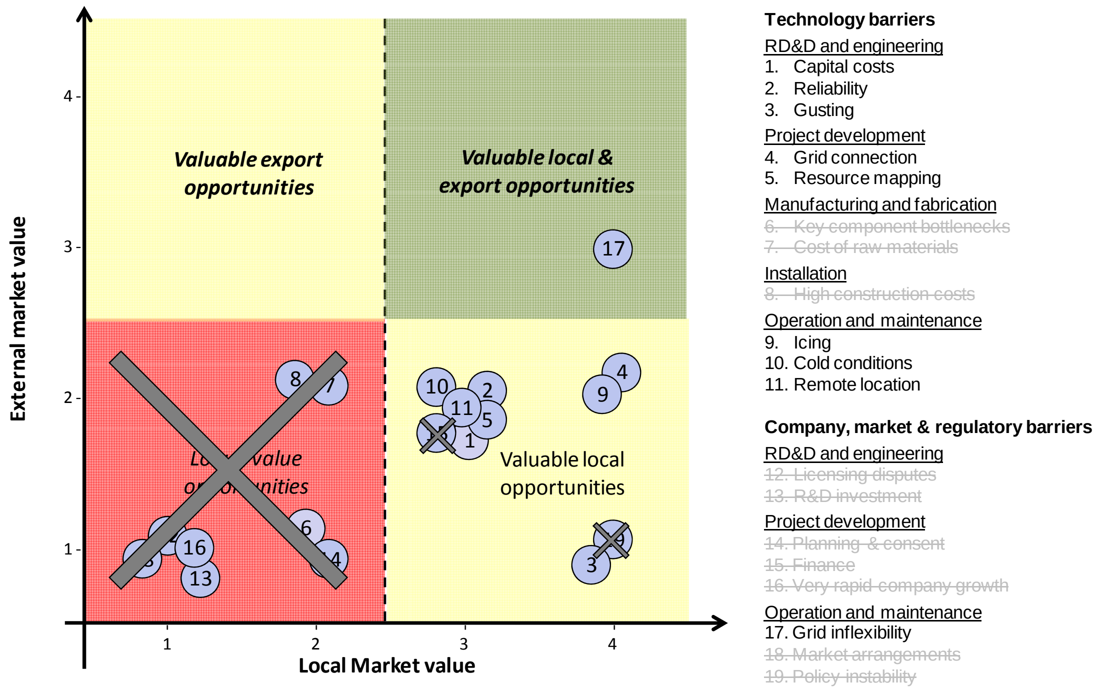


Figure 12: Onshore wind - potentially valuable innovation opportunities for NL

Value chain		Barrier	Barrier detail	Potentially valuable innovation opportunity for NL*
Technology	RD&D and engineering	1.Capital costs	Need lightweight designs (new materials), fewer, standardised components	Apply research and structural engineering skills to development of very large turbines and identifying lower cost materials/structures. Likely to be a contracted service for turbine companies, rather than 'home grown' NL turbine company
		2. Reliability	Need designs with greater uptime, ease of operation and reduced O&M	Apply mechanical engineering skills and knowledge from offshore in data monitoring to reliability modelling. Likely to be a contracted service for turbine companies, rather than 'home grown' NL turbine company
		3. Gusting	Turbines not suited to very strong gusty wind conditions	Apply research and structural engineering skills to development of turbines that are suited to gusty conditions such as those found in NL. Provide testing and monitoring facility for such turbines. Both services likely to be contracted for turbine companies, rather than 'home grown' NL turbine company
	Project development	4. Grid connection	Lack of grid infrastructure / capacity (or cheap HVDC) for remote or large projects	[see separate Transmission section]
		5. Resource mapping	High-resolution wind and ice maps, long term predictability assessment needed	Create methodology for combined wind/ice mapping and apply to NL resources in the first instance. Consider exporting methodology and/or service to other regions where similar resources exist.
	Operation and maintenance	9. Icing	Turbines usually switch off in freezing temps, due to ice forming / falling from blades	Apply mechanical engineering skills and knowledge from offshore in cold weather to turbine design for icy conditions. Also provide testing and monitoring facility for such turbines. Both services likely to be contracted for turbine companies, rather than 'home grown' NL turbine company
		10. Cold conditions	Metal contraction, need specialised lubricants, slow working conditions	Apply knowledge from offshore to cold weather turbine design and operation, including lubrication. Likely to be a contracted service for turbine companies, rather than 'home grown' NL turbine company
		11. Remote location	Lengthy and expensive repairs, lower turbine availability	See 2 above
Other	Operation and maintenance	17. Grid inflexibility	High wind penetrations need storage, controllable plants & demands, interconnection	Develop capability in techno-economic integration of high wind penetration systems featuring hydro and (possibly) gas and storage technologies. Apply this knowledge to NL and, potentially, to other power markets where similar conditions apply.

Figure 13: Onshore wind - hypotheses of valuable innovation (to be tested)

The output of this section of the evaluation is a set of potentially valuable innovation opportunities that NL could pursue, assuming that it has the resources to be competitive in doing so. The opportunities are, therefore, presented as hypotheses at this stage including an element of what the opportunity is and how it might be approached. Both aspects are needed to inform the subsequent stages of the evaluation which will assess NL competitiveness.

The following observations can be made on the hypotheses that remain at the end of this stage of evaluation:

- #1, 2, 3, 9, 10, and 11 have the common theme of drawing upon NL's capabilities developed in offshore engineering, applying these to specific wind energy innovation opportunities. The application is likely to be in the form of a contracted service to turbine developers, but may also include a physical test facility in NL to support the delivery of the service.
- #5 is a specific requirement to allow projects to be planned in NL, drawing upon the province's experience in ice monitoring combined with more conventional wind monitoring techniques.
- #17 is a key enabler to allow export of wind power and could draw upon NL's experience of operating a grid which is isolated from other systems. This capability could be marketed to others if it proved to be relevant to situations faced elsewhere in the world.

2.3 NL innovator competitiveness

2.3.1 Leading innovators worldwide and their priorities

Innovation within the onshore wind sector is carried out by three key types of players:

- Turbine and component manufacturers;
- Research centres and universities; and
- Testing facilities.

Selected examples of each of these are profiled below.

Turbine and component manufacturers

The wind turbine market is dominated by few large-scale manufacturers that together represent approximately 77% of the market (see Figure 14 below).

Name	Location of HQ	Rank (market share in 2008)[3]	Size	Revenue spend on R&D
Vestas	Randers, Denmark	1 (19.8)	Revenue: EUR 6 bn (CAN$ 9.4 bn) (2008); number of employees 21,000	7% of staff involved in R&D; R&D spend approx EUR 200 m (3.3% of total revenue)
GE Wind	Atlanta, US	2 (18.6)	GE Energy (total): US $21.8 bn (CAN$ 22.8)	Research investment in 'cleaner technologies': $1.5 bn (6.8% of revenue) annually.
Gamesa	Madrid, Spain	3 (12)	EUR 3.2 bn (CAN$ 5.0) (based on Q1 2009 EUR 800 m)	Main R&D department employs >600 people
Enercon	Aurich, Germany	4 (10)	12,000 employees worldwide	>180 engineers employed in R&D. R&D spend not available. One external report estimated

[3] http://www.enercon.de/en/_home.htm, based on installed MW.

Name	Location of HQ	Rank (market share in 2008)[3]	Size	Revenue spend on R&D
				R&D spend in 2007 at approximately EUR 17.5 m (CAN$ 21.9 m), based on expected salaries for 130 staff, but acknowledged that at 1% of turnover this is likely to be an underestimate.[4]
Suzlon*	Pune, India	5 (9)	14,000 employees worldwide. Consolidated income (inc. RE Power) Rs in Crore 26,000 (CAN$ 5.3 bn) (2009).	500 employees; R&D spend 50 Rs in Crore (CAN$ 11.3 m) (0.7% of standalone revenue) (2009).
Siemens	Brande, Denmark	6 (6.9)	Energy Sector alone EUR 22.5 bn (includes power generation/ oil and gas). 5000 employees worldwide	32,000 scientists conducting research worldwide; 1,900 undertaking basic research at Corporate Technology Department. R&D spend EUR 3.8 bn (CAN$ 5.9 bn) (4.9% of total revenue) (2008). Energy accounts for approx 17% of output (number of inventions). CAN$ 1.6 bn devoted to green technologies.

Figure 144: World leading wind turbine manufacturers

Other important players are Sinovel (5% market share); Acciona (4.6%); Goldwind (4%); and Nordex (3.8%). There are also a number of smaller manufacturers, based in Canada, including AAER Systems, Americas Wind Energy Inc, CWind Inc, Entegrity Wind Systems, Northern Power Systems, and WES (Wind Energy Solutions) Canada.

All the major manufacturers have a strong focus on R&D, with a common emphasis on reducing the cost of energy, improving reliability and launching innovative services. For example, **Vestas** states that the motivation behind its development is 'the goal of having increasingly robust turbines and the necessity of increasing output per kilogramme turbine for the benefit of the environment.'[5] A recent press release,[6] highlighted **GE Wind**'s focus on innovative services, including:

- Remote monitoring and diagnostics. Two centres (Schenectady, N.Y. and Salzbergen, Germany) provide monitoring and diagnostic services 24 hours a day, in order to increase equipment availability, and reduce downtime and operational costs.
- New upgrades that increase reliability and output such as the WindBOOST™ control system, and vibration monitoring and analysis technology that allows early detection of drive train issues.

Gamesa aims to combine the lowest cost of energy (CoE), with high reliability figures, while complying with demanding grid codes.[7] Its emphasis on cost optimization has led to the recent

[4] JRC Reference Reports, R&D Investment in the Priority Technologies of the European Strategic Energy Technology Plan, European Commission Joint Research Centre, Institute for Prospective Technological Studies, 2009

[5] Vestas Credit Crunch Wind, 2009

[6] http://www.gepower.com/about/press/en/2009_press/050409e.htm

[7] http://www.gamesacorp.com/files/Documentos%20PDF/Ingles/1Q%20Results%20Presentation2009.pdf

launch of the new G10x-4.5MW wind turbine prototype and the construction of the plant in Aoiz (Navarra – Spain) for the production of G10x-4.5MW blades.

Although manufacturing companies tend to have significant in-house research capabilities, there are also numerous examples of collaboration with leading research institutions. **Vestas**, for example, has a policy of encouraging open innovation and is continually in the process of 'mapping specific centres of knowledge around the world with R&D that might have applications for the wind industry.' This includes looking at 'adjacent industries' such as aerospace where, for example, research into novel materials could be applied to the wind sector. In addition, in 2008, Vestas established a 'Global University Programme'[8] with the aim of expanding collaboration with universities worldwide in order to accelerate global innovative wind power research. The programme will sponsor professors, PhDs and master's thesis students from leading universities. Other examples are **Siemens** which maintains strategic partnerships with leading research institutions (such as the Munich Technical University, the Aachen Technical University, MIT in Boston, Tsinghua University in China) and **Suzlon** which works closely with key technological partners (such as Hansen Transmissions (Belgium), Risø (Denmark), Delft University of Technology (Netherlands), and Fraunhofer Gesellschaft (Germany)).

Research centres and universities

Europe

R&D into technologies associated with wind power has historically been centered in Europe, and a concentration of research centres and institutes devoted to wind power, coupled with numerous universities incorporating specialist renewable energy divisions, remains in the region. Of particular importance are Denmark and Germany, with other notable institutes in Norway, UK, Spain, Greece and the Netherlands.

The EAWE (European Academy of Wind Energy) is a network of 29 entities from 7 EU countries, formed in 2003 in order to 'integrate the activities of the highest level academic and research institutes in Europe working on Wind Energy under a joint programme'[9] and to maintain Europe's leading position in wind technology development and training.

Five priority long-term R&D themes were identified for EAWE. Some of these (highlighted in yellow in the table below) coincide with those areas identified as opportunities for NL.

	Priority theme	Sub-theme
1	Long-term Wind forecast	Wind resources
		Micro-sitting in complex terrain
		Annual energy yield
		Design wind conditions (turbulence, shear, gusts, extreme winds) offshore, onshore and in complex terrain
2	Wind Turbine External Conditions	Characteristics of wind regime and waves
		Atmospheric flow and turbulence
		Interaction of boundary layer and large wind farms
		Prediction of exceptional events
3	Wind Turbine Technology	Aerodynamics, aeroelasticity and aeroacoustics
		Electrical generators, power electronics and control

[8] http://www.vestas.com/files//Filer/EN/Press_releases/VWS/2008/080519-PMUK-05.pdf

[9] EAWE, Unique European Network of Excellence, 2008; www.eawe.eu.

	Priority theme	Sub-theme
		Loads, safety and reliability
		Materials and composite structures, fracture mechanisms
		Material characterization and life cycle analysis
		New wind turbine concepts
4	System Integration	Grid connection and power quality issues
		Short-term power prediction
		Wind farm and cluster management and control
		Condition monitoring, maintenance on demand
		New storage, transmission and power compensation systems
5	Integration into Energy Economy	Integration of wind power into power plant scheduling and electricity trading
		Profile-based power output, virtual power plants
		Translational and transcontinental supply structures
		Control of distributed energy systems

Figure 15: EAWE priority themes for innovation

Canada and the US

Within Canada, the concentration of research into wind energy is found on the east and west coasts, including New Brunswick (University of New Brunswick and Université de Moncton); Quebec (The Corus Centre – a partnership between five universities and colleges) and Vancouver. At a federal level, Natural Resources Canada's CanmetENERGY[10] runs four energy research centres of expertise based in Alberta, Ottawa, Ontario and Quebec.

As is evident in Europe, many of the universities and institutions collaborate over larger scale projects in order to pool the best expertise and facilities available. For example, WESNet (Wind Energy Strategic Network)[11] is an NSERC-funded network of 39 leading Canadian researchers from 16 universities from coast to coast, working in close collaboration with 15 partners from industry, wind institutes and government. The principle aim is to 'develop innovative solutions to the most important technical issues confronting the Canadian wind sector'. The research focus has been divided into four themes (see Figure 156 below). The most relevant themes for the prioritized areas of innovation opportunity in NL are highlighted in yellow again.

	Priority theme
1	Wind resource assessment and forecasting in the Canadian climate and geography
2	Wind energy extraction in a Nordic setting, including wind turbine performance assessment and wind turbine design
3	Technologies for integration of wind power into the electrical
4	Simulation and optimization technologies to maximize the economic benefits of wind energy for Canada

Figure 16: WESNet priority themes for innovation

The US has many universities and institutions involved in wind related research, but the National Renewable Energy Laboratory is of particular importance, and is profiled in the Figure 17 below.

Other organizations and programs fostering collaboration and co-operation

[10] http://canmetenergy-canmetenergie.nrcan-rncan.gc.ca/eng/

[11] http://www.wesnet.ca/

There are a number of organisations that foster collaboration and co-operation between innovators within the wind sector. These include EAWE in Europe and WESNet in Canada, profiled above, Others include the IEA, and of particular relevance to NL, is the IEA Wind's[12] Task no 19 'Wind Energy in Cold Climates' (2001 to 2011)[13], which has the following objectives:

- Review current standards and recommendations from the cold climate point of view and identify possible needs for updates;
- Find and recommend a method to estimate the effects of ice on production;
- Clarify the significance of extra loading that ice and cold climate induce on wind turbine components and disseminate the results;
- Perform a market survey for cold climate wind technology, including wind farms, remote grid systems, and stand-alone systems;
- Define recommended limits for the use of standard technology (site classification); and
- Create and update the Task 19 state-of-the-art report and expert group study on guidelines for applying wind energy in cold climates.

The project is led by the VTT (Finland) with partners: Kjeller Vindteknikk (Norway); NREL (USA); Meteotest (Switzerland); CANMET Energy Technology Centre (Canada); ISET (Germany) and WindREN AB (Switzerland).

Other global centres of excellence in wind research can be found in China, India and Japan but have not been considered in detail for this report.

Testing facilities

Testing facilities (often associated with certification against standards) are another major source of innovation within the onshore wind value chain, and are often collaborators in primary research activities. Well known testing and accreditation companies in Europe include DEWI (current focus on offshore wind), Germanischer Lloyd (GL Group, recently acquired major consultancy Garrad Hassan), TUVSUD, CIEMAT, and NaREC (primarily offshore wind). In North America, WEICan, NREL and SWRI are good examples. Other institutions that may have an impact on wind energy innovation are metrology institutes such as NMI (UK) and the Physikalisch-Technische Bundesanstalk (PTB) in Munich.

Typical capabilities, resources and scale of activities for institutions and testing facilities

A number of different types of institutions have been profiled in more detail to give an idea of typical scales of activity and investment, and resources required.

[12] IEA Wind represents the International Energy Agency's Implementing Agreement for 'Co-operation in the Research, Development, and Deployment of Wind Energy Systems'; http://www.ieawind.org/

[13] http://arcticwind.vtt.fi/

Institution	Research/ services	Example facilities	Staff	Funding
DTU (RISO) National Laboratory for Sustainable Energy[14], Denmark	Wind energy is one of seven major divisions	HTS, a test facility for large wind turbines Syslab, a laboratory for intelligent, active and distributed power systems	Total number employees: 750, of which approx. 185 are within Wind energy	Total expenditure in 2008 for all six programmes: DKK596 m (CAN$127 m) of which DKK290 m (CAN$62 m) account for salaries and DKK276 m (CAN$59 m) for operating expenses
SINTEF Petroleum and Energy (Part of SINTEF Group)[15], Norway	SINTEF Energy Research contains three divisions: Electric Power Technology; Energy processes and Energy systems	In partnership with NTNU and IFE: VIVA test center for wind turbines and marine energy production Aerodynamic laboratory with four low speed wind tunnels	SINTEF Energy Research: 150 researchers; 27 admin; 10 technical personnel; 8 engineers	Annual turnover for SINTEF Energy Research 262MNOK (CAN$49 m) (2007) of which 51% comes from commerce and industry, approximately 30% from the RCN and 10% from International contracts
CREST (Centre for Renewable Energy Systems Technology)[16], Loughborough University, UK	CREST research operations are structured in five groups: Networks and systems; Wind and water power systems; Applied PV systems; PV materials and devices; Renewable energy in the built environment	Rig for developing optimum control system for wind-powered desalination Wind tunnel CFD software for wind resource estimation, software for modelling turbine performance	Wind power research: 1 academic, 2 post-doctoral researchers and 4 PhD students	2007 CREST portfolio of funded projects amounted to £3.75 m (CAN$6.5 m)
The Corus Centre[17], Quebec	Institute formed from a partnership between 5 Universities and colleges, focused solely on R&D and knowledge transfer in wind energy	Two nearby wind farms Multi-measurement tower Modelling and simulation software Access to wind tunnels and climatic chambers	6 researchers	Principal funding partners are the Economic Development Agency of Canada for the Regions of Quebec, and the Quebec Provincial Government. Funding for 2007-2008: was CAN$557,415 including: Ministry of Education: CAN$66,749; Ministry of Economic Development: CAN$101,782; Ville de Murcochville: CAN$182,883. R&D and rental income CAN$130,837.[18]

[14] www.risoe.dk /?sc_lang=en

[15] www.sintef.no /Home/

[16] www.lboro.ac.uk /departments/el /research/crest /profile.html

[17] www.eolien.qc.ca/ ?id=88&titre= Centre_Corus

[18] Technocentre Eolian, Annual Report 2007-2008

Institution	Research/ services	Example facilities	Staff	Funding
WEICan, Prince Edward Island (previously known as the Atlantic Wind Test Site (AWTS))[19] Incorporates University of New Brunswick's Renewable Energy Technology Research Facility	Four Areas of strategic Focus: Testing leading to certification Research, development and demonstration Training, outreach and public education Technical consultation and assistance	The North Cape Wind Farm, a 10.56 MW facility, is located adjacent to WEICan Owned by the Province of Prince Edward Island, it is available for a range of utility testing purposes	Staff consists of a board of directors (12) and 5 members of staff	Funded by NRC, ACOA and PEI Energy Corporation. Federal funding for 27 months to Sept 2008: CAN$2 million; for 36 months from Sept 2008: CAN$2 million (a cut of approx CAN$20,000 per month). Provincial contribution is CAN$285,000 per year.[20] WEICan recently (Jan 2010) received an additional CAN$10-20 million federal funds (the Clean Energy Fund of the Government of Canada's Economic Action Plan) to erect a nine-megawatt wind farm and build an energy storage facility (pending environmental approval). Revenues from the operation of the wind farm are expected to help offset WEICan's costs.[21]
Germanischer Lloyd, Hamburg[22]	Renewables is one of 10 divisions. Primary activities are certification, consulting and engineering, turbine measurements	200 stations and site offices in 80 countries	Total employees: 6,400 engineers, surveyors, experts and administrative staff in 80 countries	Total revenue EUR554 m (2008) (CAN$879 m)
NREL (National Renewable Energy Laboratory), US[23]	Focused on science & technology (all renewable energy) Technology transfer Applying technology Wind research takes place at NREL's National Wind Technology Centre (NWTC)	Advanced research turbines Dynamometer test facilities Wind turbine test pads	>70 members of staff involved in wind research	Total funding US$328 m (2008) CAN$347 m)

Figure 17: Profiles of example institutions

The 29 institutions that make up the EAWE range in size and scope from full scale universities, through technical institutes to centres focused solely on renewable energy. The scale of activity (staff numbers and programme expenditure) varies accordingly, from an upper level of 750 employees (Technical University of Denmark, DTU/RISO) down to just seven (Centre for Renewable Energy Systems Technology (CREST), Loughborough University, UK). Likewise, research themes vary

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[19] http://www.weican.ca/

[20] http://journalpioneer.com/index.cfm?sid=137701&sc=118&comments=view

[21] http://www.journalpioneer.com/index.cfm?sid=318736&sc=118

[22] http://www.gl-group.com/en/index.php

[23] http://www.nrel.gov/

between institutions, from those focused primarily on early stage research (Delft University Wind Energy Research Institute (DUWIND), The Netherlands), to those concerned with the grid integration of existing technologies (Institut für Solare Energieversorgungstechni (ISET), Germany). Several institutions have their own turbine test sites (Centre for Renewable Energy (SFFE), Norway) and some (Centro Nacional de Energias Renovables (CENER), Spain) specialize in a range of services including testing and certification.

The WESNet project provides an example of the scale of funding required for collaborative research involving multiple stakeholders. The project is expected to run from 2007-2013 with a total of CAN$6.5 m over five years, comprised of CAN$5 m from NSERC and CAN$1.5 m from the partners.

Conclusions

Figure 18 below provides an overview of the key players involved in wind energy innovation globally, together with the level of resources deployed.

Turbine Manufacturers	• The 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; employs ~1500 people and spends >US$300 million p.a. on R&D. • Most **collaborate with universities, research institutes and test facilities** for innovation. • **Innovation focus on technology** cost reduction, improved reliability, and related services.
Universities and Institutes	• **Numerous dedicated research institutes and universities** with specialist RE depts. • **Traditionally focused on Europe**. Denmark and Germany of particular significance, with other important institutes in Norway, UK, Spain, Greece and the Netherlands. Non-European specialist centres include the US (NREL), China (Uni.Tsing Hua), India and Japan. • **Broad spectrum in terms of size and focus** ranging from a few people (7 at CREST, UK) to many hundreds (750 at DTU, Denmark). • **Broad innovation focus** that includes: wind turbine technology; wind resource assessment; wind energy extraction; system integration; integration into energy economy, environmental and societal impacts..
Testing Centres	• **Small number of specialised turbine test centres**, often associated with certification against standards, that 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 include **metrology institutes** such as NMI (UK) and the Physikalisch-Technische Bundesanstalk (PTB) in Munich

Figure 18: Key players involved in onshore wind energy innovation globally

2.3.2 Onshore wind innovation capabilities within NL

All three types of innovation players are present in Canada, with a concentration on the east coast. However, as is summarised in Figure 19 below, there is nothing of significance in Newfoundland and Labrador today.

Turbine Manufacturers	• **None of the on-shore wind technology 'majors' is Canada-based**. • There are however **a number of small wind turbine manufacturers in Canada.** These include: AAER Systems (Quebec); Americas Wind Energy Inc (Ontario); CWind (Ontario).
Universities and Institutes	• **There is a concentration of research into wind energy on the east coast of Canada**, including University of New Brunswick and Universite de Moncton in New Brunswick, WEICan in PEI (See below) and the Corus Centre in Quebec (partnership of five colleges). • At a federal level, **NRC's CanmetENERGY runs clean energy research centres** in Devon, Alberta; Ottawa, Ontario; and Varennes, Quebec. • **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 governments 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; 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$6.5m comprised of CAN$5 m from NSERC and CAN$1.5 m from the partners.
Testing Centres	• **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; 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.

** Manufacture and innovation related to small scale wind turbines is addressed in 'Stream 2'*

Figure 19: Key players involved in onshore wind energy innovation in Canada

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 is shown in Figure 20.

This suggests that it will in general be easier and less costly for NL to acquire internationally competitive innovation capabilities through partnership with third parties. These third parties may well include a number of the organisations identified in Sections 2.3.1 above and 2.4.1 below. In these circumstances, NL is likely to focus on areas in which it has specific strengths or local need, and rely on exploiting third party innovations to overcome more generic barriers to deployment.

	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

Figure 20: 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)

2.4 Innovation priorities

2.4.1 Current international innovation in areas identified as opportunities for NL

As is outlined in Figure 21 below, there are ongoing international projects in all of the innovation areas identified as offering potential opportunity for NL. Some of these opportunity areas reflect barriers that are generic to all onshore wind applications and will be fully addressed by ongoing international innovation. Others include aspects that are specific to deployment in NL. While ongoing international innovation will be relevant to these barriers, it is likely that further innovation will be needed specific to deployment in NL. An example includes the mapping of wind resources and associated icing within the Province. Prioritized innovation opportunities are categorised as 'generic' or 'specific' in Figure 22 below, along with the scale of identified ongoing innovation activities in Europe and North America. This leads to the recommended prioritization for NL in Figure 23.

Innovation Opportunity	Company/Institution	Example Projects
1. Capital costs	Universität Stuttgart, Germany	Investigation of new structural concepts and semi-automated assistance in the manufacture of rotor blades
	CENER, Spain	New materials and manufacturing process for large WT; New concepts for Wind turbines and components
	NREL, US	Advanced Component Technology – WindPact. WindPact was started in 1999 to assist industry in lowering the cost of energy by designing and testing innovative components, such as advanced blades and drivetrains
2. Reliability	Aalborg University,	Develop methods to identify failures or potential failure in gearbox and high-

Innovation Opportunity	Company/Institution	Example Projects
	Denmark	voltage transformer
	RISO DTU, Denmark	Reliable Optimal Use of Materials for Wind Turbine Rotor Blades: design recommendations and improved reliability, incl. prediction of the residual strength and life to extend the life of the blade or avoid unexpected failures
	ISET Institute, Germany	Development of new control concepts for reduced load impact and improved reliability
	Leibniz Universität Hannover	Life span of large rolling bearings; improved analysis and design fundamentals for composite rotor blades (material model, failure criteria, fatigue, influence of manufacturing imperfections)
	Universität Stuttgart, Germany	Fatigue Failure Prediction of Multidirectional Laminates under Combined Stress State and Variable Amplitude Loading; Fatigue Characterization of Composite Materials using Conventional and Non-Destructive Testing
	NTUA, Greence	Aeroelastic modelling of full wind turbines configurations with emphasis on stability
	Imperial College, UK	Aerodynamic control techniques to reduce unsteady loading and increase fatigue life
	University of Manchester	Reliability, Availability and Operation of Large Wind Turbines
3. Gusting	DTU/RISO, Denmark	Detailed modeling of gusts, using proprietary WAsP Engineering computer program, developed for the estimation of extreme wind speeds, wind shears, wind profiles, and turbulence in complex terrain
	Oldenburg University, Germany	Contribution to improved standardization procedures for meteorological conditions (for example, extreme winds)
	Universität Stuttgart, Germany	Development of load monitoring and control techniques for large wind turbines through simulation, lab and field testing
	CENER, Spain	Mesoscale and statistical models for characterisation of extreme winds
5. Resource mapping	SINTEF ICT department (Norway)	Numerous examples of ‘resource modelling’, including Modelling and simulation of ice and wind conditions over complex terrain and offshore
9. Icing	VTT (Finland) and consortium	IEA Task 19 ‘Wind Energy in Cold Climates’. Task website[24] contains links to approximately 17 publications focused on turbine operation in cold and icing conditions
	Participants of the Winterwind 2008	Winterwind 2008: Wind energy in low temperature and icing conditions. Research proceedings[25] from 27 participants. Topics included ice detection; icing model verification; mapping of icing; blade characteristics and icing; production losses
	Participants of the IWAIS 2009 conference	International Workshop on Atmospheric Icing of Structure, Sept 2009. Topics included modeling of icing; icing measurements; icing in wind energy; icing on powerlines
	DHI, Denmark	Models for fatigue damage due to wave/current/wind (ice) action
	The Corus Centre, Quebec	Multi-measurement tower and measurement campaigns. Phase two: Establish the characteristic parameters of conditions conducive to the appearance, formation and build-up of ice. Phase 3: Compare some twenty measurement instruments and conduct a more in-depth study of different types of icing and their characteristic parameters. Design of an icing system for high-power wind turbines (1 MW and over); Re-

[24] http://virtual.vtt.fi/virtual/arcticwind/publications.htm#recommendations

[25] http://www.winterwind.se/index.php?choice=proceedings

Innovation Opportunity	Company/Institution	Example Projects
		create icing events under real operating conditions and control their duration. Develop de-icing systems and test concepts under development around the world. Surface treatment to prevent the formation of ice on wind turbine blades (in progress): Develop surface treatment techniques based on ion implantation and UV irradiation
	CanmetEnergy, Canada	Collaboration with the University of Manitoba simulating icing conditions using a state-of–the-art wind tunnel with icing capabilities
10. Cold conditions	VTT (Finland) and partners	IEA Task 19 'Wind Energy in Cold Climates'. Task website[26] contains links to approximately 17 publications focused on turbine operation in cold and icing conditions
	The Corus Centre, Quebec	Planned - Acquisition and instrumentation of large wind turbines (>1 MW) to identify and quantify the impact of Nordic conditions on wind turbine operation. Test pre-commercial-phase products and services (wind turbine components, lubricants, software, etc.) using the wind turbine. Partners to include turbine and component manufacturers (tbd)
	WESNet, Canada	Examination of wind energy extraction in a Nordic setting, including wind turbine performance assessment and wind turbine design
11. Remote location	Aalborg University, Denmark	Analysis and design of lightweight composite and sandwich structures
	ISET Institute, Germany	Condition monitoring and fault prediction in wind turbines as a basic for wind farm supervision and maintenance / repair scheduling
	ISET Institute, Germany	Design and execution of measurement programmes, operation and further development of remote measurement networks.
	Universität Stuttgart, Germany	Development of LIDAR technologies for support of wind turbine performance measurement and control strategies
	Energy research Centre of the Netherlands (ECN)	Developing integral design tools (and sub-models) for designing heavy-duty low-maintenance large turbines in extreme conditions - rotor aerodynamics and structural dynamics
	CIEMAT, Spain	Remote wind power systems; flywheel energy storage systems
17. Grid inflexibility	Aalborg University, Denmark	Interconnection of the wind turbines/farms into power networks
	IEE, Germany	Dimensioning a hybrid system with energy storage to balance the power from the large-scale wind farms
	CREST, UK	Energy storage technologies
	ICC at University of Strathclyde, UK	Stability and dynamic issues related to integration of very large amounts of wind generation; Improved matching of supply and demand through active load management
	NTUA, Greece	Management and control of island power systems with increased wind power penetration and power quality issues
	The Corus centre, Quebec	Several projects looking at hybrid wind-diesel systems, for example: Design two hybrid wind energy-diesel-compressed air storage systems to supply electricity to isolated sites, northern villages, telecommunication stations and scientific bases
	WEICan, Canada	Wind-hydrogen village. WEICan is collaborating with the PEI Energy Corporation to develop the potential for hydrogen storage and subsequent use, and the applications of such technology for remote and island

[26] http://virtual.vtt.fi/virtual/arcticwind/publications.htm#recommendations

Innovation Opportunity	Company/Institution	Example Projects
		communities

Figure 21: Examples of ongoing research in identified onshore wind innovation opportunity areas

1. Capital costs	• Generic barrier for all onshore wind applications; **under investigation by numerous manufacturers and institutions.**
2. Reliability	• Generic barrier for all onshore wind applications; **under investigation by numerous manufacturers and institutions.**
3. Gusting	• Generic barrier for all onshore wind applications, and primary cause of turbine failure; **under investigation by numerous manufacturers and institutions.**
4. Resource mapping	• Generic barrier **under investigation by numerous manufacturers and institutions.** • **Specific conditions in NL not well understood.** • **Manufacturers increasingly interested in ability to exploit cold northern areas.**
9. Icing	• **Barrier limited to specific areas of deployment,** but **considerable interest and expertise in Europe** (in particular in Norway, Sweden and Switzerland). • Subject of research by the **Corus Centre, Quebec**, and **CanmetENERGY** in collaboration with the **University of Manitoba.** • Ice monitoring is the subject of research for transmission lines by **Nalcor** and ice engineering is the subject of research by **MUN, C-Core and others.**
10. Cold conditions	• **Barrier limited to specific areas of deployment,** but **considerable international interest;** • **Area of IEA focus** and subject of planned research by the **Corus Centre, Quebec** and one of the four program themes of **WESnet Canada.**
11. Remote location	• Generic barrier for significant number of applications, **under investigation by numerous manufacturers and institutions.**
17. Grid inflexibility	• Generic barrier for significant number of applications, **under investigation by numerous manufacturers and institutions.** • **Limited knowledge of systems resembling NL.**

Figure 22: Summary overview of ongoing international innovation in priority areas

2.4.2 Prioritization for NL

As outlined in Section 2.4 and in Figure 3, innovation opportunities have been separated into the following three categories:

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;

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; and

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

The categorisation of prioritized onshore wind energy innovation areas is given in Figure 23 below.

It is important to note that NL will need to have a plan to overcome all barriers to the deployment of onshore wind energy in the Province. However, we anticipate that most barriers, including those in

Category C below, will be overcome by the purchase of innovative solutions from international third parties.

NL will need to address Category B barriers as we anticipate that these will not be adequately addressed by international innovators. However, as outlined in Section 2.3.2 above, we anticipate that this innovation will be done in partnership with established third parties. This will need to be determined in the next phase of this Energy Innovation Roadmapping exercise.

Category A innovation areas appear to offer the opportunity for NL to acquire an internationally competitive position, either because there is modest ongoing international activity or it is possible to exploit existing knowhow and innovation capabilities.

A	**9. Icing** **10. Cold 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, might suggest **collaboration.**
A	**17. Grid inflexibility**	• **Might merit prioritization by NL given limited knowledge of systems resembling NL and related innovation knowledge of Nalcor/others.** • High level of ongoing global activity would suggest **collaboration.**
B	**4. Resource mapping**	• **Might merit prioritisation because conditions in NL are not well understood** and this is needed for local exploitation. • High level of ongoing global activity would suggest **collaboration.**
C	**1. Capital costs** **2. Reliability** **3. Gusting** **11. Remote location**	• **Unlikely to merit prioritization by NL**, given the significant ongoing activity in these areas by turbine manufacturers and institutions … • …. however, if an institution were built in NL to focus on the niche areas above, it could also address these generic barriers.

Figure 23: Categorisation of prioritized onshore wind energy innovation areas

3 Hydroelectricity

3.1 Barriers

Hydroelectricity is defined here as larger scale applications of turbine generators in river and dam settings. The hydroelectricity industry is very established, thanks to over 100 years of activity, including major installations in Canada (including many in Newfoundland & Labrador). The value chain has become well-defined, with typical actors shown in Figure 24 and Figure 25 below.

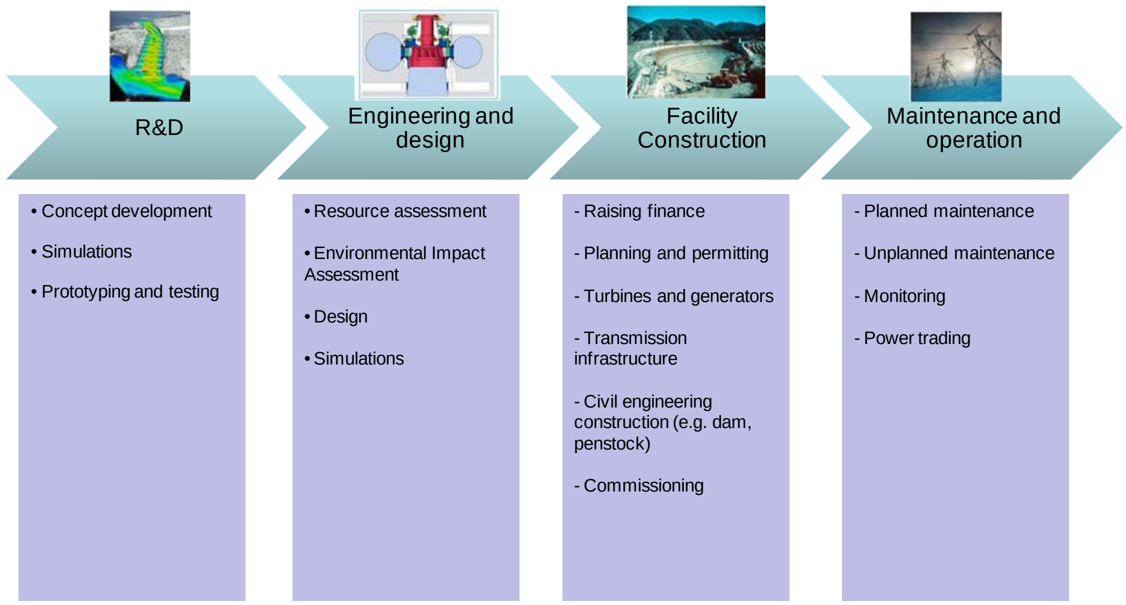

Figure 24: Hydroelectricity - industry value chain

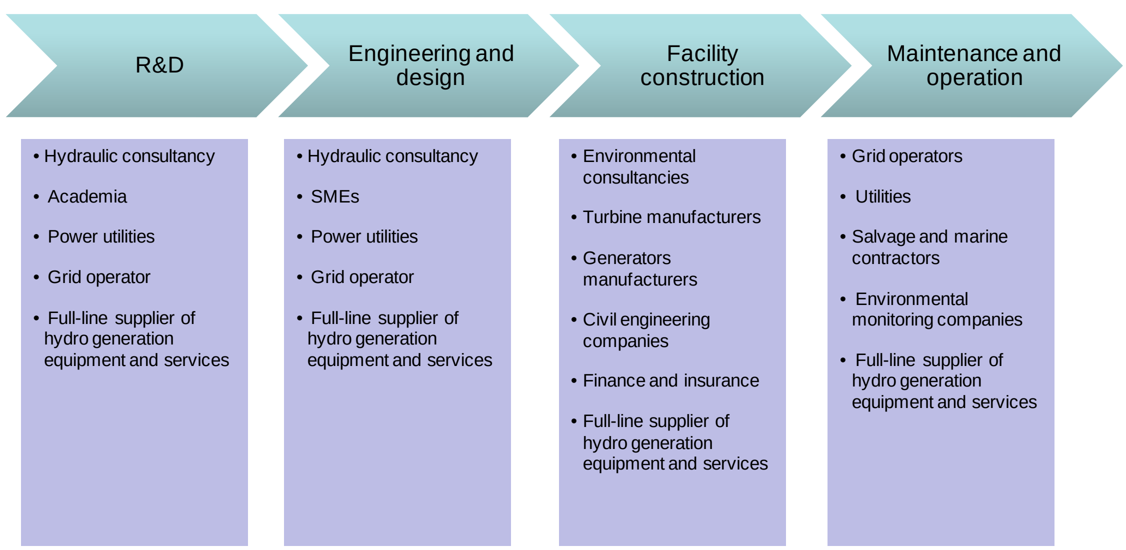

Figure 25: Hydroelectricity - typical actors along the value chain

We have drawn upon our knowledge of the hydroelectricity industry and have held discussions with stakeholders within the province to identify the following international barriers to exploitation of hydroelectricity resources. Key barriers for the further development of hydroelectricity, particularly in Labrador, are highlighted in Figure 26 below.

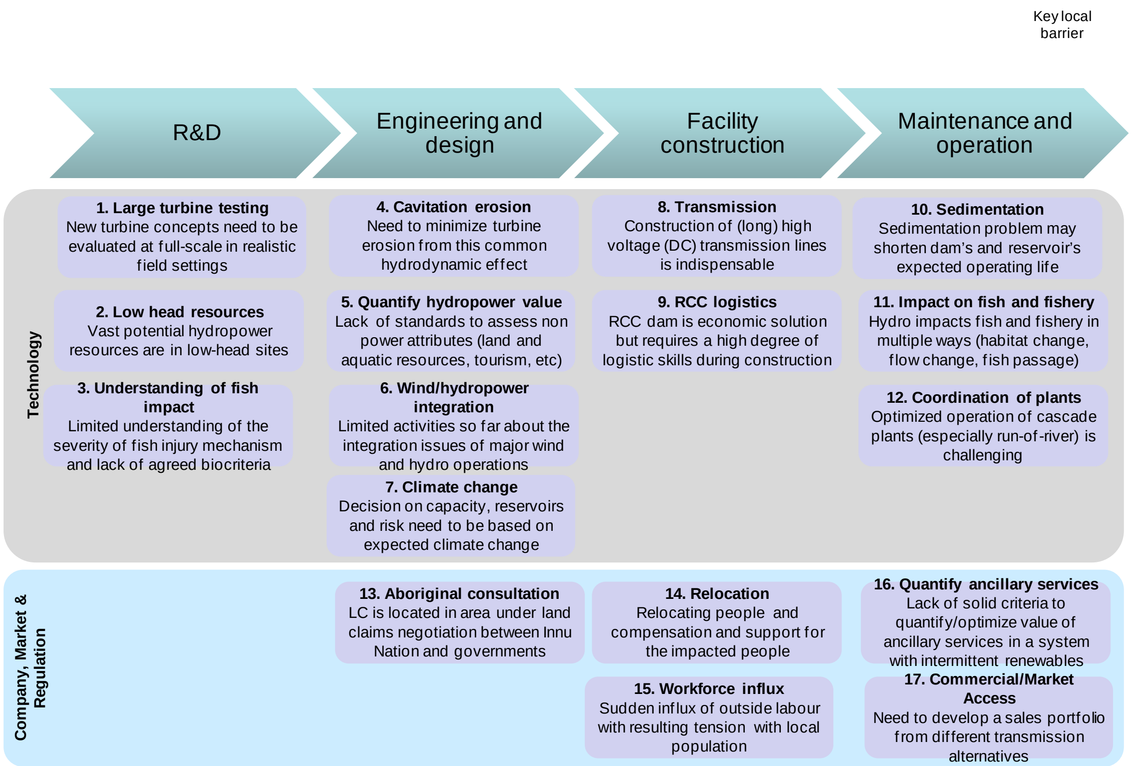

Figure 26: Hydroelectricity - main barriers worldwide

Additional information about each of these barriers is provided in the table below.

Barrier #	Additional information
1	Although a long-established sector, new turbine concepts are being developed but these need to be evaluated at full-scale in realistic field settings
2	Vast potential hydropower resources are in low-head sites, but these need new designs to exploit them efficiently
3	There is limited understanding of the severity of fish injury mechanism and lack of agreed biocriteria for measuring impacts
4	There is a need to minimize turbine erosion from this common hydrodynamic effect, through design and materials choices
5	Hydropower sites can provide other amenities (land and aquatic resources, tourism, etc), but there is a lack of standards to assess non power attributes
6	Integrating intermittent wind energy and (somewhat) more controllable hydropower provides a potentially continuous form of electricity which has greater value in power markets. However, integration on the scale and nature of the Labrador resources has little or no precedent and needs to be carefully understood
7	Hydro dams are long life assets and decisions on capacity, reservoirs and risks need to be based on expected climate change effects
8	Construction of (long) high voltage (probably DC) transmission lines is a key feature and is challenging for technical and commercial reasons

Barrier #	Additional information
9	Roller Compacted Concrete is the most economic solution but requires a high degree of logistic skills and access during construction
10	Sedimentation problems may shorten a dam and reservoir's expected operating life
11	Hydropower impacts fish and fisheries in multiple ways (habitat change, flow change, fish passage) and this can constrain operations
12	Optimized operation of cascade plants (especially run-of-river) is challenging
13	Lower Churchill is located in an area under land claims negotiation between Innu Nation and governments
14	In some large dam projects relocating people and compensation and support for the impacted people is a constraint
15	Large construction projects such as dams create a sudden influx of outside labour with potential for resulting tension with the local population
16	Services provided to grid operators include the ability to stabilise frequencies and to restart operations when all other systems are down ('black start'). These can be hard to evaluate and include in the economic case for new projects
17	A key factor for the development of Newfoundland and Labrador energy resources, including hydro, is the absence of an export route with a defined customer. This requires the development and modelling of options featuring different generation portfolios, transmission routes and customer types to maximise the commercial negotiating position.

Figure 27: Hydroelectricity - additional information about barriers

3.2 Valuable innovation opportunities

Each of the barriers identified in the previous section was examined in terms of the value that would be available to NL from overcoming it. This is expressed in qualitative terms for the export market ('external market value') and for the local resource development opportunity ('local market value').

Note: in interpreting the significance of these barriers, it is important to appreciate that the assigned values are relative to one another within the context of hydroelectricity, but are not relative to opportunities in other areas of energy such as wind, oil and gas.

The valuation of overcoming barriers through innovation was based upon judgement of the consulting team, informed by numerous consultations, and was also validated by steering group members. It was agreed that qualitative valuation would be suited to the purposes of the project, which requires sufficient evidence to justify prioritization, but not, for example, an econometric forecast of benefits. A one to four scale was chosen with a break point between scores of two and three. A more detailed description of the overall approach is provided in report 4 'Recommended Innovation Priorities'.

Type	Value chain	Barrier	Value of overcoming barrier (O =lowest, OOOO = highest) External Market Value	Local Market Value
Technology	RD&D	1. Large turbine testing	New evolutionary concepts suitable to potentially large markets worldwide need testing	Modest. Innovative concepts likely not to make it in the short term and for already on-going projects. Also, remaining resources are small/medium scale.
			OOO	OO
		2. Low head resources	Good amount of local and global hydro resources are low head resource. Innovative system design for low head resources can potentially open up a large market – if export route available	
			OOO	OOO
		3. Understanding of fish impact	Scientific knowledge of fish impact is a difficult to export skill	Better understanding can ease the design and the planning permission of new projects Typically 10% of potential rated power is lost to mitigate fish impact.
			O	OOOO
	Engineering and design	4. Cavitation erosion	Cavitation issues are very specific to turbine type and flow conditions, so difficult to export to large market	Reduced erosion can significantly expand lifetime, but are not seen as an NL problem
			O	O
		5. Quantify hydropower value	Modest. Objective quantification of additional non-power value can only (slightly) accelerated plant design and construction, but is likely not to determine the deployment rate	
			O	O
		6. Wind/hydropower integration	Integration of wind onto national grids is an issue in several countries. However, solutions will be country specific and therefore difficult to export.	Wind (or other intermittent renewable) integration in NL is strongly limited due to lack of flexibility in the grid (under current circumstances)
			OO	OOOO
		7. Climate change	Modest, since impact, assessment and mitigation methods will be site specific	Understanding impact on ice and river flow in high latitude projects is beneficial to optimize long term economic benefit, but not seen as a major issue
			O	OO
	Facility construction	8. Transmission	Some opportunity to export capabilities relating to transmission build in NL conditions	High value, since it can fully displace thermal generation on the Island
			OO	OOOO

Type	Value chain	Barrier	Value of overcoming barrier (O =lowest, OOOO = highest) External Market Value	Local Market Value
Technology	Project development	9. Roller-compacted concrete logistic	Logistic is typically a local issue and depends on the construction project management. Low export potential	Medium. Gull Island dam will be rock filled and Muskrat Falls dam will be concrete (not clear if RCC though)
			O	OO
	Maintenance and Operation	10. Sedimentation	Sedimentation studies are site specific and involve sampling. Low export value	High sedimentation rate with can reduce plant availability but not a major NL issue
			O	OO
		11. Impact on fish and fishery	Site specific, with know-how difficult to export.	Relatively high value, since it can severe impact on fishery and ecosystems
			O	OOO
		12. Coordination of plants	Site specific, with know-how difficult to export.	Some value. Multiple plants system on the same river (Churchill) but limited by the fact that non of them is run-of-river.
			O	OO
Company, Market & Regulation	Engineering and design	13. Aboriginal consultation	Local issue only	Major issue to be solved for project viability
			O	OOOO
	Facility construction	14. Relocation	Severe issue in general, but solutions are local therefore external market value is nil	Typically not applicable to NL, due to the extremely low population density.
			O	O
		15. Workforce influx	Severe issue in general, but solutions are local therefore external market value is nil	Addressing the issue can avoid delays and tension with local population
			O	OO
	Operation and maintenance	16. Quantify ancillary services	Possible export value to other markets, but remote location acts against this	Some value in understanding and quantifying ancillary services for planning transition to low carbon electricity sector
			OO	OO
		17. Commercial/ Market Access	Crucial issue determining the economic output of large scale hydropower projects	
			OOOO	OOOO

Figure 28: Hydroelectricity - value of overcoming barriers

The outputs of the tables above are represented graphically in Figure 9, below.

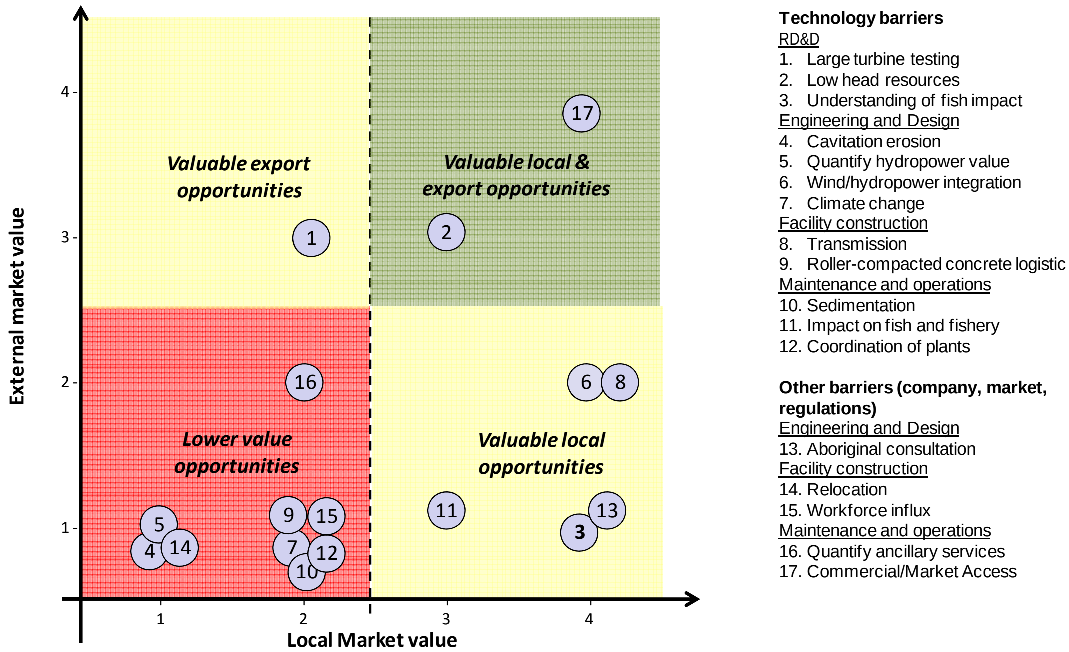

Figure 29: Hydroelectricity – theoretical value of overcoming barriers (summary)

The following observations can be made about the assessment of value:

- The largest number of potential opportunities fell into the 'lower value' category. The external market value of many innovation opportunities is deemed to be low in view of the inherently site-specific nature of the barriers (e.g. #7, 9, 12, 14, 15, and 16). In the case of these nine barriers, the local value was not high either since they do not represent major challenges for the industry.
- The local market value scored more highly in seven cases, since there are significant resources that could be developed if these key barriers are overcome, mostly relating to the Lower Churchill project.
  - Of these seven, only two are deemed to have significant external market value ('valuable local and export opportunities') – #2, low head resources are worldwide opportunities requiring technology solutions, and #17, the need to model commercial/market access for different transmission routes could be applied in other parts of the world.
  - The other five fell into the 'valuable local opportunities' category because the external market value is lower due to the inherently site-specific nature of the barriers.
- Large turbine testing (#1) is no longer required for the remaining NL projects, but would, in theory, be valuable as a service if provided to others.

Each of the barriers was considered further where the value in the external and/or local market value is high. Current innovation activities of leading innovators were assessed to determine whether there is a valuable innovation gap that NL might be able to address. These are presented in Figure 1029 and Figure 1130 respectively.

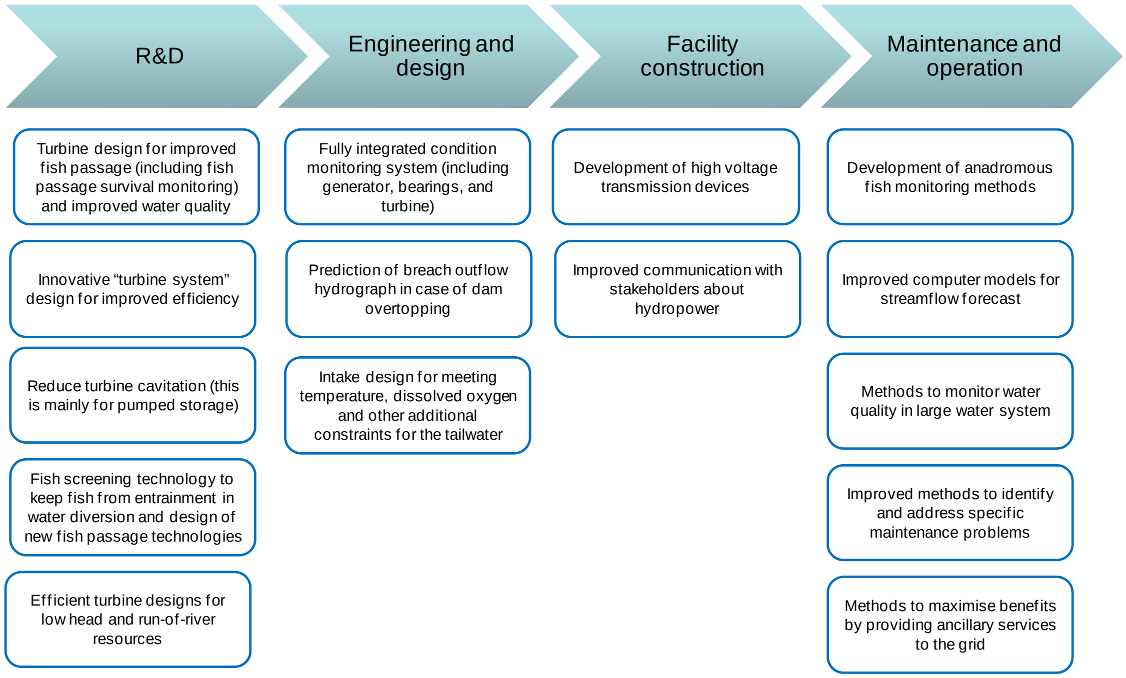

Figure 30: Hydroelectricity - main innovation currently occurring worldwide

As can be seen, there are examples of ongoing activity in all value chain stages. The maturity of hydroelectricity as an industry means that many of these innovations are via well-established companies and organizations. These findings are matched to the specific barriers below to identify any significant gaps which NL may be able to address.

Type	Value chain	Barrier	Innovation to address the barrier	
			Innovation currently occurring	Remaining gaps
Technology	RD&D	1. Large turbine testing	US DOE current activity covers large turbine testing for turbines that have an improved overall performance	Limited. Current program passing the a prototype testing phase and reaching rollout
		2. Low head resources	Turbine design, simulation and resource assessment. Increased interest due to lower environmental impact than dams	Minor gaps in resource assessment
		3. Understanding of fish impact	Intense research activity on this topic. By now, fish impact assessment is becoming a consolidated and standard practice in hydro project development	Some innovative concepts still to be deployed and proved at scale.
	Engineering and design	4. Cavitation erosion	Blade design advances (also from other sectors)	Not as big a challenge as in recent past
		5. Quantify hydropower value	System wide simulations and studies occurring	Not as big a challenge as in recent past
		6. Wind/ hydropower integration	Power system simulation tools development. Network operator worldwide gaining experience and techno-commercial acumen	Still a challenge in competitive market. Limited knowledge of systems resembling NL
		7. Climate change	Understanding of climate change science is constantly increasing	Long term impact on economics and environment still to be fully understood.
	Facility construction	8. Transmission	Work ongoing in HVDC systems,	HVDC systems suited to NL context, including icing [see separate Transmission section]

Type	Value chain	Barrier	Innovation to address the barrier	
			Innovation currently occurring	Remaining gaps
Technology	Project development	9. Roller-compacted concrete logistic	Growing experience in the industry	Not seen as big a challenge
	Maintenance and Operation	10. Sedimentation	Screening and control	Not seen as big a challenge
		11. Impact on fish and fishery	Intense research activity on this sensible topic. By now, fish impact assessment is becoming a consolidated and standard practice in hydro project development	Some innovative concepts still to be deployed and proved at scale, however not seen as a big challenge.
		12. Coordination of plants	Modelling and growing experience with multiple plants on same basin.	Limited knowledge of systems resembling NL
Company, Market & Regulation	Engineering and design	13. Aboriginal consultation	Stakeholder involvement improved drastically	Not as big a challenge as in recent past
	Facility construction	14. Relocation	Stakeholder involvement improved drastically	Not as big a challenge as in recent past
		15. Workforce influx	Stakeholder involvement improved drastically	Not as big a challenge as in recent past
	Operation and maintenance	16. Quantify ancillary services	Power system simulation tools development. Network operator worldwide gaining experience and techno-commercial acumen	Still a challenge in competitive market. Limited knowledge of systems resembling NL
		17. Commercial/Market Access	Some techno-economic assessment	Still a key challenge [see separate Transmission section]

Figure 31: Hydroelectricity - worldwide innovation gaps

Overall, there are few gaps which are not being addressed in some way. Combining these findings with the earlier analysis of innovation value leads to the following summary of valuable innovation opportunities for NL (Figure 31).

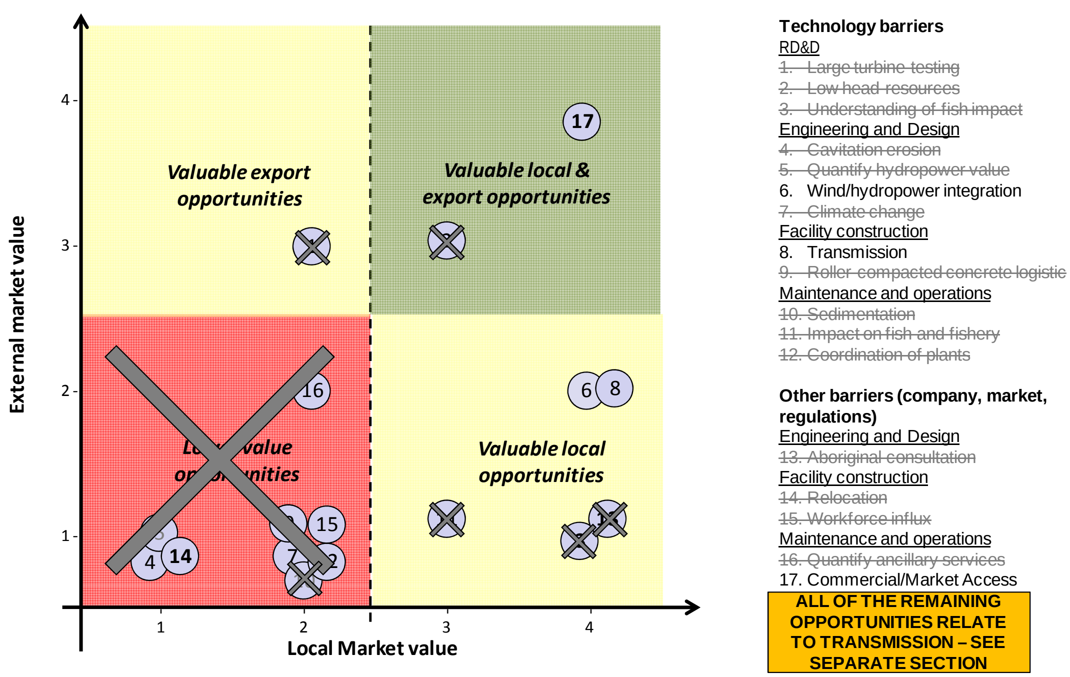

Figure 32: Onshore wind - potentially valuable innovation opportunities for NL

In Figure 31, both lower value opportunities and those where there is no main innovation opportunity gap have been eliminated. In practice, there is so much ongoing activity in the hydroelectricity sector that there are very few innovation gaps where NL needs to innovate. Those that remain relate to the unique challenges associated with the transmission of electricity from a large remote project, such as the Lower Churchill, to distant markets in Canada in the US. Due to the importance of transmission for several areas within the Energy Plan, in addition to hydroelectricity, it was decided to investigate transmission as an innovation opportunity area in its own right (see section 4). With the segregation of transmission innovation opportunities, consequently, no other innovation opportunities remain for further investigation in this section.

4 Transmission

4.1 Innovation barriers

Transmission is defined here as the establishment and operation of infrastructure for transmitting electricity at high and medium voltages. It is very well-established in many areas, but new technologies are also entering to improve efficiency. The value chain has become well-defined, with typical actors as shown in Figure 32 and Figure 33 below.

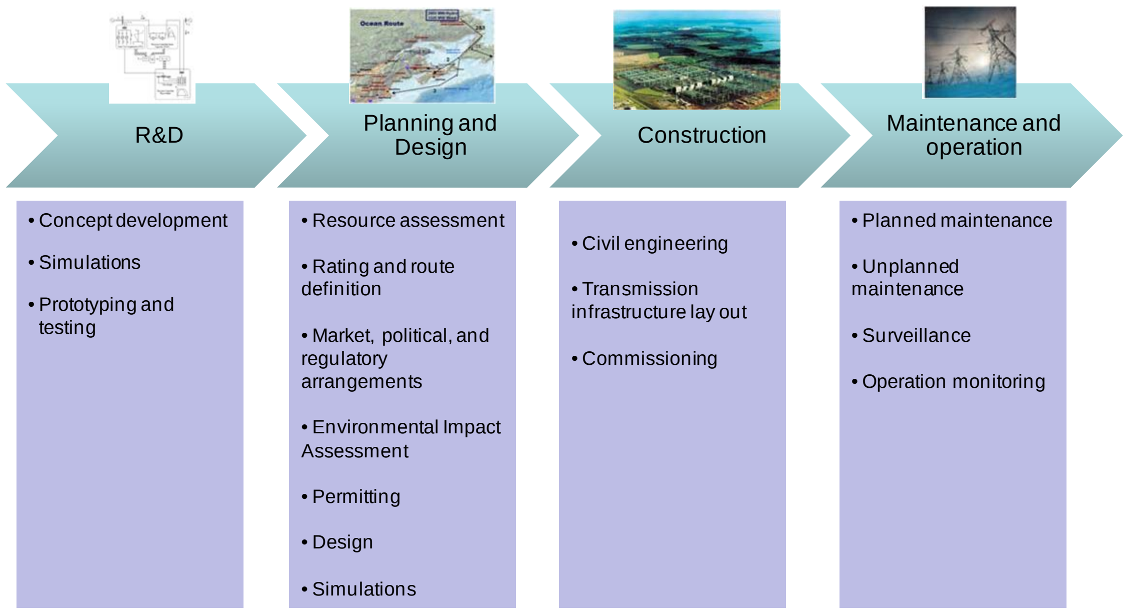

Figure 33: Transmission - industry value chain

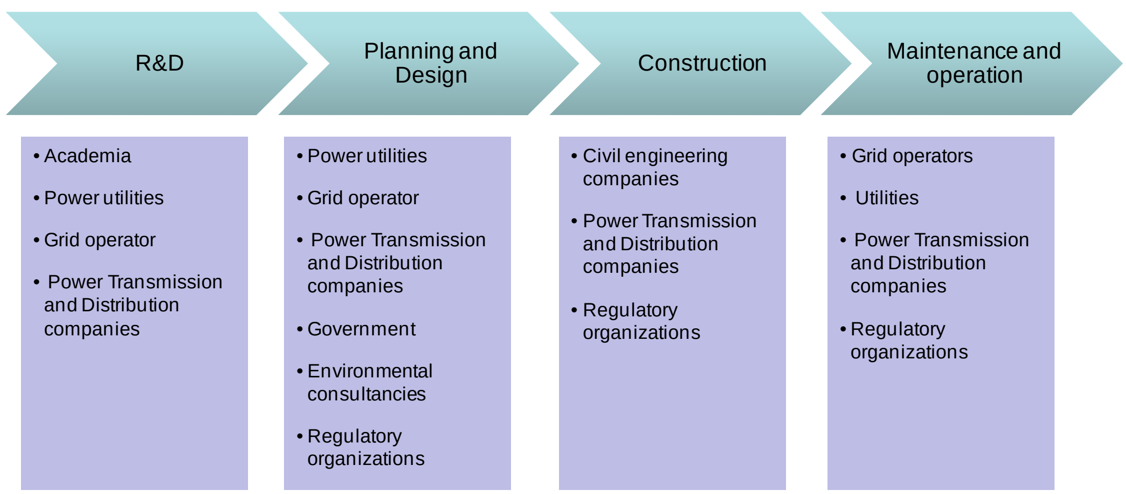

Figure 34: Transmission - typical actors along the value chain

We have drawn upon our knowledge of the transmission sector and have also had discussions with stakeholders within the province to identify the following barriers to the development and operation of transmission internationally. Key barriers for the exploitation of transmission in NL, particularly in relation to the Lower Churchill Hydroelectric project, are highlighted.

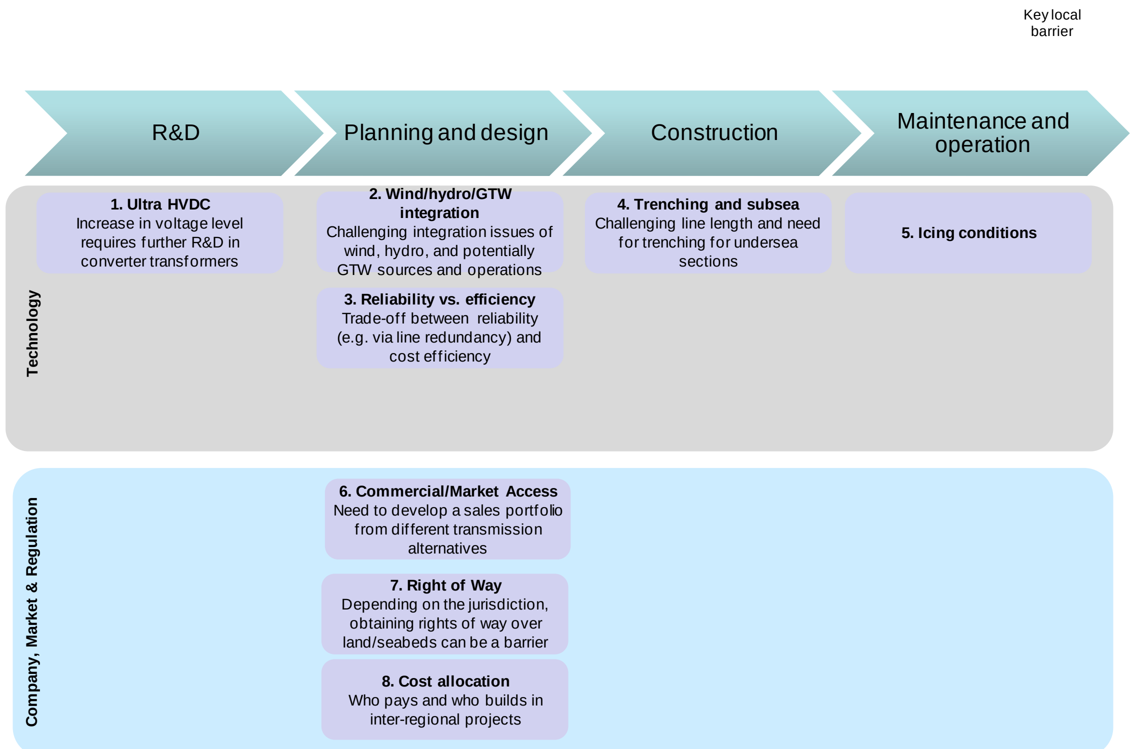

Figure 35: Transmission - main barriers worldwide

Additional information on each of the barriers is provided in the table below.

Barrier #	Additional information
1	High voltage DC transmission is increasingly regarded as the default solution for long distance transmission, with increasing voltages. However, a potentially limiting factor is transformer performance and efficiency
2	The province's large and diverse resources are a significant opportunity, but their integration and control as part of a large scale export-oriented system poses transmission planning and design challenges that do not have obvious precedents. These challenges range from technical (how to connect, how to balance frequency, how to maintain in remote settings etc) to commercial (who owns risks, cost-effectiveness of storage and upgrade capacity etc)
3	Line redundancy (e.g. parallel lines) is expensive but offers potential commercial benefits. The considerations are different for AC and DC systems.
4	Several of the power export options from Newfoundland and Labrador would require subsea cables to be trenched over distances that are challenging
5	Icing of above ground power lines is a hazard faced in many parts of the world and can bring down lines over long distances. It is a key factor for some parts of Labrador energy development since there are unlikely to be alternative routes to provide redundancy. Mitigation, prediction, monitoring and control strategies need to be developed for Newfoundland and Labrador transmission options.
6	A key factor for the development of Newfoundland and Labrador energy resources is the absence of an export route to a defined market. This requires the development and modelling of options featuring different generation portfolios, transmission routes and customer types to maximise the commercial negotiating position.

7	Rights of way (or wayleaves) are required for transmission corridors, whether on land or sea. In some jurisdictions these can be difficult to secure.
8	Cost allocation is an important inter-regional consideration, particularly where construction benefits (e.g. jobs) are shared with the region(s) through which the transmission route passes.

Figure 36: Transmission - additional information about barriers

4.2 Valuable innovation opportunities

Each of the barriers identified in the previous section was examined in terms of the value that would be available to NL from overcoming it. This is expressed in qualitative terms for the export market ('external market value') and for the local resource development opportunity ('local market value').

Note: in interpreting the significance of these barriers, it is important to appreciate that the assigned values are relative to one another within the context of transmission, but are not relative to opportunities in other areas of energy such as wind, oil and gas.

The valuation of overcoming barriers through innovation was based upon judgement of the consulting team, informed by numerous consultations, and was also validated by steering group members. It was agreed that qualitative valuation would be suited to the purposes of the project, which requires sufficient evidence to justify prioritization, but not, for example, an econometric forecast of benefits. A one to four scale was chosen with a break point between scores of two and three. A more detailed description of the overall approach is provided in report 4 'Recommended Innovation Priorities'.

Type	Value chain	Barrier	Value of overcoming barrier Value of overcoming barrier (O =lowest, OOOO = highest) External Market Value	Local Market Value
Technology	RD&D	1. Ultra HVDC	First applications to be deployed in China in 2010 though may not be needed for NL	
			O	O
	Planning and Design	2. Wind/hydro/GTW integration	System capability could be exportable, though not major market opportunity	Important to enable integration of energy exports
			OO	OOOO
		3. Reliability vs. Efficiency	Useful to understand, but hard to export	Important, but relative value of reliability vs. efficiency is unclear
			O	OOO
	Construction	4. Trenching and subsea	Fairly specific to each market, but some possibility to export	Important to be able to build subsea routes (Belle Isle and potentially Gulf of St Laurence
			OO	OOOO
	Maintenance and operation	5. Icing conditions	Valuable capability for range of markets worldwide	High value, since it can impact value of sales
			OOOO	OOOO
Company, Market & Regulation	Planning and design	6. Commercial/Market access	Specific to NL only – not exportable service	Key aspect of monetising NL energy resources
			O	OOOO
		7. Right of Way	Limited export value	Not critical in NL, and in general less an issue for DC that AC connections
			O	O
		8. Cost allocation	Limited export value per se.	High value, especially in very long distance connection
			O	OOO

Figure 37: Transmission - value of overcoming barriers

The outputs of the tables above are represented graphically in Figure 9, below.

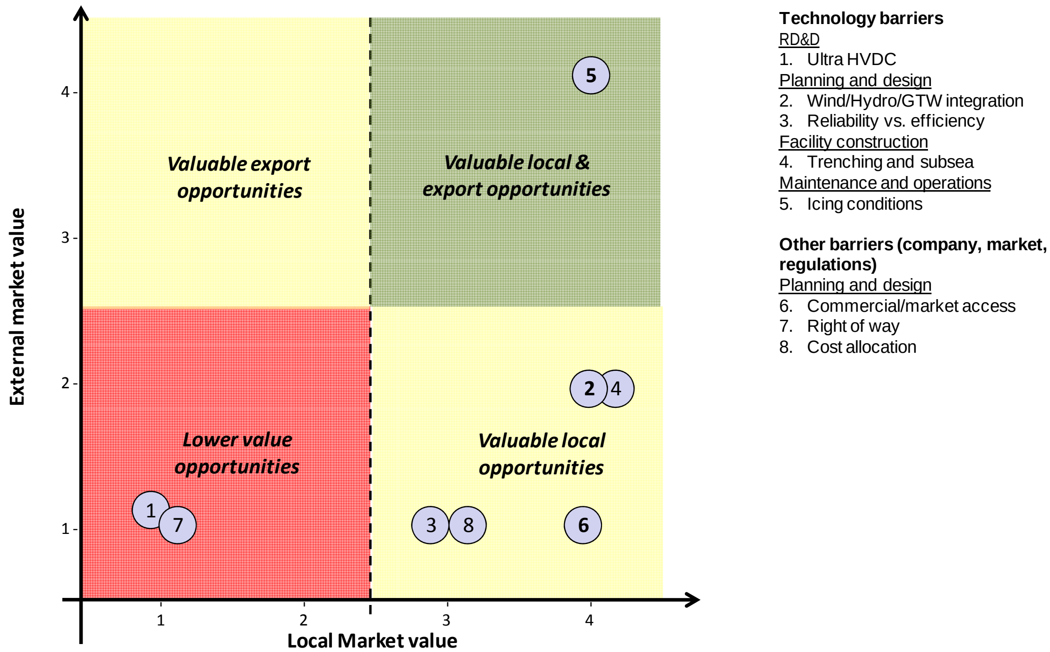

Figure 38: Transmission - theoretical value of overcoming barriers (summary)

Several observations can be made about this assessment of value:

- Almost all opportunities have limited external value, since they are inherently hard to export as products or services, in particular given that NL does not have a strong base of technological innovators in the transmission sector (this will be discussed more in section 4.3).
  - Five are 'valuable local opportunities' since they are key to unlocking the value of NL electricity resources. They are all issues that are closely linked to the design and selection of the power export options from Labrador in particular.
  - Two are 'lower value opportunities' since both are not expected to be applicable to any significant extent in the NL context.
- Tackling the icing conditions that prevail in NL is vital to development of NL resources as no satisfactory 'off the shelf' solution currently exists. Were such a solution to be developed for NL, then it is likely that it would be valuable to others outside NL.

Each of the barriers for which there was a high value in the external and/or local market value was considered further. Current innovation activities of leading innovators were assessed to determine whether there is a valuable innovation gap that NL might be able to address. These are presented in Figure 10 and Figure 11, respectively.

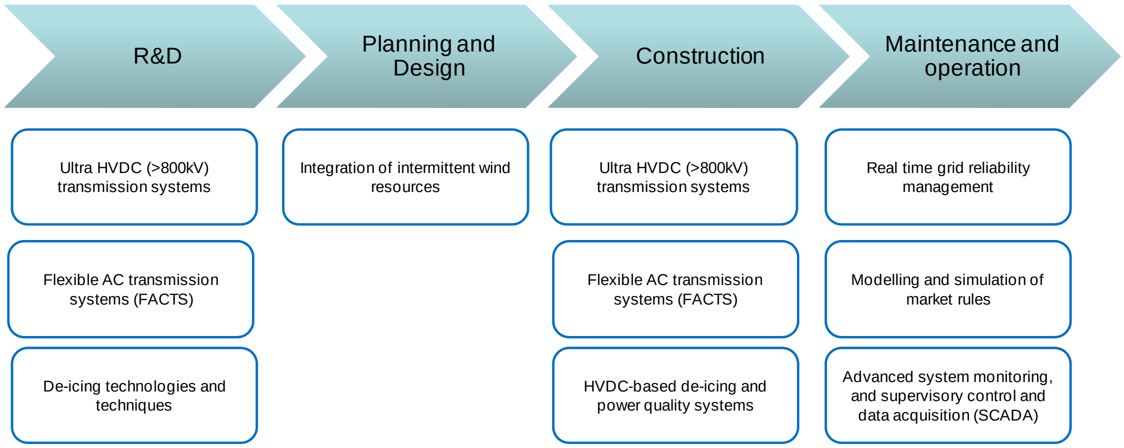

Figure 39: Transmission - main innovation currently occurring worldwide

There is innovation activity at all stages of the value chain, much of it focused on the barriers identified, involving major institutions worldwide (discussed further in section 4.3). However, only challenges relating to HVDC systems can be seen as close to satisfactory resolution.

Type	Value chain	Barrier	Innovation to address the barrier	
			Innovation currently occurring	Remaining gaps
Technology	RD&D	1. Ultra HVDC	Deployment of first Ultra HVDC system is expected to occur in the next year(s)	Limited. Technology is close to commercialization
	Planning and Design	2. Wind/hydro/GTW integration	Limited activity at system-wide level	Still a big challenge (or a missed opportunity if not tackled)
		3. Reliability vs. Efficiency	Design trade-off studies	Explore how this trade-off changes with ultra HVDC and recent advances in HVDC technology
	Construction	4. Trenching and subsea	Innovation in subsea infrastructure and interaction with icebergs	Not as big a challenge as in recent past, but still a concern for some NL export routes
	Maintenance and operation	5. Icing	Use of HVDC-based transmission as heat source for de-icing (and power quality support in normal condition)	Still a major challenge
Company, Market & Regulation	Planning and design	6. Commercial/ market access	Limited activity visible	Still a major need
		7. Right of Way	Limited activity in the sector	Not as big a challenge in scarcely populated area as NL
		8. Cost allocation	Limited activity in the sector	Still a major need for some NL export options

Figure 40: Transmission - worldwide innovation gaps

Combining these findings with the earlier analysis of innovation value leads to the following summary of valuable innovation opportunities for NL (Figure 40). Hypotheses for how NL may be able to capture this value were also generated as an input to the next section of the analysis and are detailed in Figure 12 below.

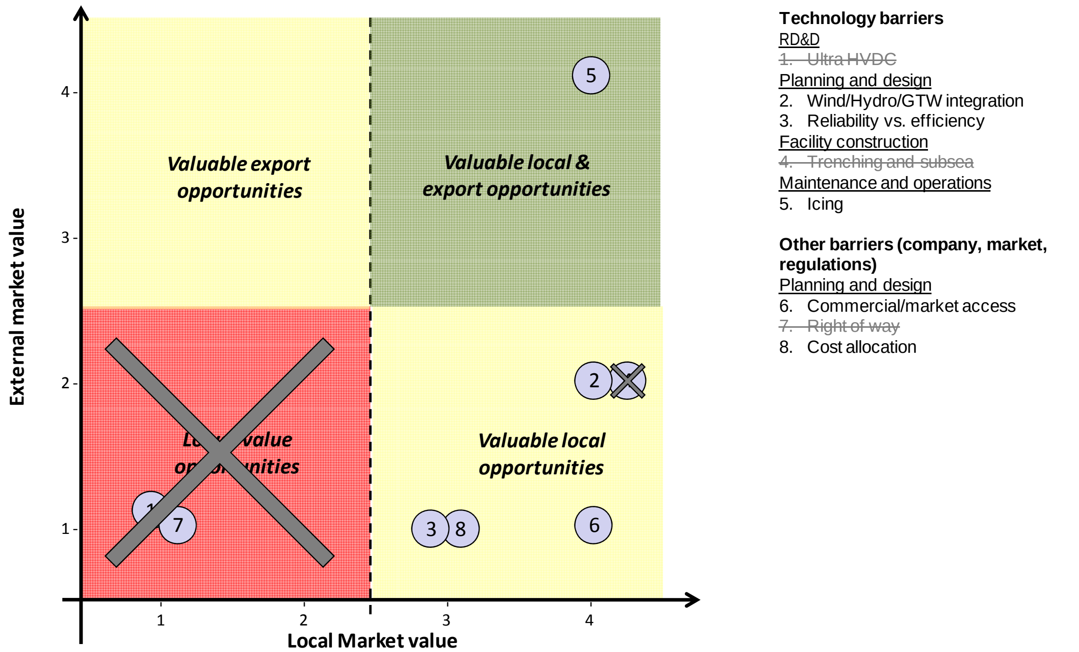

Figure 41: Transmission - potentially valuable innovation opportunities for NL

Barrier	Barrier detail	Potentially valuable innovation opportunities for NL*
2. Wind/hydro/GTW 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 -Preparation of negotiating position vis-à-vis neighbouring provinces with regard to way leaves and territorial rights
3. Reliability vs. Efficiency	Trade-off between reliability (e.g. via line redundancy) and cost efficiency	
6. Commercial/ market access	Need to develop a sales portfolio from different transmission alternatives	
8. Cost allocation	Who pays and who builds in inter-regional projects	
5. Icing	Ice conditions act as constraint on system operation and can lead to outages	Enhance power line icing capabilities (prediction, monitoring, control strategies, deicing technologies). Offer as service to other transmission system operators.

Figure 42: Transmission - hypotheses of valuable innovation (to be tested)

The output of this section of the evaluation is a set of potentially valuable innovation opportunities that NL could pursue, assuming that it has the resources to be competitive in doing so. The opportunities are, therefore, presented as hypotheses at this stage and also include a consideration of what the opportunity is and how it might be approached. Both aspects are needed to inform the subsequent stages of the evaluation which will assess NL competitiveness.

The following observations can be made on the hypotheses that remain at the end of this stage of evaluation:

- #2, 3, 6, and 8 are closely related and can be considered as an integrated opportunity to build a capability in techno-economic system modelling that will inform project development and commercial decisions for power export from NL sources. Existing NL capability is assumed to be modest at present, but there is some understanding of operating an isolated system.

- Power line icing is an important challenge that could also lead to an opportunity to sell services externally, if the existing capabilities can be built upon to achieve a successful outcome.

4.3 NL innovator competitiveness

4.3.1 Leading innovators worldwide and their research priorities

Innovation in power transmission takes place within a range of organizations including:

- Electric power utilities
- Universities and institutes
- Technology and solutions providers

Selected examples of each of these, relevant to NL, are profiled below.

Electric power utilities

Canada and the US

There are approximately 100 generation, transmission and distribution companies within Canada, the majority (65%) operating out of Ontario. Companies working in extreme Northern conditions include:

- Hydro-Québec (QC): including IREQ and Hydro-Québec TransÉnergie
- Northwest Territories Power Corporation
- Yukon Energy (YT)
- Qulliq Energy Corporation (Nunavut) (formerly Nunavut Power Corporation)
- Northland Utilities (distribution only)

With the exception of Hydro-Québec, none of these companies describe R&D programmes, but all have capabilities in the construction and maintenance of transmission lines in extreme environments. Although Qulliq Energy Corp operates the Nunavut Energy Centre, this is focused on energy efficiency and demand side management.

Hydro-Quebec and other Canadian utilities with a focus on innovation in power transmission are outlined below.

Hydro-Québec generates, transmits and distributes electricity and is one of the largest utilities in North America. Strategies laid out in the 2009-2013 Sustainable Development Action Plan[27] include increased investment in hydro (CAN$6.5 bn Romaine hydropower complex) and wind powered generation. A recent call (May 2008) for the purchase of wind power resulted in the acceptance of fifteen new bids totaling 2,004 MW which will come on stream between 2011 and 2015.

The company has its own **'Institute de Recherche' (IREQ)** with a total of six laboratories in Varennes and Shawinigan. The company invests approximately CAN$100 m annually in the institute. Six areas

[27] http://www.hydroquebec.com/sustainable-development/index.html

of expertise are described, some of which (highlighted in the table below) coincide with those areas identified as opportunities for NL shaded in yellow.

	Areas of research expertise
1	Mechanical, metallurgical and civil - problems related to the **failure, fatigue**, welding, wear, degradation and aging of equipment
2	Electrical equipment – with a focus on performance under harsh conditions
3	Automation and measurement systems – including high-tech tools used for preventive and corrective maintenance
4	Power system analysis, operation and control – including all aspects related to system stability, reliability and security
5	Chemistry and materials
6	Energy use – primarily energy efficiency

Figure 43: Hydro-Quebec Institute de Recherche's areas of research expertise

Within generation and transmission, core research is conducted into nine key areas including:

	Areas of core research
1	To develop new generating facility concepts
2	To optimize transmission system management
3	To reduce the impact of extreme weather events

Figure 44: Hydro-Quebec Institute de Recherche's areas of core research within generation and transmission

According to the 2008 Annual Report,[28] the focus of research in 2008 was the integration of wind power, new renewable energies and the long-term operability, reliability and optimization of facilities. For example 'We continued to develop management tools **for balancing hydro and wind power**, as well as models for simulating the behavior of wind turbines and wind farms connected to the Hydro-Québec grid.' IREQ is a member of WESNet, the pan-Canadian network of wind energy experts (see Section 2.3.1 above).

Hydro-Québec TransÉnergie is a separate division, which operates the company's extensive transmission system (33,000 km of lines) throughout North America. The company has specialized in innovation relating to long distance transmission through a number of technologies, including:

	Areas of focus for innovation
1	DC power transmission, such as the MDCS (multiterminal DC system) that links direct current transmitted 1,200km from James Bay, with alternating current received from Churchill Falls via the Nicolet converter substation
2	A control mechanism that allows a reduction in voltage on the transmission system at peak periods without affecting service quality
3	Various tools for de-icing operations on transmission lines. For example, the System Control Centre uses the STRADEG de-icing software to produce and help deploy optimized de-icing scenarios in the event of ice storms

[28] http://www.hydroquebec.com/publications/en/annual_report/pdf/annual-report-2008.pdf

Figure 45: Hydro-Quebec TransÉnergie's areas of focus for innovation

The Manitoba HVDC Research Centre Inc.[29] was established in 1981 as a non-profit research company jointly created by **Manitoba Hydro**, Teshmont Consultants, Federal Pioneer, and the University of Manitoba. In 2000, the Centre became a wholly-owned subsidiary of Manitoba Hydro. Technical issues are guided by the Manitoba Hydro executive and the Technical Advisory Board. The Centre has become a world leader in electric power system simulation, applied power systems analysis, and related technologies. It develops and markets an array of products and services worldwide including the renowned power system simulation software PSCAD® (PSCAD®/EMTDC™) and real time playback system RTP™. PSCAD®, commercially available since 1993, embodies years of continuous research and development from 1988 to the present.[30]

At present the **British Columbia Transmission Corporation**[31] supports technology innovation through development and demonstration of technologies new to the transmission industry. It is currently running 80 –90 concurrent projects and has a CAN$1.5 million annual budget leveraged up to 10 times with research partners. Activities are aligned with the B.C. Energy Plan direction to ensure transmission technology and infrastructure remains at leading edge. BCTC's Technology Roadmap addresses the major themes of the Energy Plan, including: Energy Security, Environmental Leadership, Conservation and Efficiency, and the Future Grid.

Within the US, the **Bonneville Power Authority** (BPA) provides about half the electricity used in the Northwest region and operates over three-fourths of the region's high-voltage transmission. The BPA is highly supportive of the development of wind power in the Pacific Northwest, and has recently announced the following focus on bringing wind into the transmission system:[32]

	Areas of innovation focus for bringing wind into the transmission system
1	Revamping the way BPA operates its system to allow the grid to work reliably with large amounts of variable generation
2	Creating new wind power-friendly business practices and institutional arrangements with other utilities across the Western Interconnection. An example of a new mechanism to increase transmission capacity is the 'Conditional Firm' service which provides transmission with the potential for a small amount of interruption if transmission becomes congested
3	Integrating wind with traditional power sources

[29] https://pscad.com/home/

[30] Walter Parsons, pers. comm.

[31] http://www.bctc.com/home

[32] Bonneville Power Administration Factsheet, How BPA supports windpower in the Pacific Northwest, March 2009

4	A Wind Integration Team (launched 2008) to tackle the grid operation, business practice and institutional arrangements needed to make the most of the wind resource. Five key areas are new operating procedure; tools for transmission dispatchers (minute to minute generation control); sub-hourly transmission scheduling; dynamic scheduling (allowing support from other utilities' balancing authorities); third party supply

Figure 46: Bonneville Power Authority's areas of innovation focus for bringing wind into the transmission system

International

Numerous international power utilities (outside North America) operating in Northern regions also invest substantial sums in innovation related to power transmission. Two companies are profiled in more detail below.

Landsnet is an Icelandic public company that owns and runs the electrical transmission system in Iceland, as well as handling its power system operation[33]. The company, in turn, is owned by Landsvirkjun (65%) and a number of Icelandic power utilities. In 2008[34], the research focus included:

- Feasibility studies for new line routes (including the advantages of employing new tunnels to install lines in order to avoid the use of overhead lines along mountain roads where weather conditions are harsh);
- Measurements of conductor vibration, salt accumulation on insulators and soil thermal conductivity on planned underground cable routes;
- Use of webcams and tension recorders for real-time monitoring of important transmission lines in places where icing and extreme weather load can be expected; and
- Selection of line routes and related research on the seabed between Landeyjasandur on Iceland's south coast and Gjábakkafjara in the Westman Islands.

The company keeps a systematic record of icing events on all transmission lines operated in the country and is an active participant in international co-operation on icing research and the design of switchgear and transmission lines.

The **Vattenfall Group**[35] (Sweden) is Europe's fifth largest generator of electricity, with operations in Germany, Poland, Netherlands, United Kingdom and the Nordic countries (Denmark, Finland, Norway and Sweden).

The company has a strong focus on R&D, in particular on the development of new and existing technologies to provide clean electricity. Their stated aim is to be 'climate neutral by 2050' and large scale R&D programmes are conducted in the following areas:

- Carbon Capture and Storage;
- Future Production Technologies;
- Intelligent networks (smart grid technology);
- Thermal technology; and

[33] http://www.landsnet.is/english/english.html

[34] http://www.landsnet.is/Uploads/document/Annual_Report%202008.pdf

[35] http://www.vattenfall.co.uk/en/index.htm

- Wind Power (including the integration of high volumes of wind power into the electrical grid system).

In 2008, Vattenfall invested SEK1.529 billion (Can$230 million) in R&D, of which SEK143 million was allocated to renewable energy. Vattenfall claims to invest more in R&D than other European energy companies at close to 1 % of turnover.

Universities and institutes

There are numerous universities and institutes (both within Canada and internationally) with specialist energy technology related departments, whose research programmes are targeted at, or have an impact on, power transmission. In particular, there is a great deal of research into the optimization of integrating wind energy into the electricity transmission system. Much of this deals with the need to balance the intermittent provision of wind power, but does not specifically address the use of hydro-power for this purpose. However, Integration of Wind and Hydropower Systems (2004-2008) was dealt with specifically by Task 24 of the IEA[36]. The task was delivered by NREL with Canadian participants, Natural Resources Canada, Hydro-Quebec and Manitoba Hydro. Other partners were Hydro Tasmania; VTT (Technical Research Centre), Finland; Sintef Energy Research and Statkraft Energy, Norway; KTH Swedish Institute of Technology; EW Ursern, Switzerland; Arizona Power Authority; Bonneville Power Administration and Grant County Public Utility District, USA. The aims of the task were to provide answers to the following questions:

- The technical and economic feasibility of wind/hydro integration in specific case studies;
- Identification of practical W/H configurations;
- A consistent method of study and comparison;
- The ancillary services required by wind energy, and the electric system reliability impacts, of incorporating various levels of wind energy into utility grids that include hydro generation;
- An understanding of the costs, benefits, challenges opportunities, and how to manage impacts; and
- Hydro simulation and optimization

Task 24 was run alongside Task 25 '**Power Systems with Large Amounts of Wind Power**' (2006-2008) which aimed to facilitate economically feasible wind energy penetration within electricity power systems worldwide. Results for Task 25 were published in Environmental Research Letters, April 2008[37]; see also http://www.ieawind.org/AnnexXXV.html for additional publications, and the final report was published in September 2009. The final report for Task 24 is not yet available.

In terms of resources and scale, these institutions present a similar range of profiles to those described in Section 2.3.1 for onshore wind, and this information has therefore not been repeated here.

Fewer institutions are focused principally on electricity generation and transmission, but an important exception is the US **Electric Power Research Institute**. The EPRI conducts R&D relating to

[36] http://www.ieawind.org/

[37] Holtinnen, H., Estimating the impacts of wind power on power systems—summary of IEA Wind collaboration, April 2008, *Environ. Res. Lett.* **3** 025001.

the generation, delivery and use of electricity. The institute focuses on 'challenges in electricity, including reliability, efficiency, health, safety and the environment; and provides technology, policy and economic analyses to drive long-range research and development planning, and support research in emerging technologies.' Their 2010 renewable energy research portfolio is focused on 'helping the electricity industry develop large-scale and distributed generation technology, and to expand and equip the grid to operate efficiently and reliably with diverse renewable sources.' Three of the six core programmes are particularly relevant to NL: generation; power delivery and utilization; and renewables. Examples of projects planned for 2010 are given below.

Power delivery and utilization		
Area of research focus		**Example projects**
Transmission lines and substations	Overhead transmission: Program 35: estimated 2010 funding US$6.5 m	Design, Reliability and Performance for Overhead Transmission - Project Set 35F
		Increased Overhead Transmission Capacity - Project Set 35G
	Underground transmission: Program 36: estimated 2010 funding US$2.5 m	Design, Reliability and Performance for Underground Transmission - Project Set 36A
		Cable Dynamic Rating and Increased Power Flow Guidebook - Project Set 36B
		Superconductivity - Project Set 36C
	HVDC systems – Program162: estimated 2010 funding US $1.0 m	HVDC Technology Assessment and Evaluation - Project Set 162A
		HVDC Performance and Effects - Project Set 162B
Grid operations and planning	Grid Planning – Program 40: estimated 2010 funding US$2.0 m	Strategic Planning - Project Set 40D (Economic Assessment of Technology Options for Increasing Transmission Capacity - Project 40.009)
		Modeling and Standardization - Project Set 40A 40A (Transmission System Model Management - Project 40.014)
		Reliability Assessment - Project Set 40B (Application of Transmission Availability Statistics for Reliability Assessment - Project 40.003; Balancing Economics and Reliability to Evaluate Planning Options in a Competitive Environment - Project 40.015)
	Integration of variable and controllable loads – Program 173: estimated 2010 funding US$1.3 m	Grid Performance and Modeling of Variable Generation and Evolving Power System Resources - Project 173.003
		Determination of Optimal Reserve with Consideration of Variable Generation and Controllable Loads - Project 173.004
		Advanced Frequency Control for High Variable Generation Systems and Evolving System Resources - Project 173.005
		Advanced Planning Tools to Study the Impact of Variable Generation and Controllable Loads - Project 173.006

Generation	
Area of research focus	**Example projects**
Generation planning (Power Technologies and Markets Analysis): estimated 2010 funding US$1.3 m	Technology-based business planning information and services – Project Set 178A
	Understanding Power and Fuel Markets and Generation Response - Project Set 178B
	Power Markets and Enterprise Risk - Project Set 178C (Forecasting Prices and Volatility of Power, Fuel, Transmission, and Carbon - Project 178.003; Optimizing Portfolio Risk and Return: Energy, Assets, and Carbon - Project 178.004; Enterprise Risk Management for the Energy Business - Project 178.005; Managing the Risk of Integrating Demand Response and Intermittent Resources - Project 178.006)
Renewables	
Area of research focus	**Example projects**
Renewable Generation – Program 84: estimated 2010 funding US$3.0 m including	Renewable Energy Economics and Technology Status - Project Set 84A (Renewable Energy Technology Guide and Updates - Project 84.001;Renewable Engineering and Economic Evaluations - Project 84.002; Renewable Energy Analysis and Strategy - Project 84.003)
	Wind - Project Set 84D (Wind Power Technology Assessment - Project 84.010; Wind Power Asset Management - Project 84.011)

Figure 47: Electric Power Research Institute example projects

The EPRI organized a workshop in December 2009 entitled 'Enabling Transmission for Large Scale Renewable Integration Workshop'. This included 'designing the architecture to integrate renewable resources into system operations and system planning'.

There does not appear to be an equivalent federal laboratory in Canada. The Program of Energy Research and Development (PERD) is a federal, interdepartmental program operated by Natural Resources Canada (NRCan) and delivered by 13 federal partners and agencies. These include CanmetEnergy which undertakes a research into offshore wind and harsh conditions (see Section 0) but does not have a focus on transmission.

As seen in the onshore wind sector, the transmission sector also engages in large scale collaboration between major industry players, Government departments and academia. For example, the **Utility Wind Integration Group (UWIG)** is a partnership between the U.S. Department of Energy, the National Renewable Energy Laboratory (NREL) and a range of major stakeholders. It was set up in 1989 to 'accelerate the development and application of good engineering and operational practices supporting the appropriate integration of wind power into the electric system in collaboration with and utility research organizations.'[38] In addition to Canadian and US Utilities, membership includes turbine manufacturers (e.g. Vestas, Suzlon), utilities from other parts of the world, trade associations and consultancies. The group undertakes and participates in research, as well as organizing knowledge sharing workshops and conferences. In 2007, UWIG (in partnership with the NREL,

[38] http://www.uwig.org/

Bonneville Power Administration, American Wind Energy Association, and Canadian Wind Energy Association) held a workshop on the integration of wind energy and hydropower. This included presentations by Manitoba Hydro; Avista Corporation; VTT (Finland) and Northern Arizona University (see Section 4.4.1).

Technology and solutions providers

Technology and service providers are often at the forefront of developing innovative solutions and services for transmission and distribution systems.

For example, **Areva T&D**[39] employs more than 1,300 engineers and scientists and has established partnerships with 40 universities and institutes throughout the world. R&D teams are focused on improving:

- Reliability, through state-of-the-art products, such as FACTS (Flexible AC Transmission Systems) and HVDC (High Voltage Direct Current) technology;
- Stability, through FACTS devices that help integrate renewable generation onto the grid and stabilize AC networks; and
- Efficiency, through power electronics applications that improve active power flow and reduce congestion; market management systems that allow the efficient operation of and trading between energy markets; and low-loss transformers that increase network performance.

Areva operates three specialized research and technology centers in France, a broad-based research and technology center in the UK, and over 20 dedicated Centers of Excellence worldwide.

IPA Energy + Water Economics is an economic consultancy specializing in 'pricing and markets, trading and risk, regulation, project economics, financing and PSP across the Electricity, Gas, Water, Sustainable Energy & Carbon, Transport and Infrastructure sectors'. Services include power market modeling using proprietary software ECLIPSE (Emissions Constraints and Policy Interactions in Power System Economics) which includes interactions between renewable power, emissions, carbon and other economic drivers.[40]

Similarly **Econ Pöyry**[41] has devised a number of in-house power market models including the ECON BID – Price structure model which analyses the functioning of the power system in Northern and Central Europe, incorporating the impact of variability and uncertainty in wind power, thermal production and hydropower on the hour-by-hour price level and structure, price volatility and price differences between market areas.

Lastly US-based **ICF International** uses proprietary tools to undertake power market modeling. For example, their Integrated Planning Model can be used to used 'to determine the least cost means of meeting electric generation energy and capacity requirements while complying with specified air pollutant regulations, fuel limitations, and operating constraints'[42]

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[39] http://www.areva-td.com/profile/US_181_Research+%26+Development.html

[40] http://www.ipaenergy.co.uk/507_PowerMarketModelling.html

[41] http://www.econ.no

[42] http://www.icfi.com/markets/energy/doc_files/energy-market-models.pdf

Conclusions

Figure 48 below provides an overview of the key players involved in innovation globally in power transmission, together with the level of resources deployed.

Electric Power Utilities	• There are approximately **100 generation, transmission and distribution companies within Canada alone.** A number, including BC Hydro and Hydro-Quebec face similar innovation challenges to NL and have significant research and innovation capabilities. • **Hydro-Quebec** has its own **'Institut de Recherche'** with a total of six laboratories in Varennes and Shawinigan. The company invests approx. Can$100 m annually. **Hydro-Québec TransÉnergie** is a separate division, which operates the company's extensive transmission system (33,000 km of lines) throughout N. America. The company specialises in innovation relating to long distance transmission. • Numerous international power utilities operating in Northern regions invest substantial sums in innovation related to power transmission. For example, **Vattenfall** (Sweden) invested SEK1.529 billion in R&D in 2008 (~Can$230 million). It claims to spend proportionately more on R&D, at approximately **1% of sales revenue**, than other European companies.
Technology Solution Providers	• There are **numerous technology and service providers** who are often at the forefront of developing innovative solutions and services for transmission and distribution systems. For example, **Areva operates three specialized research and technology centres in France, a broad-based research and technology centre in the UK, and over 20 dedicated Centres of Excellence worldwide.** • Areva's R&D teams focus on improving reliability and stability through state-of-the-art products, such as Flexible AC Transmission Systems and HVDC technology; and on improving efficiency thorough power electronics applications, market management systems, and low-loss transformers.
Universities and Institutes	• **A number of dedicated research institutes,** such as the Electric Power Research Institute in California conducting research into all aspects of generation, delivery and use of electricity. • **Numerous universities with specialist** energy technology related **departments,** such as the Norwegian University of Science and Technology.

Figure 48: Key players involved in innovation in power transmission

4.3.2 Transmission innovation capabilities within NL

There is limited power transmission-related innovation activity within NL relative to the scale of international competition. Nalcor has a small research facility with many years of specialist research into ice monitoring of overhead power lines. 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 for remote power generation and storage.

Nalcor, along with Newfoundland Power, manages the Island system with substantial wind and hydro capacity and they can therefore be assumed to have first-hand experience of relevance to innovation related to the grid integration of renewable power sources.

MUN Department of Engineering conducts some research into grid integration and reliability issues.

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 Figure 49 below.

Practicalities and costs would suggest that NL is likely to favour collaborative options for engagement. Potential collaborative partners may well include a number of the organisations identified in Sections 4.3.1 above and 4.4.1 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

Figure 49: 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)

4.4 Innovation priorities

4.4.1 Current international research in relation to specific opportunities identified for NL

Ongoing international innovation projects have been identified in each of the prioritized innovation areas. Selected examples are detailed in Figure 50. Unlike onshore wind, we do not see any NL-specific barriers that will not be addressed by ongoing international innovation. A summary overview of current research activity in Europe and North America in prioritized innovation areas is given in Figure 51.

Innovation Opportunity	Company/Institution	Example Projects
2. Wind/hydro/GTW integration	UWIG, US and International	Wind Hydro Integration Workshop 2007: **Manitoba Hydro** 'Wind/Hydro integration for Manitoba's Hydro System; **VTT Technical Research Centre Finland** 'Wind Hydro Integration on a Large Hydro System' - this presentation incorporated research into sale of wind powered electricity through the Nordpool spot market, the requirement for imbalance payments for prediction errors and the ability of hydro to regulate against imbalances. Also used simulation (WILMAR model) to look at impact of wind power on the electricity markets of the Nordic countries and Germany **IEA Task 24** 'Integration of Wind and Hydropower systems' **Avista** 'A Parametric Evaluation of Wind/Hydro Integration in the Avista System in the Pacific Northwest'. Partnership with EnerNex Corporation.

Innovation Opportunity	Company/Institution	Example Projects
		Presentation also included valuation of wind resources
	NREL and consortium, US	**IEA Task 24** 'Integration of Wind and Hydropower systems'
	DOE, US	Wind and Hydropower technologies program[43] including Grid planning; integration of wind and hydropower technologies
3. Reliability vs. efficiency	EPRI, US	Transmission lines and substations program
	ABB, Switzerland and Teshmont, Ontario	Techno-economic feasibility of HVDC systems up to 800 kV (contributions to a Workshop held in Dehli, 2005) Internal R&D
6 & 8. Commercial/Market Access and Cost Allocation	NREL, US	Market Analysis including: production of technology and program market reports together with the Office of Energy Efficiency and Renewable Energy (EERE). *No information on hydro technologies* Transmission and generation planning in relation to wind power including the impact of reliability characteristics (capacity credit) resulting from wind and utility load temporal profile matches on the valuation of wind from a planning perspective
	UWIG, US and International	Topic included in the Wind Hydro Integration Workshop 2007
	EPRI, US	Power markets and enterprise risk program including price volatility of fuel, power, transmission and emissions; regulatory uncertainty, such as carbon restrictions, capacity markets, transmission load relief calls (TLRs), and transmission allocation or pricing schemes. Renewable Generation program including: How to capitalize on market opportunities for renewable compliance and power purchases, resulting in improved decision making and better revenue potential; Identify the appropriate role of diverse renewable resources in expanding new and sustainable generation capacity; Apply results from modeling, simulation, and future energy scenario analyses that will help guide investments in renewable energy. *Note hydro power not included*.
	Consultancies such as IPA Economics and Econ Pöyry	Most specialist consultancies have proprietary models for the evaluation of technical and commercial options, and the associated economics.
	Bonneville Power Administration, US	Internal focus; Wind Integration Team
5. Icing	Participants of the IWAIS 2009 conference, International	International Workshop on Atmospheric Icing of Structure, Sept 2009. Topics included icing on powerlines with contributions from Université du Québec à Chicoutimi 'Overview of Atmospheric Icing of Power Networks: State of our Knowledge and Future Challenges', 'Theoretical Studies and Quantification of Ice Adhesion Mechanisms', 'Modeling Wet-Snow Shedding from Current-Carrying Conductors'; Landsnet (Iceland) 'Ice Accumulation at measuring site Hallormsstadahals'; College of Electrical Engineering of Chongqing University (China); Survey and analysis of Ice Accidents of Early 2008 in Southern China'; Technical University Braunschweig (Germany) 'A Numerical Model for Atmospheric Icing of Conductor Bundles'; Xi'an Polytechnic University (China) 'A New On-line Monitoring System of Transmission Line Icing and Snowing'; Electric Power Research Institute – VNIIE (Russia) 'Modern techniques of ice-load assessment and icing maps creation for the design of overhead transmission lines used in the Russian Federation'. Additional institutions supplying poster contributions were CESI RICERCA (Italy); STRI AB

[43] http://www1.eere.energy.gov/windandhydro/renewable_systems.html

Innovation Opportunity	Company/Institution	Example Projects
		(Sweden); Hydro-Quebec Transenergie (Quebec)
	Areva, France and Hydro-Quebec, Quebec	AREVA's Transmission and Distribution division was been awarded a 25-million euro contract in Canada to build the world's first HVDC-based de-icing and power quality system (2005)[44]

Figure 50: Examples of ongoing research in identified transmission innovation opportunity areas

2. Wind/hydro/GTW integration	• Research and innovation related to **wind energy integration** into the grid is the **focus of numerous utilities and academic organisations** (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. • Specific innovation related **wind hydro integration** is the **subject of research by utilities** (such as Avista) **and institutes** (such as VTT in Finland). It is also the focus of **IEA Implementing Agreement** for Cooperation in RDD of Wind Energy Systems (Task 24).
3. Reliability vs Efficiency	• Focus for research and innovation by **numerous electric power utilities** (such as Hydro-Quebec), **technology providers** (such as ABB) and **specialist institutes** (such as EPRI).
6 & 8. Commercial Market Access and Cost Allocation	• Numerous **commercial consultancies, and specialist institutes** (such as NREL and EPRI) conduct research into commercial/ market access and cost allocation. Much research is jurisdiction / regulatory environment specific.
5. Icing	• Research and innovation related to icing is the **focus of a number of utilities operating in northern environments and of research institutes.** Contributors to the International Workshop on Atmospheric Icing of Structures Sept 2009 topic on icing on powerlines 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). This 13th International Workshop was held in Andermatt, Switzerland.

Figure 51: Summary overview of ongoing international innovation in innovation opportunity areas

4.4.2 Prioritization for NL

As outlined in Section 2.4, innovation opportunities have been separated into the following three categories:

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;

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; and

[44] http://tdworld.com/news/AREVA-deicing-system/

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.

The categorisation of prioritized transmission innovation areas is given in Figure 52 below.

It is important to note that NL will need to have a plan to overcome all barriers to the deployment of long-distance electricity transmission. However, we anticipate that virtually all barriers, including those in Category C below, will be overcome by the purchase of innovative solutions from international third parties.

Category A innovation areas appear to offer the opportunity for NL to acquire an internationally competitive position, either because there is modest ongoing international activity or it is possible to exploit existing knowhow and innovation capabilities.

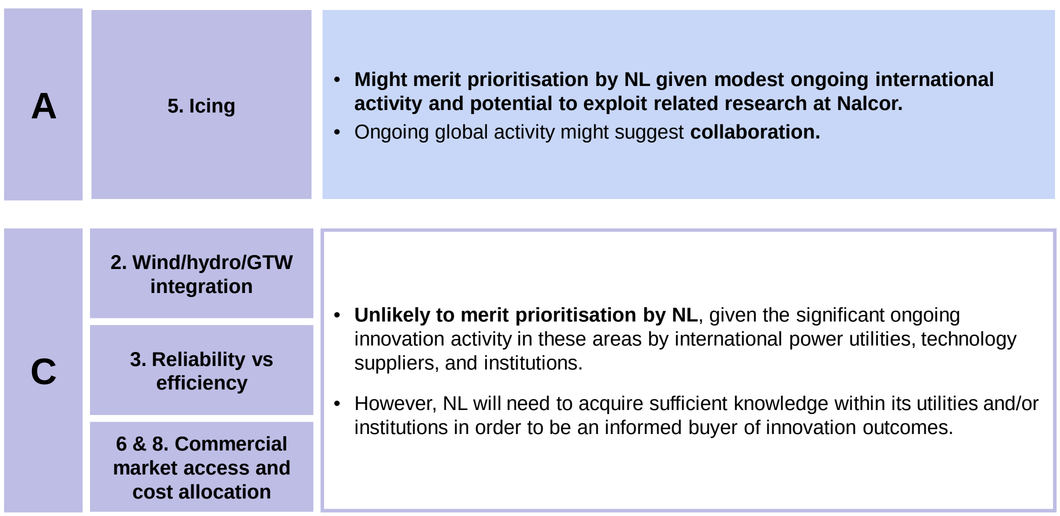


Figure 52: Categorization of prioritized transmission innovation areas

5 Upstream oil and gas

5.1 Innovation barriers

Upstream oil & gas is dealt with separately from mid/downstream gas, which was felt to have a number of sufficiently distinct issues to merit separate consideration (see section 7 of this report). In practice the resulting innovation opportunities from these two areas were found to be sufficiently close for these analyses to converge in the presentation of recommendations (see report 4: Recommended Innovation Priorities). Mid/downstream oil was also considered separately, but in view of the much lower overall activity level - and therefore opportunity - when compared with other oil and gas areas, this is treated in the Appendix to this report.

The value chain for upstream oil and gas is well-defined though terminology varies a little internationally. For the purposes of the project the following generic value chain has been defined (Figure 52), with typical actors shown in Figure 53 below.

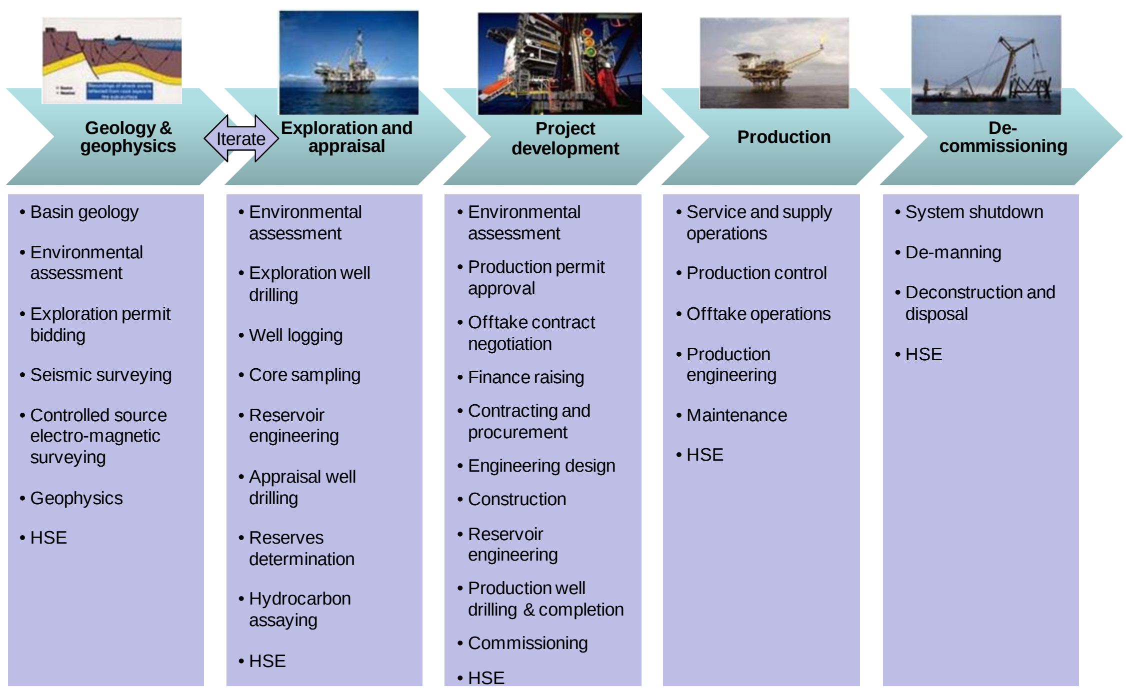


Figure 53: Upstream oil & gas - industry value chain

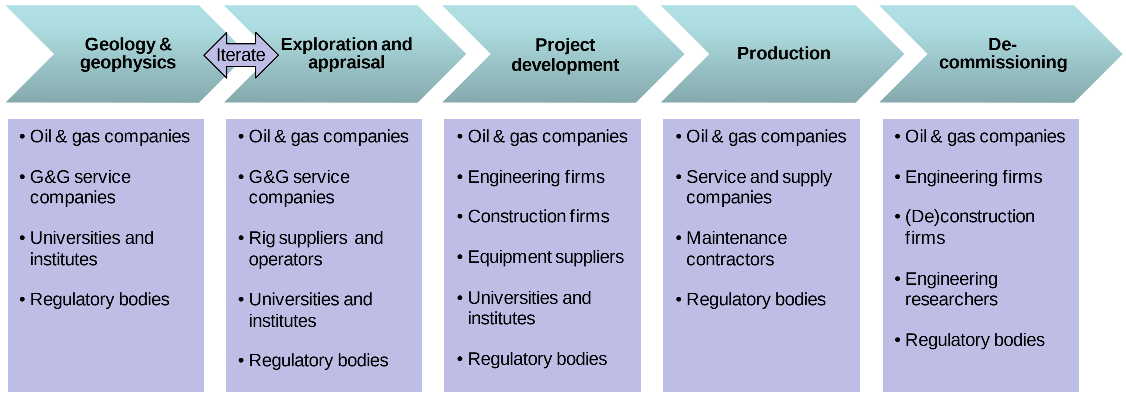


Figure 54: Upstream oil & gas - typical actors along the value chain

We have drawn upon our knowledge of the oil and gas sector and have also had numerous discussions with NL stakeholders to identify the following barriers to the development of resources offshore and onshore in all areas of NL. In view of the enormous diversity of challenges in the international oil and gas industry, only barriers relevant to the local context have been captured.

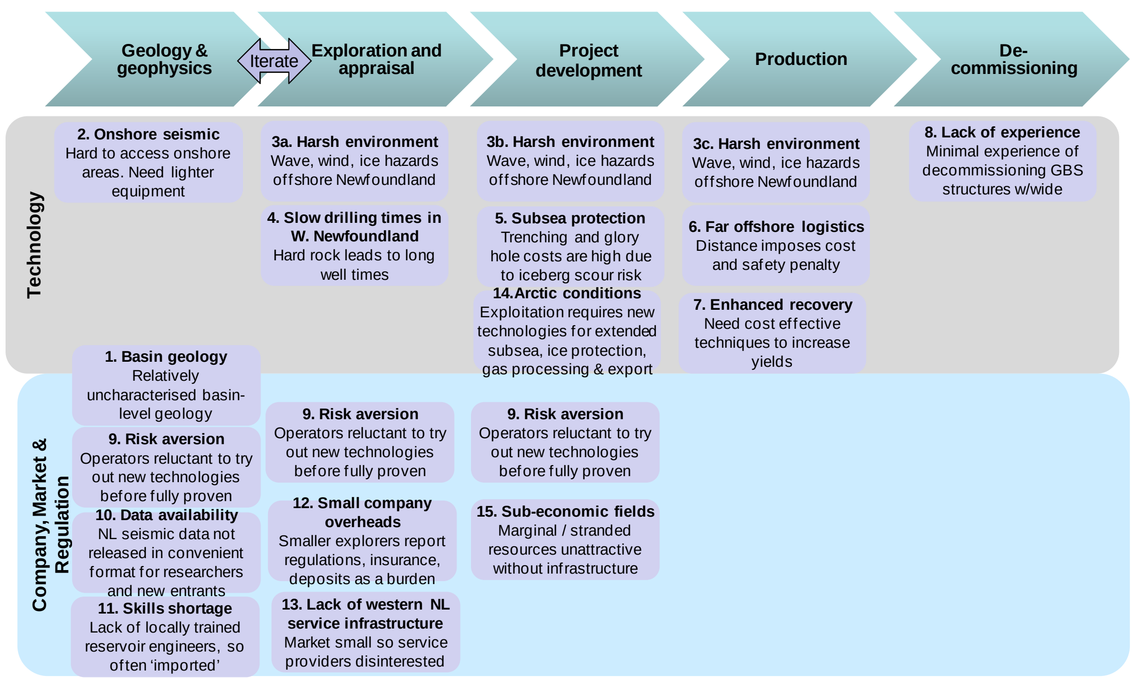


Figure 55: Upstream oil & gas - main barriers

Additional information on each of these barriers is provided in the table below.

Barrier #	Additional information
1	Prospective explorers have lower levels of basin-level data available to them compared with other oil & gas regions
2	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
3	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

Barrier #	Additional information
	(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 #14)
4	Western Newfoundland features very hard rocks leading to slow rates of penetration in drilling. For smaller companies this means more costly wells than equivalents in other oil and gas regions
5	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.
6	Many of the fields are far offshore and, in combination with very variable weather, this means that supply logistics are often stretched.
7	Improving recovery rates is a fundamental challenge across the industry. It is particularly relevant to some Newfoundland and Labrador reservoir types (e.g. Ben Nevis-Avalon reservoir expected to yield only 5-10% with currently known techniques)
8	Experience with decommissioning of steel structures is increasing rapidly worldwide, but for Hibernia-type large GBS structures there is much less experience worldwide
9	Explorers and developers are reluctant to deploy any technology where there is a limited track record and where the consequences of failure are costly (which is often the case in upstream oil & gas). This is a vicious cycle and as a result new technologies take longer to become commercial in upstream oil and gas than many other industrial sectors.
10	Seismic data is not provided to companies and researchers in digital format, unlike other jurisdictions. This hampers their ability to process it and prospect in new areas.
11	Few reservoir engineers are currently trained locally and so those that work on Newfoundland and Labrador projects are mostly secondees who spend only a few years becoming familiar with local reservoirs before moving on.
12	Smaller exploration companies (in Western Newfoundland) find the overhead costs associated with insurance, deposits and other regulatory requirements burdensome. Some comment that the regulations are more appropriate to larger exploration plays, rather than Western Newfoundland.
13	The early stage nature of Western Newfoundland as an oil and gas region makes it hard to attract service companies to support exploration activities. This reduces productivity and increases costs for the exploration companies
14	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 #15)
15	The large distances between existing offshore facilities and export routes means that there are numerous fields that are sub-economic. Known gas in Grand Banks and offshore Labrador fields currently lack an export route (it is currently reinjected for oil drive in Hibernia and Terra Nova, but in White Rose it is merely stored for future recovery). This feature may act as a disincentive to further gas exploration offshore Labrador for some companies (see #14)

Figure 56: Upstream Oil & gas - additional information about barriers

5.2 Valuable innovation opportunities

Each of the barriers identified in the previous section was examined in terms of the value that would be available to NL from overcoming it. This is expressed in qualitative terms for the export market ('external market value') and for the local resource development opportunity ('local market value'). The latter scored highly in most cases, since there is significant resource that could be developed if several key barriers are overcome. The export value is also high in cases where barriers are representative of those facing the industry in other parts of the world.

Note: in interpreting the significance of these barriers, it is important to appreciate that the assigned values are relative to one another within the context of transmission, but are not relative to opportunities in other areas of energy such as wind and transmission.

The valuation of overcoming barriers through innovation was based upon judgement of the consulting team, informed by numerous consultations, and was also validated by steering group members. It was agreed that qualitative valuation would be suited to the purposes of the project, which requires sufficient evidence to justify prioritization, but not, for example, an econometric forecast of benefits. A one to four scale was chosen with a break point between scores of two and three. A more detailed description of the overall approach is provided in report 4 'Recommended Innovation Priorities'.

Type	Value chain	Barrier	Value of overcoming barrier (O = lowest, OOOO = highest)	
			External Market Value	Local Market Value
	Geology & geophysics	1. Basin geology	Intrinsically local so not easy to export	Important for continued exploration attraction
			O	OOO
		2. Onshore seismic	Some export value for areas with equivalent terrain	Would increase attractiveness of western province exploration
			OO	OOO
	Exploration & appraisal	3a. Harsh environment	Growing desire to explore safely and effectively in harsh environments worldwide e.g. Arctic	Significant challenge for continued exploration in Labrador in particular
			OOOO	OOOO
		4. Slow drilling times in W. Newfoundland	Novel techniques would be valuable worldwide	Would improve western province economics to some extent
			OOOO	OO
	Project development	3b. Harsh environment	Growing desire to pursue developments in harsh environments worldwide e.g. Arctic	Still need to improve ability to deal with waves in particular for Grand Banks, ice for Labrador
			OOOO	OOOO
		5. Subsea protection	Challenge for shallow water Arctic conditions	Specific challenge for Grand Banks and Labrador
			OOOO	OOOO
		14. Arctic conditions	Techniques could be used for other ice-bound gas	Would unlock potential of offshore Labrador
			OOOO	OOOO
	Production	3c. Harsh environment	There will be need to maximise uptime and safety in new harsh environment frontiers	Increasingly well understood, but innovation would benefit future developments throughout NL
			OOOO	OOOO
		6. Far offshore logistics	Mostly NL specific, but could be some export of techniques	Could increase productivity, safety and staff retention in NL
			OO	OOO
		7. Enhanced recovery	Key factor worldwide	Key factor for NL
			OOOO	OOOO
	Decommission-ing	8. Lack of experience	Increasingly important worldwide, but many requirements are project-specific	Will be a key consideration
			O	OOO

Type	Value chain	Barrier	Value of overcoming barrier (O = lowest, OOOO = highest) External Market Value	Local Market Value
	Geology & geophysics	9. Risk aversion	Limited as intrinsically local	Would provide greater demand for NL service sector
			O	OOO
		10. Data availability	Intrinsically local	Would increase competitiveness of NL for explorers and researchers
			O	OOO
		11. Skills shortage	Intrinsically local	Would increase use of local staff
			O	OOO
	Exploration & appraisal	9. Risk aversion	Limited as intrinsically local	Would provide greater demand for NL service sector
			O	OOO
		12. Small company overheads	Intrinsically local	May increase competitiveness of NL for small explorers
			O	OO
		13. Lack of western NL service infrastructure	Intrinsically local	Would increase competitiveness of western province
			O	OO
	Project development	9. Risk aversion	Limited as intrinsically local	Would provide greater demand for NL service sector
			O	OOO
		15. Sub-economic fields	Intrinsically local	Vital factor for increased NL development
			O	OOOO

Figure 57: Upstream Oil & gas - value of overcoming barriers

The outputs of the tables above are represented graphically in Figure 9, below.

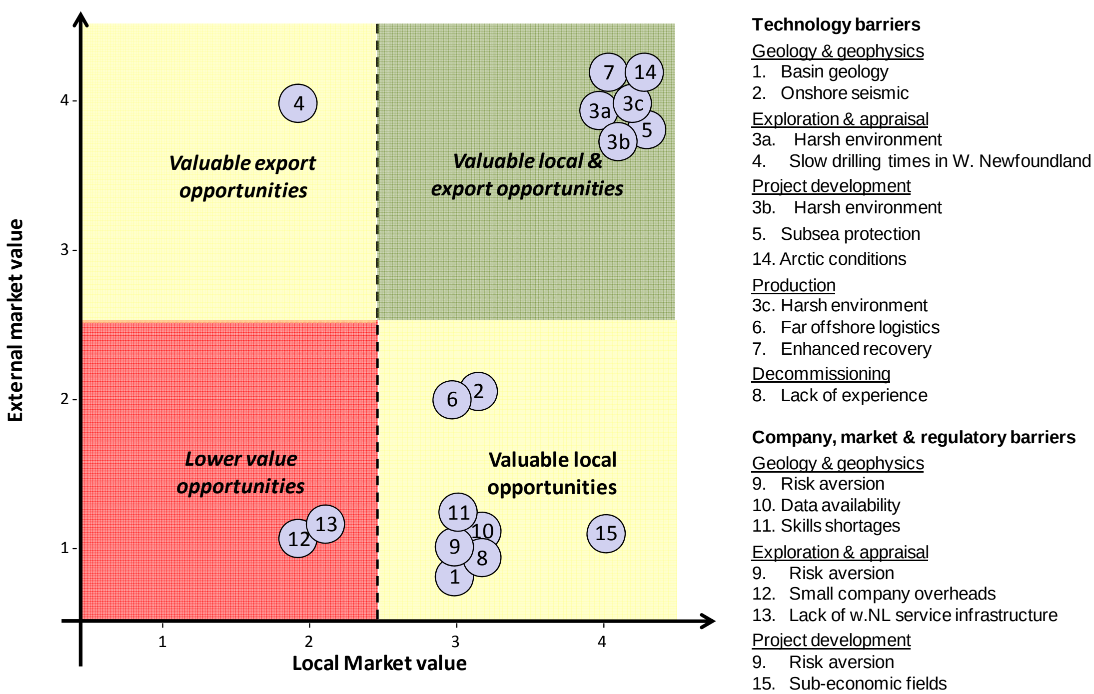


Figure 58: Upstream oil & gas - theoretical value of overcoming barriers (summary)

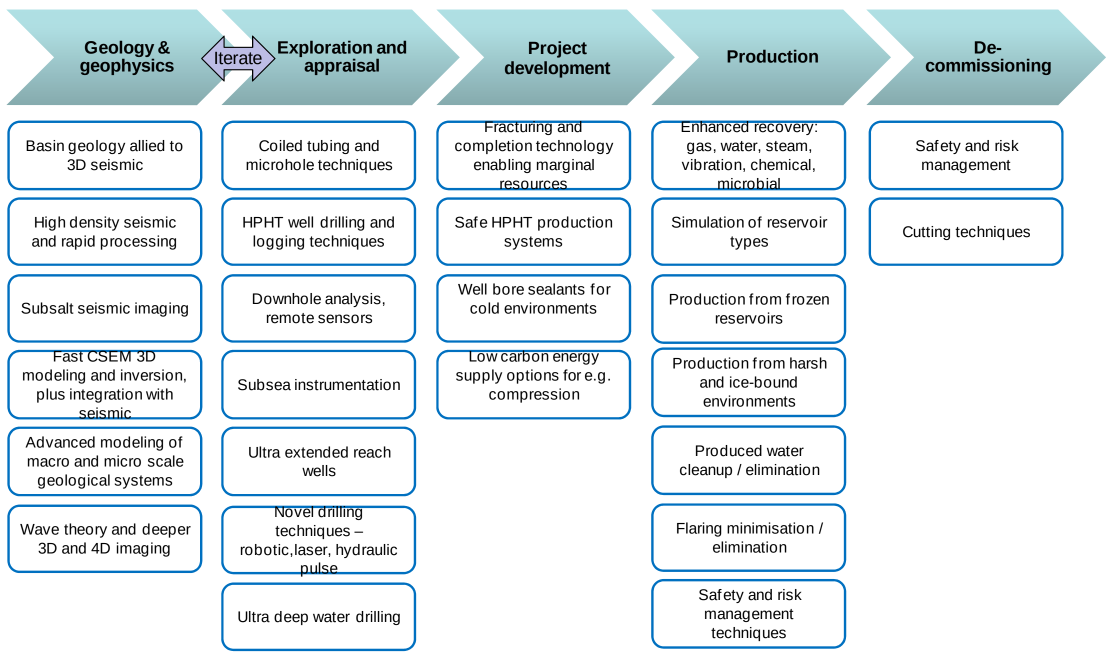
The following observations can be made with regard to the valuation of opportunities:

- Local market value is high for most opportunities, since the barriers which are not relevant for NL have already been screened out. Three which relate to western Newfoundland (#4, 12, and 13) were felt to have modest local value in relative terms, given the enormous scale of known opportunities elsewhere in the province. However, slow drilling times (#4) is a problem throughout the industry and a technology for faster drilling would greatly improve economics, not just in NL;
- Eight opportunities relate to barriers for which a solution would be valuable locally, but is unlikely to be exportable. Of these, the highest local value would be derived from

overcoming barriers to exploration and development of currently sub-economic fields, such as gas resources (#15); and

- Six barriers represent potentially valuable local and external market opportunities. The harsh conditions represent a major opportunity to innovate in exploration, development and production, (#3a, 3b, and 3c) and also offer valuable opportunities for improved subsea protection techniques (#5). Arctic conditions (#14) impose more unique challenges and needs, but overcoming them would unlock major markets. Enhanced recovery (#7) is also a huge opportunity for the whole industry and any findings in NL would be beneficial for similar reservoirs worldwide.

Each of the barriers where the value in the external and/or local market value is high, was considered further. Current innovation activities of leading innovators were assessed to determine whether there is a valuable innovation gap that NL might be able to address. These are presented in Figure 10 and Figure 11, respectively.



Source: US DOE database, NL industry meetings, E4tech analysis

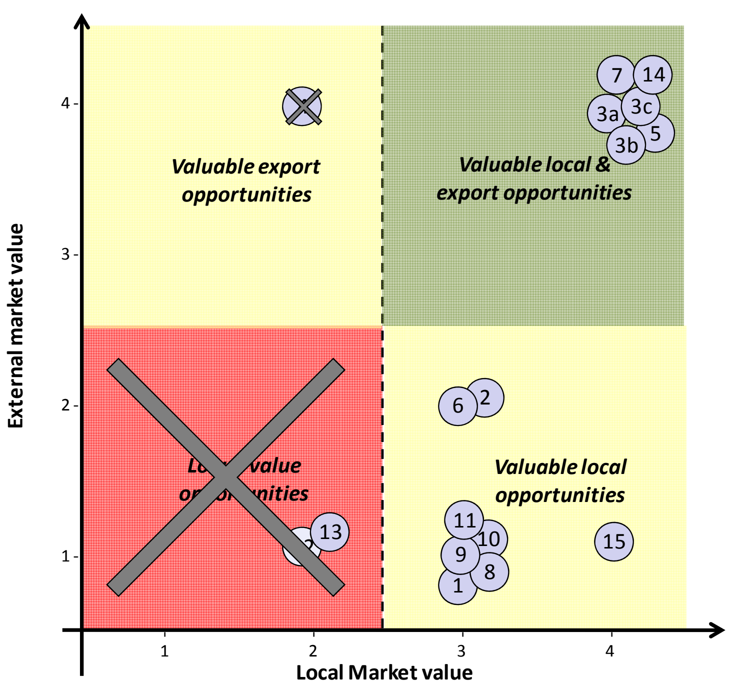
Figure 59: Upstream oil & gas - main innovation currently occurring worldwide

This information, derived in part from US Department of Energy R&D databases, indicates the extent of research occurring across the value chain. However, the extent of the challenges is such that there is scope for additional innovation efforts in many areas, as discussed in the following table, which considers the remaining innovation gaps relative to NL barriers.

Type	Value chain	Barrier	Innovation to address the barrier	
			Innovation currently occurring	Remaining gaps
	Geology & geophysics	1. Basin geology	Major research topic worldwide	Requires additional seismic and G&G, focused on NL, though not significant innovation
		2. Onshore seismic	Not aware of lightweight seismic equipment innovation	Lightweight equipment/ vehicles needed
	Exploration & appraisal	3a. Harsh environment	Companies operating in Alberta, Alaska, Norway, Russia developing aspects of Arctic O&G	Many aspects unsolved e.g. unmanned drilling, safe evacuation
		4. Slow drilling times in W. Newfoundland	Improvements in conventional techniques, novel techniques in research	Limited for NL
	Project development	3b. Harsh environment	Companies operating in Alberta, Alaska, Norway, Russia developing aspects of Arctic O&G	Many aspects unsolved e.g. subsea processing, long distance tiebacks, anchor handling
		5. Subsea protection	Various experience worldwide, but no 'perfect solution'	Need to demonstrate cost effective solution
		14. Arctic conditions	Companies operating in Norway and Russia developing aspects of subsea Arctic O&G	Many aspects unsolved for application in Labrador
	Production	3c. Harsh environment	Companies operating in Alberta, Alaska, Norway, Russia developing aspects of Arctic O&G	Many aspects unsolved e.g. metocean data monitoring and interpretation
		6. Far offshore logistics	Growing experience, but each solution needs to be customised	May be better solution(s) for offshore NL
		7. Enhanced recovery	Major innovation topic worldwide	Need more specific understanding of NL reservoirs
	Geology & geophysics	9. Risk aversion	PRAC have compiled industry directory	De-risk use of local resources for oil companies
		10. Data availability	None yet	Improve data availability in electronic format
		11. Skills shortage	Discussion of Reservoir Engineering course at MUN	Limited if course goes ahead.
	Project development	15. Sub-economic fields	Nalcor evaluating electricity export options	Requires large scale wide-ranging techno-economic analysis of export routes, taking into consideration all export options.

Figure 60: Upstream oil & gas - worldwide innovation gaps

Combining these findings with the earlier analysis of innovation value leads to the following summary of valuable innovation opportunities for NL (Figure 60). Hypotheses for how NL may be able to capture this value were also generated as an input to the next section of the analysis and are detailed in Figure 12 below.



Technology barriers

Geology & geophysics
1. Basin geology
2. Onshore seismic

Exploration & appraisal
3a. Harsh environment
~~4. Slow drilling times in W. Newfoundland~~

Project development
3b. Harsh environment
5. Subsea protection
14. Arctic conditions

Production
3c. Harsh environment
6. Far offshore logistics
7. Enhanced recovery

Decommissioning
8. Lack of experience

Company, market & regulatory barriers

Geology & geophysics
9. Risk aversion
10. Data availability
11. Skills shortages

Exploration & appraisal
9. Risk aversion
~~12. Small company overheads~~
~~13. Lack of w.NL service infrastructure~~

Project development
9. Risk aversion
15. Sub-economic fields

Figure 61: Upstream oil & gas - potentially valuable innovation opportunities for NL

	Value chain	Barrier	Barrier detail	Potentially valuable innovation opportunity for NL*
Technology	Geology & geophysics	1. Basin geology	Relatively uncharacterised basin geology across province	Conduct more subsurface characterisation at whole basin and sub-basin level in order to improve appeal of NL for exploration
		2. Onshore seismic	Hard to access onshore areas. Need lighter equipment	Develop lighter seismic equipment and soft tyre vehicles that can access sensitive areas when ground is not frozen
	Exploration, Project development, Production,	3a-c. Harsh environment	Wave, wind and ice hazards in exploration	Develop technologies and techniques that can be applied in increasingly harsh environments including frozen waters. Covering exploration, project development and production phases (including gas export innovations such as LNG loading)
			Wave, wind and ice hazards in project development	
			Wave, wind and ice hazards in production phase	
	Project development	5. Subsea protection	Trenching and glory hole costs high due to NL conditions	Develop and demonstrate cost effective subsea pipeline and facility protection solutions that can reduce future project costs
		14. Arctic conditions	New techniques required for extended subsea tie-backs, ice protection, processing and export	(See also 3b, 5, 15) – Focus innovation program featuring the techniques that will unlock known and potential Labrador gas and also other Arctic gas
	Production	6. Far offshore logistics	Distance imposes cost and safety penalty	Research and model logistics solution(s) for offshore NL. Consider supporting shared facility for whole industry
		7. Enhanced recovery	Need cost effective techniques to increase yields	Intensify research into reservoir structures prevalent in NL. Model and then trial techniques for enhanced recovery
	Decomm-issioning	8. Lack of experience	No decommissioning experience for larger NL type structures	Predict decommissioning needs of NL structures and identify where similar abilities will be required internationally, understand technical requirements

	Value chain	Barrier	Barrier detail	Potentially valuable innovation opportunity for NL*
Company, market, regulation	Geology & geophysics, Exploration, Project development	9. Risk aversion	Operators reluctant to apply new technologies until fully proven	Demonstration of technologies in relation to the innovations identified here to build awareness and overcome resistance
	Geology & geophysics	10. Data availability	NL regulations curtail access to seismic data and new entrants	Make seismic data available in electronic format to enable research
		11. Skills shortage	Lack of local trained reservoir engineering specialists	Ensure reservoir engineering courses are launched and that future needs are predicted and met over time
	Project development	15. Sub-economic fields	Marginal / stranded resources unattractive without infrastructure	Large scale wide-ranging techno-economic analysis of export routes needed, taking into consideration all oil, gas and electricity options (including marine CNG). May require NL government to play catalysing role in funding and development of infrastructure

Figure 62: Upstream oil & gas - hypotheses of valuable innovation (to be tested)

The output of this section of the evaluation is a set of potentially valuable innovation opportunities that NL could pursue, assuming that it has the resources to be competitive in doing so. The opportunities are, therefore, presented as hypotheses at this stage including an element of what the opportunity is and how it might be approached. Both aspects are needed to inform the subsequent stages of the evaluation which will assess NL competitiveness.

The following observations can be made on the hypotheses that remain at the end of this stage of evaluation:

- #1, 9, 10, and 11 and to some extent #15 are opportunities whose resolution requires mostly nontechnical innovation. NL may be able to pull the correct levers to enable these barriers to be overcome. #15 may require the co-ordinated evaluation of options to address the 'market failure' aspect of individual companies not being prepared to invest without a shared solution;
- #3, 5, 6, and 14 could build upon NL's solid track record in dealing successfully with the extreme climatic and geographic conditions over many years. This would unlock NL resources in currently hard-to-reach locations, as well as providing solutions of use in equivalent areas worldwide;
- Enhanced recovery (#7) would make a large difference in several field developments; and

- Decommissioning (#8) is a longer term need, but there is limited understanding of gravity-based structure decommissioning worldwide and none at the scale of Hibernia.

5.3 NL innovator competitiveness

5.3.1 Leading innovators worldwide and their research priorities

There are three principal types of players involved in upstream oil and gas innovation globally:

- Oil and Gas companies;
- Geology and geophysics service providers, equipment suppliers and operators, construction and engineering firms; and
- Universities and Institutes.

Selected examples of each of these, relevant to NL, are profiled below.

Oil and gas companies

The research capabilities and focus of some of the oil majors, and national/independent companies involved in northern exploration are outlined below.

ExxonMobil[45] is world's largest non-government producer of oil and gas with particular experience in Arctic exploration and production. The company has projects in Alaska, The Northwest Territories (Canada), Offshore Eastern Canada (including NL) and Norwegian Barents Sea. Its first ice-resistant offshore platform was erected in 1966 (Granite Point, Alaska). In 1973, ExxonMobil built the world's largest ice-test basin in Calgary to study interactions between ice and offshore structures, and pioneered the use of gravel islands for exploration drilling activities. A list of technological innovations associated with arctic environments is given in the report 'Arctic Leadership'[46], with those most relevant to identified innovation opportunity areas for NL shaded in yellow.

	Technological innovation in arctic environments
1	Remote Reservoir Resistivity Mapping (R3M)
2	Enhanced Oil Recovery (EOR)
3	Advanced reservoir simulation
4	Ice load simulation
5	Strain-based reliability framework for pipeline design in demanding environments (including ice gouging)
6	Fast drill process (FDP)

Figure 63: Exxon Mobil technological innovations in arctic environments

Research into Arctic conditions has also focused on iceberg hazards and the company has been responsible for the production of the iceberg database developed by **Memorial University of Newfoundland**, the Canadian Hydraulics Center and **C-CORE**; and the Ice Data Acquisition Program (IDAP) in conjunction with the Norwegian Polar Institute and the Russian Arctic and Antarctic

[45]5 http://www.exxonmobil.com/corporate/

[46] Arctic Leadership, ExxonMobil, May 2008

Research Institute. ExxonMobil also participated in the 1995 Grappling Island iceberg impact test program to measure iceberg impact loads and the **offshore Newfoundland and Labrador impact field program** (2001).

ExxonMobil has been extensively involved in the development of the **Hibernia field** (the first offshore development project in an iceberg environment) and **Terra Nova fields** (the first harsh-environment development in North America to use an FPSO vessel along with subsea production and injection).

Exxon invested approximately $3.5 billion in research between 2003 and 2008 (Can$3.6 billion) and supports more than 15,000 scientists and engineers. Current (2008) areas of Arctic technology research and development by ExxonMobil are given in Figure 64 below, with those most relevant to identified innovation opportunity areas for NL shaded in yellow.

	Focus for arctic technology research
1	Seismic acquisition in ice environments
2	Year-round offshore production in heavy ice conditions, including multi-year ice in deepwater Arctic environments
3	Long-distance tiebacks and flow assurance
4	Remote detection of spilled oil under ice
7	Crafts for safer offshore platform evacuation in ice conditions
8	Year-round and extended-season drilling
9	Remote sensing of ice, permafrost and icebergs
10	Subsea processing, including gas compression and power transmission
11	High-strength steel for gas-transmission pipelines from remote locations

Figure 64: Exxon Mobil's current focus for arctic technology research

Chevron Corporation (Chevron) [47] is one of the world's largest integrated energy companies. It is engaged across all industry activities including exploration and production, refining and transportation, chemicals manufacturing, and power generation. It is headquartered in California with operations in 180 countries across the globe.

At the company's 2008 Annual Meeting of Stockholders, Chevron Chairman and CEO Dave O'Reilly highlighted technology among several key elements contributing to Chevron's continued success. Technology centres (operated by the Chevron Energy Technology Company) are located in California and Texas, and more recently in Perth, Australia and Aberdeen, Scotland. Chevron Centres of Research Excellence have been established in collaboration with a number of institutions, including University of Tulsa; University of Southern California; MIT (ultra-deepwater research program); University of Texas (EOR); Russian Academy of Sciences; and Western Australian Energy Research Alliance.

In Canada, Chevron has ownership interests in oil sands projects at Athabasca and Ells River in the province of Alberta, exploration and development projects offshore in the Atlantic region (including NL), and exploration and discovered resource interests in the Mackenzie Delta and Beaufort Sea region of Canada's western Arctic.

[47] http://www.chevron.com/

Chevron is a participant in Australia's North West Shelf Venture, which ships LNG to customers in Japan, South Korea and China and is currently pursuing two major LNG supply projects in Africa. The company also has a strong focus deepwater drilling. Innovation described in the 2008 'Next Magazine'[48] includes the following relevant areas:

	Innovation focus
1	Thermal, chemical and miscible gas EOR
2	Deep-sea drilling using a chemical (methyl methacrylate-MMA) developed through collaboration with the US Los Alamos National Laboratory to prevent deep-sea damage to drilling equipment
3	Metocean research including ocean current forecasting

Figure 65: Chevron innovation focus

ConocoPhillips[49]**,** which has just completed drilling in offshore NL, is the third-largest integrated energy company and the second-largest refiner in the United States. Headquartered in Houston, ConocoPhillips operates in more than 30 countries. In 2008, the company had 33,800 employees worldwide, assets of $143 billion (Can$145 billion) and had doubled its annual technology spend to $500 million (Can$508 million).

Innovation and technology development is divided into five principal areas: upstream; downstream; emerging technologies; LNG; and chemicals technologies. Upstream innovation includes:

	Innovation focus
1	Finding new resources (including land-based Arctic rigs)
2	Asset integrity and sustainability (including microbially influenced corrosion)
3	Challenged resources (focused on oil sands)
4	Existing assets (including wellbore strengthening and fractured reservoir modeling)

Figure 66: ConocoPhillips upstream innovation focus

However, there is currently little technology development that overlaps significantly with NL aspirations.

In Canada, **BP**'s activities focus on the production of natural gas and derivatives. In relation to arctic exploration, the company has acquired three offshore exploration licences in the Canadian Beaufort Sea[50] and the Pokak 3D seismic program was conducted in the Canadian Beaufort Sea during the summer 2009.

BP conducts a number of university research programmes in collaboration with a range of institutes. Relevant University science programmes include:

	University Science Programme
1	Understanding the flow of gas, liquids and solids (BP Institute of Multi-phase Flow at the UK's University of Cambridge): multiple applications including improving production
2	Gaining a better understanding of the ocean's environment and hazards (Scripps Institution of Oceanography, US):

[48] Next Magazine, 2008

[49] http://www.conocophillips.com/EN/Pages/index.aspx

[50] http://www.bp.com/modularhome.do?categoryId=7070&contentId=7052829

	improved assessment of marine geo-hazards but with a focus on Gulf of Mexico
3	Establishing centres of excellence in enhanced oil recovery at Gubkin and in Arctic and cold region technology in St Petersburg (through collaboration with Saint Petersburg State Polytechnical University and the Arctic and Antarctic Research Institute). Developing Arctic technology is described as an area of 'strategic importance' for BP: at the Arctic and Antarctic Research Institute, BP sponsored a theoretical course for the training of ice experts

Figure 67: BP University Science Programmes

Statoil is an international integrated energy company with operations in 40 countries[51], including in NL. Large scale upstream innovation programmes are taking place in the following areas:

- Finding more oil and gas (e.g., seismic imaging; seabed logging);
- Optimizing reservoir recovery (e.g., recovery methods; advanced drilling; smart wells); and
- Field development (subsea; topside; flow assurance).

The company has particular experience in production from subsea wells and subsea technology is of strategic importance to the company. Technology development is being carried out in four areas:

	Areas of technology development
1	Compact and environment-friendly solutions
2	Solutions which improve recovery from the reservoirs
3	Technology which permits long tie-backs to land
4	Equipment for ultra deep water

Figure 68: Statoil's areas of technology development

Long tie-back to land is being demonstrated by the Snøhvit project in the Barents sea, 160 km from land. Improved oil recovery projects include increased subsea handling of liquids; reduced subsea wellhead pressure; and integrated operations. The company is preparing to carry out subsea gas compression on the Åsgard field in the Norwegian Sea from 2013. Subsea processing (Tordis field) demonstrated an increase in oil recovery by using a subsea separation station in which water and sand are separated from the well stream close to the reservoir and injected into a subsea formation for storage, whilst oil and gas are pumped along a 10km pipeline to an offshore processing platform.

Development of the Ormen Lange field was undertaken in partnership with a number of major oil and gas companies (Statoil, Shell, Petoro, Dong Energy, and ExxonMobil). The field is situated 120km off the Norwegian coast (Barents Sea), at a sea depth of 800-1,100m. There is no offshore platform and seabed installations are combined with an onshore plant for processing. The installations must withstand the exceptional currents that are characteristic of this part of the Norwegian Sea, as well as sub-zero temperatures on the sea bed, and extreme wind and wave conditions.

Husky Energy[52] is a Canadian-based integrated energy and energy-related company which operates primarily in the western provinces and off the East Coast of Canada (NL). The company is the operator and majority shareholder in the White Rose oil field and satellite expansions, and has ownership interests in the Terra Nova field. White Rose uses a floating production, storage and offloading (FPSO) vessel, which controls a range of subsea equipment (manifold valves and

[51] http://www.statoil.com/en/Pages/default.aspx

[52] http://www.huskyenergy.ca/

wellheads). Major pieces of subsea equipment are placed in **glory holes** and a mobile semi-submersible drilling unit is used for development wells.

Its exploration of this area is set to continue with 17 exploration licences (35-100% interest) and interests in 22 Significant Discovery Licences (SDLs) in the Jeanne d'Arc Basin, Flemish Pass, Central Ridge, Sydney Basin and offshore Labrador. The company is also looking to use the expertise gained offshore NL to explore the similar geology off the west coast of Disko Island, Greenland

Upstream operations include the exploration, development and production of crude oil, bitumen and natural gas. Husky's strategy off Canada's east coast is to 'maximize the value of the White Rose assets; develop satellite oil pools to extend the life of White Rose; evaluate development alternatives for natural gas; and explore for oil and natural gas.' In 2003, Husky established the Husky Energy Chair in Oil and Gas Research at Memorial University, Newfoundland with a $2 million endowment.

Their sustainable development report (2009) lists innovative drilling and production techniques and enhanced oil recovery as primary areas of innovation.

G&G service providers, equipment suppliers and operators, construction and engineering firms

A wide range of companies serving the upstream oil and gas sector are conducting innovation into all aspects of exploration and production. Two key examples are outlined below.

Schlumberger is a major G&G service provider, employing over 77,000 people in approximately 80 countries. The company has 25 R&D facilities around the world, including Schlumberger Cambridge Research (Cambridge, UK) and Schlumberger-Doll Research (Cambridge, Massachusetts) both of which are centres of excellence for oilfield research. There is also a research centre in Moscow which focuses on gas condensates, carbonates, heavy oil, arctic frost, and permafrost. In 2008, the company invested $818 million in R&D.

Technip[53] is a multi-national company providing engineering, technologies and project management for the oil and gas industry. The headquarters is in Paris, but additional operating centres are located globally, including UK, Norway and US. The company operates in subsea, offshore and onshore markets.

Subsea activities include:

- Subsea field development. Transportation and control systems: design, manufacturing, installation and commissioning of pipeline systems; and
- Development of **innovative products** through R&D (e.g., deepwater flexible and rigid pipelines, risers and umbilicals);
- Integrated Production Bundle (IPB) which allows high-level flow assurance of hydrocarbon fluids in difficult conditions).

The focus is on deep water issues.

[53] http://www.technip.com/english/index.html

Offshore activities include:

- Offshore field development including design, fabrication, installation and commissioning of offshore platforms; and
- Development of **proprietary products** through R&D (e.g., fixed platforms for shallow waters; floating platforms for deep waters; and floatover technology).

A recent contract awarded by Eni Norge AS, involves development of the Goliat field, the first Norwegian oil producing field north of the Arctic Circle in the Barents Sea.[54] Technip operates its own fleet of specialized vessels for pipeline installation and subsea construction.

Universities and institutes

There are a great many universities that are recognized for their research into oil and gas related topics. Some of the best known are listed below, together with examples of their research activities within O&G.

Location	Institution	Examples of research areas relating to O&G
Alberta, Canada	The University of Calgary	Pipeline Engineering Centre: multi-phase flow; improvements in safety and environmental control; integrity management; efficiency in fluid and gas pipeline flow; new coatings synthesis
New Mexico, US	New Mexico Institute Mining & Technology	Petroleum Recovery Research Centre, e.g. gas flooding processes and flow heterogeneities; reservoir sweep improvement and reduction of saltwater production during oil and gas recovery operations.
Massachussetts, US	MIT Energy Centre	Reducing environmental impact of production and distribution through improved efficiency; developing resources in hostile environments such as ultra-deepwater depths of 5,000 feet or more; EOR
Texas, US	Texas A&M University	Crisman Institute for Petroleum Research (within department of Petroleum Engineering) including: Chevron Centre for Well Construction and Production; Halliburton Centre for Unconventional Resources; Schlumberger Centre for Reservoir Description and Dynamics
Texas, US	Offshore Technology Research Center	Research carried out by members of Texas A&M University and The University of Texas at Austin. Incorporates an OTRC wave testing basin (simulating conditions facing deepwater structures)
Illinois, US	Gas Technology Institute	Gas hydrates; field drilling and completion; plastic pipe testing and services; pipeline integrity management.
Trondheim, Norway	Sintef/NTNU	Incorporates The Gas Technology Centre (with Statoilhydro as strategic partner); Petroleum Centre for Better Resource Utilization
Aberdeen, UK	Aberdeen University	Institute Energy Technologies incorporating the Oil and Gas Centre. Focus on petroleum geology, engineering and economics
Edinburgh, UK	Heriot-Watt University	The Energy Academy: gas hydrates; oil and gas reservoir discovery

Figure 69: Selected university research of relevance to upstream oil and gas

Specific research activities from these and other universities, which overlap with NL identified opportunities, are listed in Section 5.4.1 below

[54] http://www.technip.com/english/experience/e_offshorefield.html

Organisations and programmes fostering collaboration and co-operation

As seen in the onshore wind and transmission sectors, there are a number of national and international organisations, and large-scale programmes that promote collaboration between major oil companies; and between oil companies, service companies, SMEs and academia in the oil and gas sector. These bodies are also often responsible for setting/implementing long-term, strategic R&D priorities. Five examples are described in more detail below.

The Global Petroleum Research Institute

The US GPRI (headquartered at the Texas A&M University) was set up more than 10 years ago to direct essential research into the development of petroleum technology. It is the managing partner for collaborative research among major, international oil producing companies under the Petroleum E&P Research Cooperative Agreement. Current members are: Anadarko; BP; BHP Billiton; Chevron; ConocoPhillips; ExxonMobil; Marathon; Shell; Statoil; and Total.

The major areas of research are generic in nature and do not appear to overlap significantly with NL specific opportunities:

- Capital Cost Reduction, in particular relating to deepwater; drilling enhancements; and horizontal/multilateral drilling;
- Expense reduction, in particular relating to water management; multi-phase fluid handling (separation of water, sand and gas and reinjection en route to the surface); hydrates, paraffin and scale;
- Production rate, in particular relating to damage prevention (drilling and workover fluids); Horizontal/Multilateral Wells: Stimulation and Completions; and Advanced Completions Technology; and
- Reservoir evaluation in particular relating to imaging fluids (4D seismic and beyond); reservoir characterization (to define the physics of the coupled fluid/rock system); and well testing (to detect reservoir heterogeneity).

National Petroleum Council

The National Petroleum Council (NPC) is a US federally chartered and privately funded advisory committee. Membership is made up of integrated and independent oil and gas companies; oil transporters, refiners and marketers; service companies; large consumers and non-industry members.

The organization has recently produced a report 'Facing the Hard Truths about Energy', 2007 (updated 2008) which provides a framework for America's oil and natural gas position in the short and long term. Input to the final analysis was provided by a number of topic papers produced by a series of Task forces. Relevant examples are:

Deepwater Technology Report: Going Deep[55]

The Deepwater subgroup of the Technology Task Group (NPC Committee on Global Oil and Gas) produced a working paper highlighting the priority deepwater technology challenges. This formed

[55] Deep water technology report: going deep, Deepwater subgroup of the technology task group, Working Document of the NPC Global Oil and Gas Study. Made available July 2007.

part of the final NPC report 'Facing the Hard Truths about Energy', 2007. The four principal challenges identified were:

	Principal challenges
1	Reservoir characterization
2	Extended system architecture (subsea systems that improve recovery and extend the reach of remote resources)
3	High pressure and temperature completion systems
4	Metocean forecasting and systems analysis

Figure 70: Principal deepwater technology challenges

Participants in the taskforce included: Shell; Chevron; ExxonMobil; MIT; Texas A&M University; Schlumberger; Transocean and the US Minerals Management Service.

Conventional oil and gas[56]

This report looked at the state of conventional oil and gas wells (including enhanced oil recovery and arctic technology), and made predictions on how technology advances could impact these businesses in the future.

The following seven technologies were identified as having significant impact on enhanced recovery:

	Technology
1	An increase in controlled reservoir contact; horizontal, multilateral and fishbone wells; arthroscopic well construction
2	Drilling efficiency
3	Increased automation within knowledge management; analysis; simulation and uncertainty management; prognosis; decision analysis; and execution (action)
4	Improving SWEEP efficiency
5	Artificial lift and downhole refinery
6	CO2 flood mobility control
7	Reservoir characterization and simulation

Figure 71: Technology advances that could have the most significant impact on enhanced oil & gas recovery

The following 12 technologies were identified as having a significant impact on arctic operations:

	Technologies
1	**Arctic subsea to beach technology (overcoming problems with ice scouring)**
2	Higher definition 3D seismic
3	Increase amount of drilling accomplished in narrow weather window (earlier access, later departure)
4	Digital processing revolution, modeling capacity
5	Electric submersible pump (ESP) evolution, extended run lives
6	High gas volume-fraction multiphase pumping

[56] Conventional oil and gas, Conventional wells subgroup of the technology task group, Working Document of the NPC Global Oil and Gas Study. Made available July 2007.

7	High-pressure gas transmission in arctic conditions
8	**Improved underwater slow leak detection (oil)**
9	**Increased communications capacity allowing remote drilling, construction, and operation**
10	**Longer distance multiphase flow with reliable modeling including hydrates and freezing**
11	**Lower cost of subsea pipeline construction and protection in ice-scour areas**
12	New high-strength steels with welding systems, including sour service

Figure 72: Technology advances that could have the most significant impact on arctic operations

Participants in the taskforce included: Shell; ExxonMobil; MIT; Texas A&M University; The University of Texas; Schlumberger; Ryder Scott Company; Rice University and US DOE.

Industry Technology Facilitator (ITF)

The Industry Technology Facilitator (ITF)[57] is a not-for-profit organization, owned by 22 major international operators and service companies, which aims to identify technology needs, foster innovation and facilitate the development and implementation of new technologies. The organization has successfully facilitated the launch of more than 150 joint industry projects (with a value > £45m) addressing issues such as seismic resolution, complex reservoirs, cost effective drilling and intervention, subsea engineering, maximizing production, integrity management and environmental performance.

The organisation sets regular 'Technology Challenges' which begin with a workshop and result in a call for proposals (funded by the members). The six challenges for 2010 are:

- EOR: mapping and development of additives/technology;
- Tight and shale gas, and coal bed methane;
- Drilling efficiency;
- Completions technology;
- Produced fluids management; and
- HPHT (production).

Two challenges in 2009 focused on subsea technologies:

- **Subsea Long Tiebacks**: including Multiphase Fluid Flow and Flow Assurance (especially hydrate management); Subsea Processing; Subsea Electrical Power Supply and Distribution; Control, Communication and Instrumentation; Lower Cost Pipelines; and Information Management ; and
- **Subsea Intervention**: including subsea power; AUVs; cost effective light well intervention; downhole diagnostic tools; HPHT technology; and better artificial lift.

Another challenge looked at technology development for arctic conditions:

- **Arctic Challenge**: (including The Harshness of the Arctic Climate; The Impact of Ice; The Sensitivity of the Environment; and The Remoteness of the Location).

Decommissioning was the subject of a call in 2008:

[57] http://www.oil-itf.com/

- **Decommissioning**: (including mapping hazardous materials; well plug and abandonment; hydrocarbon free (cleaning contaminated tanks); facilities and pipeline cleaning; removal; legacy and monitoring).

PETROMAKS

Norway has demonstrated particular success in transforming their petroleum sector into a highly competitive national industry, breaking away from an initial dependence on foreign companies.[58] PETROMAKS (2004-2013)[59] is the umbrella for most of the petroleum-oriented research supported by the Research Council of Norway, and is considered to be a good example of a national large-scale programme which successfully delivers the innovation and skills needed to support an area of high strategic importance to the Norwegian Government.

The programme's vision is 'To contribute to value creation in society by optimizing the recovery of petroleum resources, through promoting increased industrial development, the development of knowledge and strengthened international competitiveness.'

This central mandate is based on the direction and challenges laid out in the National Technology Strategy for the Petroleum Industry, developed by the OG21 (Oil & Gas in the 21st Century) Task Force in 2002. The task force[60] united oil companies, universities, research institutes, the supply industry and the authorities and argued strongly for an increase in public spending on R&D in the petroleum sector.

PETROMAKS focuses on basic and applied research, technological development, and in fostering an active industrial cluster that is needed to maintain the petroleum sector at a sustainable level. Although the portfolio of projects is oriented towards industrial development (with focus on innovation, new research-based business start-up, productivity, cost reductions and export), there is also the understanding that basic research is crucial to resolving the existing technological challenges. In particular, the programme aims to intervene where technical problems have become a bottle neck for technological solutions. This often involves basic research in other subject areas such as mathematics, materials technology, geophysics and IT.

The programme also includes activities that support forging alliances, creating networks, and facilitating different types of cooperation around the world. Projects organized as syndicates are particularly encouraged (i.e., collaborations between knowledge communities, large businesses and SMEs).

The annual budget for PETROMAKS is approximately CAN$44.5 million. Approximate key operating figures for PETROMAKS in 2008 include:[61]

- 160 running projects; with a total value of Can$370 million;
- 60 projects with international participation;
- 250 PhD and post-doctoral students financed, with candidates applying from more than 27 countries.

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[58] European Commission, 2008, Erawatch research inventory report for Norway, http://cordis.europa.eu/erawatch

[59] http://www.forskningsradet.no

[60] http://www.og21.org/

[61] RCN, How OG21 could make a difference within PETROMAKS? No date

The programme has a number of areas of research of relevance to NL which are listed in Section 5.4.1 below.

Centre for offshore oil and gas environmental research

COOGER[62] was established by Fisheries and Oceans Canada in order to coordinate the department's nation-wide research into the environmental and oceanographic impacts of offshore petroleum exploration, production and transportation. The secretariat is based in Nova Scotia, but research is carried out in 18 participating universities all over the country. Projects focus on effect of activities and accidents on marine organisms and ecosystems. The Newfoundland Offshore Petroleum Board (CNOPB); Memorial University; BP Canada; ExxonMobil; Hibernia Management Development Corp; Petro-Canada; Shell; Chevron; and CAPP are all participants (amongst many others).

The centre also fosters international collaboration as part of its mandate.

Conclusions

Figure 73 below provides an overview of the key players involved in upstream oil and gas innovation, together with the level of resources deployed.

Oil and Gas Companies	• **Small number of international 'oil majors' that make significant investment in in-house and third party innovation.** For example, ExxonMobil spent US$3.5 billion on research between 2003 and 2008 and supports more than 15,000 scientists and engineers; ConocoPhillips doubled its annual research and technology spending to US$500 million in 2008. • **National oil companies**, many holding large reserves such as Saudi Aramco and Kuwait Petroleum Company, that have historically relied on third party innovation but which are **investing increasing sums in in-house innovation**. • **Large number of 'independents'** that are typically more **reliant on innovation by third party suppliers and institutes.**
G&G Service Companies etc.	• **Large number of companies** serving the upstream oil and gas sector conducting innovation into all aspects of exploration and production. These **range from small, single product / service entities to large specialist firms** such as Schlumberger, which has 25 R&D facilities around the world and spent $818 million on R&D in 2008.
Universities and Institutes	• **Numerous dedicated research institutes,** such as the Global Petroleum Research Institute in Texas. • **Numerous universities with specialist** upstream oil and gas related **departments,** such as the Norwegian University of Science and Technology.

Figure 73: Key players involved in innovation in upstream oil and gas

There are also a number of significant large scale collaborative organizations and/or programmes involving co-operation between O&G companies, service companies, SMEs and academia.

5.3.2 Oil and Gas innovation capabilities within NL

All the key players involved in upstream oil and gas innovation are present in NL, although there is a current bias towards university establishments for ongoing innovation, as summarized in Figure 74 below. In particular, NL has globally competitive infrastructure and resources for addressing innovation related to arctic and harsh ocean conditions (see Figure 75 below).

[62] http://www.dfo-mpo.gc.ca/science/coe-cde/cooger-crepge/index-eng.htm

Oil and Gas Companies	• **Multiple local and international oil & gas companies with an interest in NL** incl. Chevron Canada, CIVC, ConocoPhilips, Deer Lake Oil and Gas, ExxonMobil, Husky Energy, Investcan Energy, Murphy Oil, Nalcor, NWest, PDI Production, Statoil, Suncor, Vulcan Minerals. • **Currently no dedicated oil and gas company research facilities within the province.**
G&G Service Companies, Equipment Suppliers and Contractors, and Engineering and Construction Companies	• **Large international service companies have a presence in NL**, including Halliburton, Schlumberger but **none currently have dedicated research facilities within the province.** • **Numerous smaller local companies have specialised niche innovation activities**, including Marport (sonar), Pangeo (acoustic imaging), Rutter (marine electronics), VMT (lifeboat training simulators, Oceanic Consulting (ocean engineering) and others.
Universities and Institutes	• **There are a number of university establishments and and institutes in NL, with significant infrastructure and resources dedicated to research and innovation that are of relevance to the upstream oil and gas sector**, particularly off-shore. These include: NRC's IOT; MUN OERC; C-CORE; Marine Institute; and Centre for Marine CNG.

Figure 74: Key upstream oil and gas players in NL

Institution	Resources	Ongoing Innovation
MUN OERC	• Numerous specialist staff • Facilities incl. 58 m long tow tank; process safety and risk engineering lab; cold room and AUV lab.	• Research programs cover topics such as structures for operation in ice, underwater vehicles, marine safety and fluid-structure interaction.
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.
• Other existing institutions of relevance include **MUN Ocean Sciences Centre, Maritime Studies Research Centre, Bonne Bay Marine Station, MUN Applied Seismology,** and **3-D Visualisation Centre.** • **Proposed institutions of relevance include ABS Harsh Environment Technolocy Centre.**		

Figure 75: NL ocean technologies innovation infrastructure

NL has a number of options for future engagement in innovation in the upstream oil and gas sector. These sensibly build on existing strengths, particularly as they relate to ocean technologies and associated institutes.

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 Figure 20 below.

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. Potential collaborators may well include a number of the organisations identified in Sections 5.3.1 above and 5.4.1 below.

	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

Figure 76: Options for NL engagement in upstream 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)

5.4 Innovation priorities

5.4.1 Current international research in relation to specific opportunities identified for NL

There are ongoing international projects in all of the innovation areas identified as offering potential opportunity for NL. Selected examples are given in Figure 77 below.

Some of these opportunity areas reflect barriers that are generic to all oil and gas applications and will be fully addressed by ongoing international innovation. Others include aspects that are specific to deployment in NL. While ongoing international innovation will be relevant to these barriers, it is likely that further innovation will be needed specific to deployment in NL. An example includes addressing the challenges associated with far offshore logistics. A summary overview for each of the innovation areas is given in Figure 78, leading to the recommended prioritization for NL in Figure 23.

Innovation Opportunity	Company/Institution	Example Projects
2. Onshore Seismic	ConocoPhillips	Finding new resources (including land-based arctic rigs) are cited in upstream innovation projects. The area is reachable only during winter freezing, because the land is too soft during the thawed months. No specific target of looking for novel equipment, but the challenge is likely to be similar.
3 a-c. Harsh environment	Shell	FLNG technologies (floating liquefied natural gas); innovation relating to deep water recovery; Sakhalin II project.
	Statoil	Development of Ormen Lange field; subsea processing; overall strong focus on technology innovation for application on

Innovation Opportunity	Company/Institution	Example Projects
		Norwegian Continental Shelf
	BP	Improved assessment of marine geo-hazards
	Schlumberger Technip	Self-healing cement IPB improving flow assurance; floating offshore platforms
	NTNU/SINTEF	Offshore fields without platforms.
	Advanced Energy Centre (AERTC)	Safety of operations under extreme climate conditions
	CRISMAN Institute	Modeling and Characterization of Drilling Fluid Used in Ultra Deepwater; liquid loading in Gas Wells; Investigation of Swirl Flows Applied to the Oil and Gas Industry.
	Offshore Technology Research Centre (OTRC)	Loads due to extreme wave crests; ocean turbulence loads and effects on offshore structures; loads on tie-down systems for drilling rigs; application of high-performance composite materials to offshore structures.
	Advanced Energy Centre (AERTC)	Safety of operations under extreme climate conditions
	Gas Technology Institute	Gas hydrates; improved field drilling and completion (e.g. the potential for use of fiber optics as a method for transmitting data at higher speeds from the drillbit to the surface). Plastic pipe testing; pipeline integrity management
5. Subsea protection	Shell, USA and Netherlands	Sakhalin II project (pipelines buried under sea bed).
	Participants in NPC Conventional Oil and Gas report	Arctic subsea to beach technology (overcoming problems with ice scouring); and lower cost of subsea pipeline construction and protection in ice-scour areas identified as having a significant impact on arctic operations. *However these are part of a report identifying needs rather than actual research*
	Husky, Canada	Experience with glory holes at White Rose oil field
	PETROMAKS programme	*No specific mention of glory holes but*; development of solutions to problems resulting from ice and the icing of installations, vessels and equipment during field development and operation; development of new systems for subsea installation, inspection and maintenance of equipment and pipelines.
	OTRC	CFD modeling of Ice ridge/seafloor/pipeline interaction during ice gouging
	NTNU-SINTEF	Strong focus on subsea technology and arctic technology. However, Glory holes only mentioned specifically in a single report from 2000 (SINTEF).
14. Arctic Conditions	ExxonMobil	Previously: novel platform concepts (e.g. suction-pile structures with minimal offshore facilities) and arctic mobile drilling unit concepts; IDAP Ice-test basin in Calgary. Current research into seismic acquisition in ice environments; year-round offshore production in heavy ice conditions, including multi-year ice in deepwater Arctic environments; crafts 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 (relating to arctic conditions) Long-distance tiebacks and flow assurance; remote detection of

Innovation Opportunity	Company/Institution	Example Projects
		spilled oil under ice; high-strength steel for gas-transmission pipelines from remote locations
	Statoil	Development of Ormen Lange field; subsea processing; overall strong focus on technology innovation for application on Norwegian Continental Shelf. Strategic focus on subsea technology development including long tieback. Experience in arctic waters.
	PETROMAKS programme	Enhanced knowledge about risk and risk management; development of leakage detection systems; innovative drilling processes for arctic waters; Development of solutions to problems resulting from ice and the icing of installations, vessels and equipment during field development and operation; Development of new systems for subsea installation, inspection and maintenance of equipment and pipelines. This includes wirelessly-controlled autonomous underwater vehicles (AUV); LNG technology for offshore facilities
	ITF	Subsea Long Tiebacks Arctic Challenge (including the impact of ice)
	Advanced Energy Centre (AERTC)	Safety of operations under extreme climate conditions
	NTNU/SINTEF	Cold Flow Technology (avoiding gas hydrates without need for heating pipelines); Offshore fields without platforms. Strong focus on subsea technology and arctic technology.
	RICE University Heriot Watt Uni	Gas hydrates
	Participants in NPC Conventional Oil and Gas report	Electric submersible pump (ESP) evolution identified as having a significant impact on Arctic operations. Arctic subsea to beach technology (overcoming problems with ice scouring); and lower cost of subsea pipeline construction and protection in ice-scour areas identified as having a significant impact on arctic operations. Improved leak detection; Increased communications capacity allowing remote drilling, construction, and operation; Longer distance multiphase flow with reliable modeling including hydrates and freezing identified as having a significant impact on arctic operations. *Note that these are contained within a report identifying needs rather than actual research*
6. Far offshore logistics	Shell	Smart fields technology
	ExxonMobil	High-strength steel for gas-transmission pipelines from remote locations
	BP	Monitor, predict and manage corrosion to increase operating efficiency
	Schlumberger	Flow assurance
	ITF	Arctic Challenge (including the remoteness of the location)
	Gas Technology Institute	Pipeline integrity management
7. Enhanced recovery	Shell, USA and Netherlands	Variety of technologies
	Chevron	Thermal, chemical and miscible gas EOR

Innovation Opportunity	Company/Institution	Example Projects
	ConocoPhillips	Fractured reservoir modeling
	BP	Established centre of excellence in Enhanced Oil Recovery at Gubkin: various technologies
	Statoil	Various technologies
	Cenovus Energy	SAGD (steam-assisted gravity drainage) using electrical submersible pumps and solvent aided process; CO2 enhanced oil recovery; water flood technology using polymer;
	PETROMAKS progamme	Increased recovery from existing fields
	GPRI	Reduction in capital costs relating to horizontal and multilateral drilling
	Canadian Energy Research Institute (CERI)	Potential expertise (e.g. 'CERI's Natural Gas Research Team consists of expert economists and industry professionals who understand the technical, operational, regulatory, financial and economic aspects of supply, transportation and demand in natural gas markets'). However, no specific projects listed (current focus on oil sands).
	ITF	EOR: mapping and development of additives/technology
	Numerous institutions: AERTC; MIT; CRISMAN Institute; University of Texas; Louisiana State Uni; RICE Uni;	Various technologies
8. Decommissioning	ITF	Decommissioning call. Completed project: 'Enhancement of Abrasive Water Jet Cutting Techniques for Well Decommissioning'.

Figure 77: Examples of ongoing research in identified upstream oil and gas innovation opportunity areas

2. Onshore Seismic	• Research into improved seismic technologies and data interpretation is being undertaken by numerous companies and institutions. However, we found **no specific mention of a focus on lighter equipment, other than for the Nalcor-funded MUN Swept Impact Seismic**.
3 a-c. Harsh Environment	• **Focus for research and innovation by numerous oil and gas companies, suppliers, and institutions,** in particular for those operating in far Northern or deep water locations. • Despite the involvement of many players, **it is a large area of research and significant opportunities are likely to remain.**
5. Subsea Protection	• **Subsea protection is a focus of a number of organisations working in arctic conditions** (incl. ExxonMobil. Shell, Statoil) **and specialist institutions** (NTNU-SINTEF, OTRC).
14. Arctic Conditions	• **Several major oil companies and institutions are covering research that impacts on operating in arctic conditions, subsea technology in particular.** A smaller but significant number have programmes targeted directly at the arctic environment.
6. Far Offshore Logistics	• **Limited research identified** that is aimed specifically at far offshore logistics. Peripheral research likely to have an impact (e.g. remote subsea processing). • **Specific barrier in NL.**
7. Enhanced Recovery	• Generic barrier, **under investigation by numerous oil & gas companies and institutions.** • **Specific barrier for application in NL.**
8. Decomm.	• **R&D being carried out by operators, major contractors, specialist suppliers and universities** in areas that include alternative removal methods; underwater cutting; drill cuttings removal; lifting, back-loading and sea-fastening methods.

Figure 78: Summary overview of ongoing international innovation in innovation opportunity areas

5.4.2 Prioritization for NL

As outlined in Section 2.4, innovation opportunities have been separated into the following three categories:

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;

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; and

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.

The categorisation of prioritized upstream oil and gas areas is given in Figure 79 below.

It is important to note that NL will need to have a plan to overcome all barriers to the exploitation of oil and gas resources within the Province. However, we anticipate that most barriers, including those in Category C below, will be overcome by the purchase of innovative solutions from international third parties.

NL will need to address Category B barriers as we anticipate that these will not be adequately addressed by international innovators.

Category A innovation areas appear to offer the opportunity for NL to acquire an internationally competitive position, built largely on existing knowhow and innovation capabilities. The manner in which all barriers are to be addressed, will need to be determined in the next phase of this Energy Innovation Roadmapping exercise.

A	**3 a-c. Harsh environment** **14. Arctic conditions** **5. Subsea protection**	• **Merits prioritization by NL based on local and international need, and existing globally competitive innovation infrastructure and resources.**
B	**2. Onshore seismic** **6. Far offshore logistics**	• **May merit prioritization by NL based on limited ongoing research and NL strategic need.**
C	**7. Enhanced recovery**	• **Unlikely to merit prioritization by NL**, given the significant ongoing activity by oil and gas companies, **equipment suppliers, service companies** and specialist institutions.
	8. Decommissioning	• **Unlikely to merit prioritization by NL**, given the ongoing activity by oil and gas companies, major contractors, specialist **suppliers and** institutions and long time to decommissioning in NL relative to other jurisdictions.

Figure 79: Categorization of prioritized upstream oil and gas innovation areas

6 Mid and downstream gas

6.1 Innovation barriers

Mid/downstream gas is defined as shown in the value chain in Figure 79. The value chain has several variants, though all are shown here in generic form. Typical actors are shown in Figure 80 below.

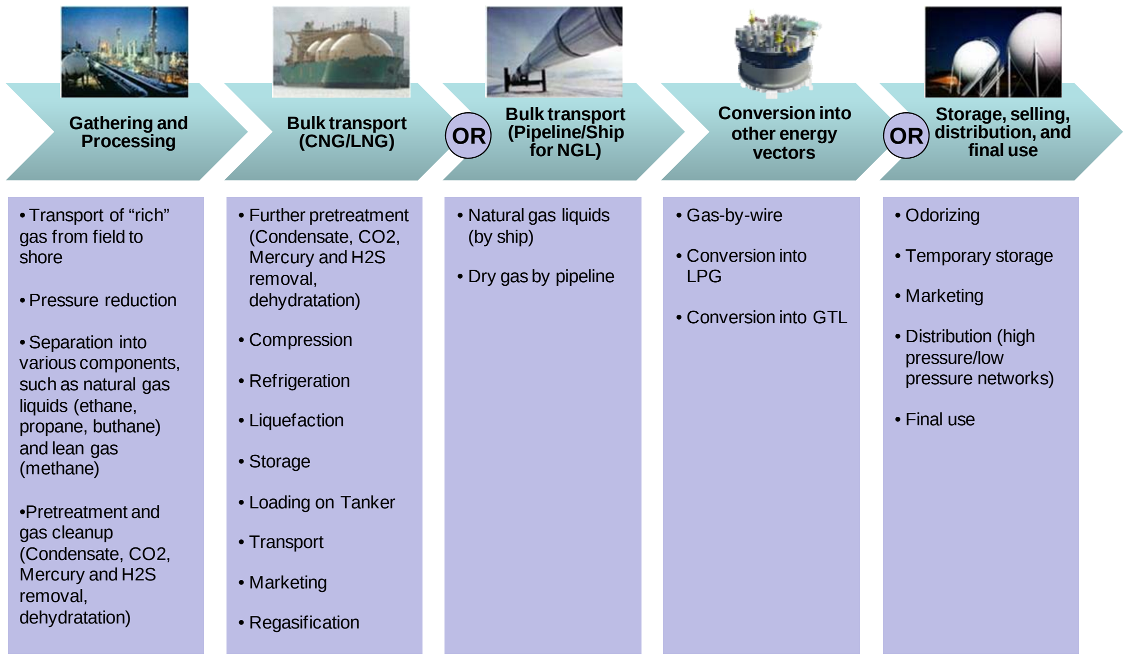


Figure 80: Mid/downstream gas - industry value chain

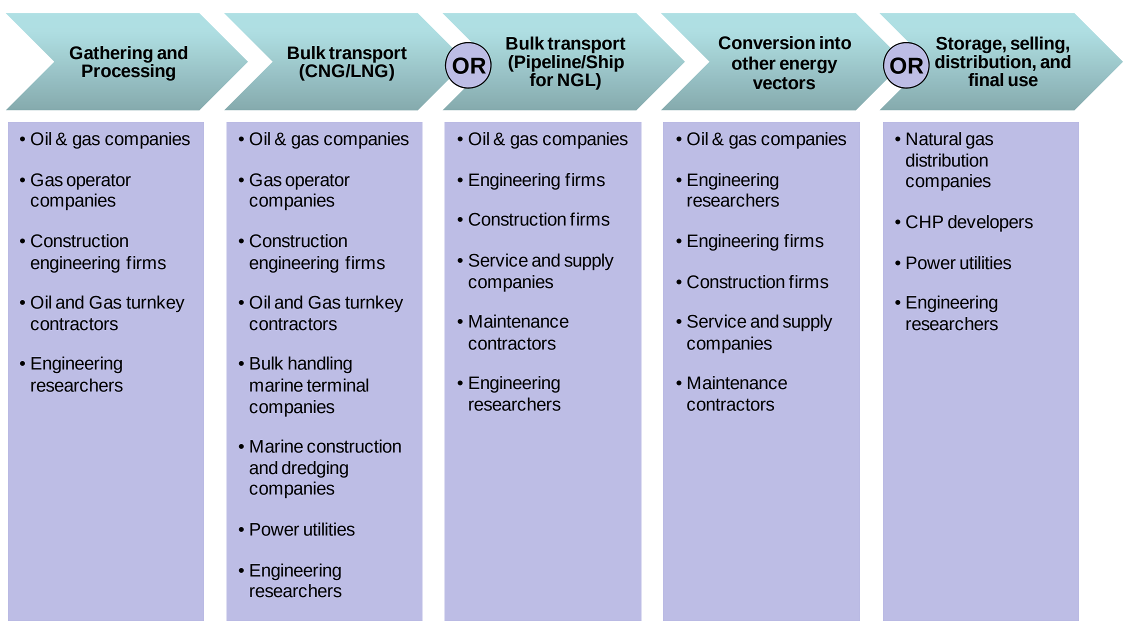


Figure 81: Mid/downstream gas - typical actors along the value chain

We have drawn upon our knowledge of the oil and gas sector and have also had numerous discussions with NL stakeholders in order to identify the following barriers to the development of gas in both Newfoundland and Labrador. In view of the enormous diversity of challenges in the international oil and gas industry, only barriers relevant to the local context have been captured.

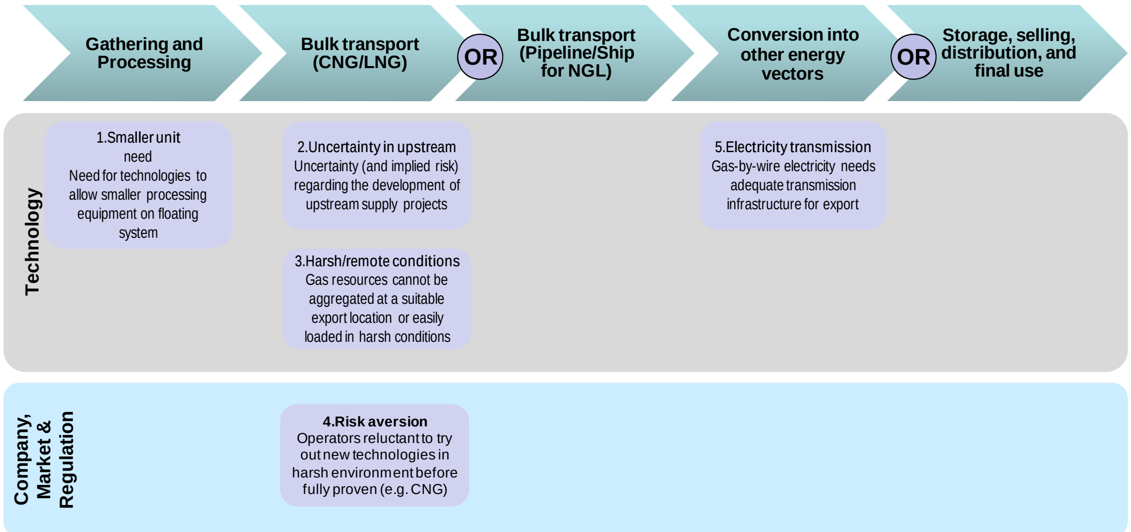


Figure 82: Mid/downstream gas - main barriers relevant to NL

Key local barriers are described in more detail below:

Barrier #	Additional information
1	Floating gas processing is a potential option for NL, but the weight of processing equipment needs to be reduced to make this effective
2	The uncertainty associated with development of smaller gas reserves in NL means that options requiring large scale (potentially from multiple fields), in particular LNG and pipelines, are hard to make cost effective (see upstream oil and gas #14 and 15). This uncertainty results from the remoteness of resources from land in many cases.
3	The harsh and remote conditions in which NL oil and gas must operate makes offshore loading particularly challenging. LNG loading is technically challenging in any case, whilst marine CNG is unproven at scale, making both of these options difficult in the NL context. This links to barrier #4 below.
4	Operators are reluctant to adopt unproven technologies, particularly in harsh settings such as NL. See barrier #3 above.
5	Gas to wire is a potentially attractive means to monetize NL gas resources. However, this is linked to uncertainty about onshore transmission options (see transmission barrier #6)

Note that barriers relating to the onshore distribution of gas are not relevant to NL, since there is no gas grid or applications in the province.

6.2 Evaluation of opportunities

When considering the barriers for mid/downstream gas it became clear that there were three main categories, each of which merited consideration in a different way:

1. Challenges caused by the harsh environment such as offshore LNG loading and seabed scouring by icebergs (#3 Harsh/remote conditions and #4 Risk aversion). In practice some of

these barriers sit at the interface between upstream and midstream, hence their repetition. These barriers are also dealt with in upstream barriers #3 'harsh environment' #5 'subsea protection' and #14 'Arctic conditions' so the evaluation of value, competitiveness and innovation prioritization is the same for midstream gas as for upstream gas (see previous section). Specific insights which relate to midstream gas rather than upstream oil and gas are as follows:

- Innovations relating to pipeline transport of gas from ice-prone waters will draw upon the same innovation strengths as apply to subsea protection of, for example, infield flowlines. This is a known strength for NL;
- Floating LNG is a potential game-changer for NL's far-offshore gas resources. However, innovation is required in LNG processing and loading in rough seas. This can draw upon the known strengths in marine engineering; and
- Innovation in marine CNG has been a strength, but recently this has taken a lower profile in NL. Given the sector's aversion to unproven technologies it would seem that this technology awaits proving in another part of the world before it can be deployed in the riskier environment of NL.

2. Barriers which relate to uncertainty about export options in NL (#2 Uncertainty in upstream and #5 Electricity transmission). These are dealt with in Upstream oil & gas barriers #15 Sub-economic fields, which also relates to #14 Arctic conditions for Labrador, and Transmission barrier #6 Commercial/market access. Again, the evaluation of value, competitiveness and innovation prioritization is the same for midstream gas as for upstream gas, hence the analysis is not repeated. Specific insights which relate to midstream gas are as follows:

   - Techno-economic modelling of electricity export options is crucial and should contemplate the export of electricity from gas to wire schemes in several locations. This modelling must enable decisions about the alternative sources, routes and destinations for NL electricity on a fully-integrated basis.

3. Innovation for smaller units on floating gas processing systems is required, but NL does not possess the necessary process engineering capabilities in this field and so this does not represent an opportunity for the province.

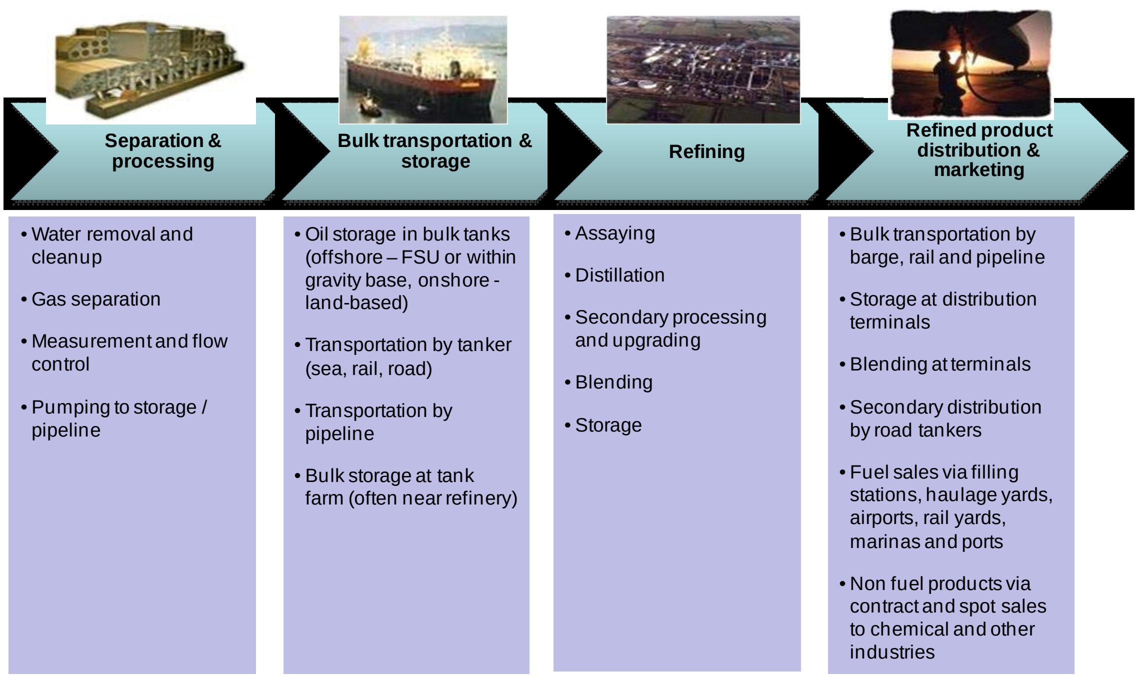
7 APPENDIX: Mid and downstream oil

This sector was discussed with stakeholders, but the view soon emerged that the overall opportunity is lower for several reasons:

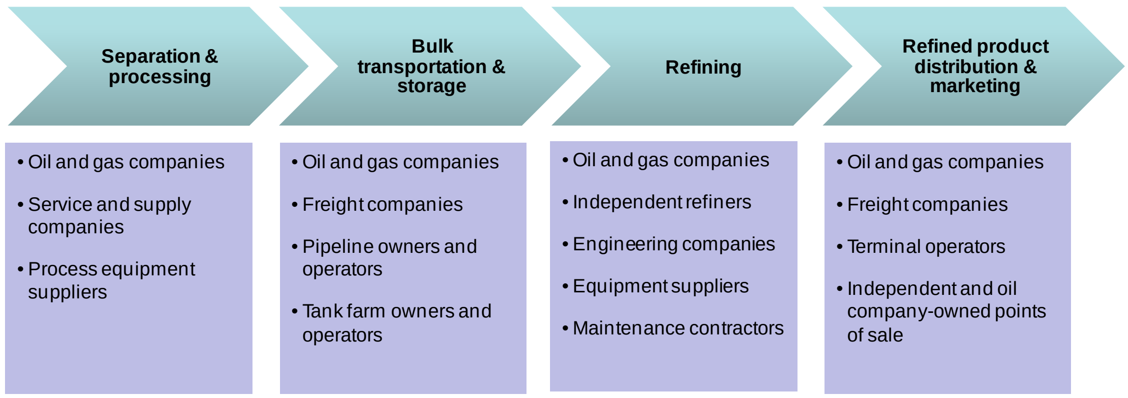
- The sector is largely mature technologically and so the innovation opportunities are in narrow areas;
- NL is not a major actor in the innovation for mid and downstream oil so export opportunities are likely to be very limited; and
- There are many players in this industry, meaning that solutions are largely available 'off the shelf'.

Where specific innovation needs/opportunities may arise due to NL's environment (for example, offshore loading of oil in rough seas), this overlaps with the opportunities identified in the upstream oil and gas section of this report.

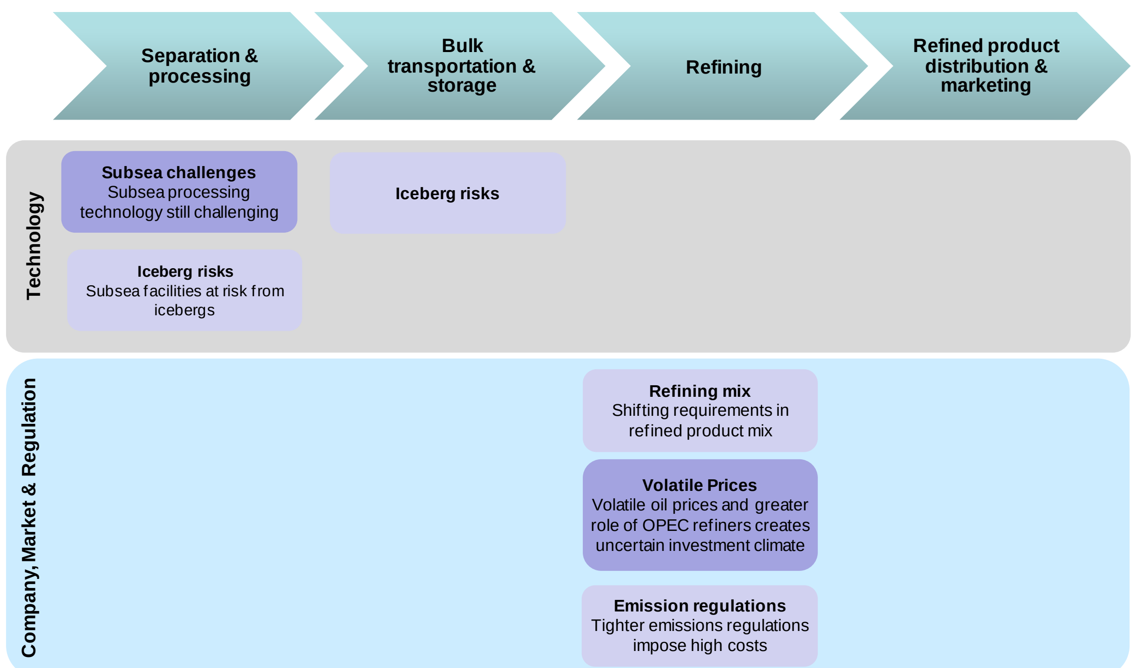
An introduction to mid/downstream oil and a summary of the main barriers are presented below.



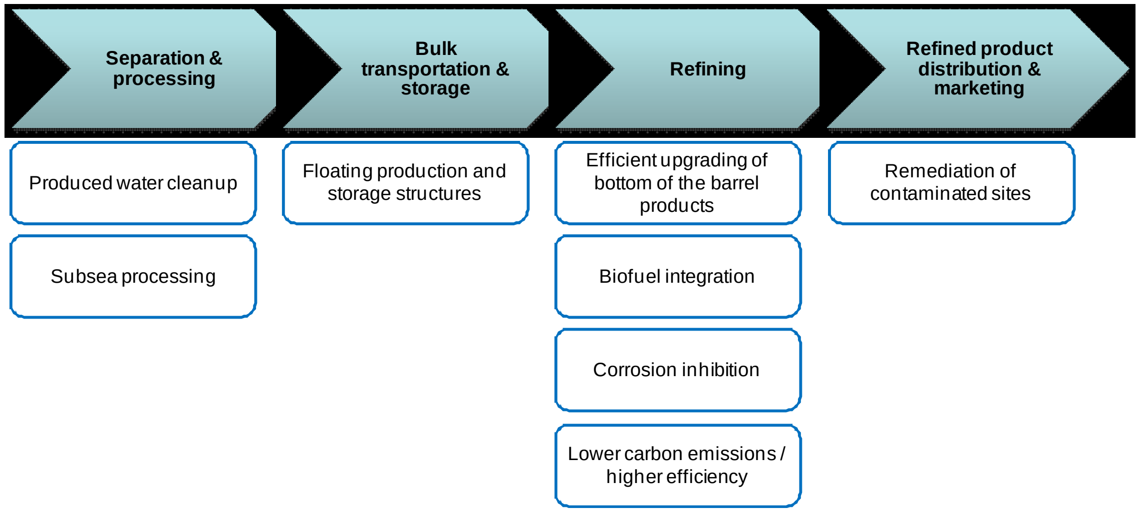
Mid/downstream oil - main barriers



Mid/downstream oil – main actors along the value chain



Mid/downstream oil – Main barriers



Mid/downstream oil – main areas of innovation worldwide