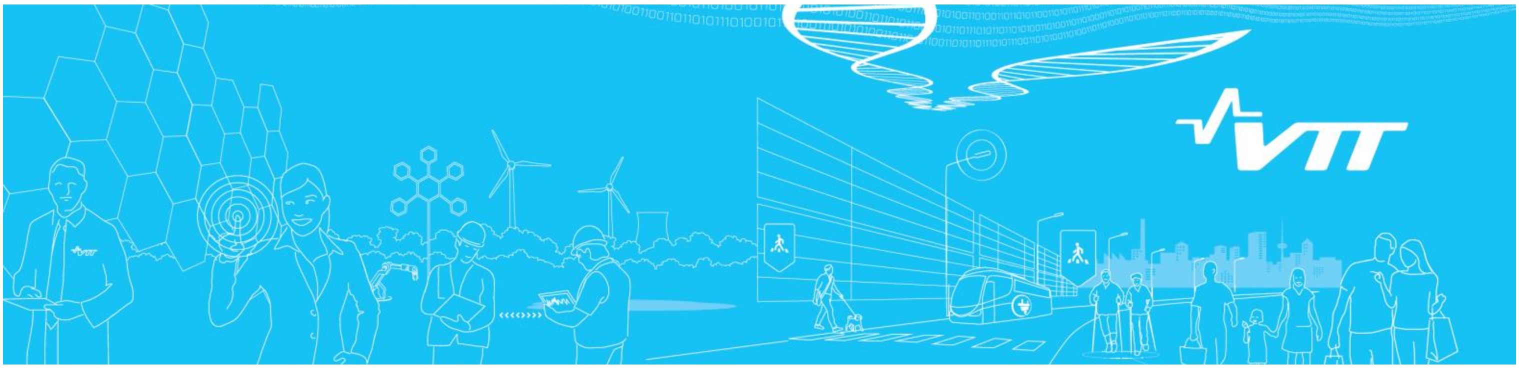


RESEARCH REPORT

VTT-R-05901-14

Roadmaps to Arctic Opportunities
Futures of Arctic competences and technologies in the Finnish context

Authors: Anna Leinonen, Toni Ahlqvist, Henna Sundqvist-Andberg, Arho Suominen, Jouko Myllyoja, Leena Grandell, Maria Tikanmäki, Kaisa Oksanen, Hannes Toivanen

Confidentiality: Public

Report's title	
Roadmaps to Arctic Opportunities, Futures of Arctic competences and technologies in the Finnish context	
Customer, contact person, address Innovaatiorahoituskeskus Tekes, Kimmo Kanto, PL 69, 00101 Helsinki	**Order reference** 1513/31/2012
Project name Arctic competence roadmap - Strategic openings for Finland	**Project number/Short name** 80035/ SMARCTIC
Author(s) Anna Leinonen, Toni Ahlqvist, Henna Sundqvist-Andberg, Arho Suominen, Jouko Myllyoja, Leena Grandell, Maria Tikanmäki, Kaisa Oksanen, Hannes Toivanen	**Pages** 91
Keywords Roadmap, Arctic technology, foresight process	**Report identification code** VTT-R-05901-14

Summary

Finland, as a country with significant parts located beyond the polar circle, has some intrinsic expertise on Arctic issues and technologies. In order to really benefit from the Arctic competencies calls for long term research activities and the development of competencies. This report is an outcome of an expert process (2013–2014), which aimed at identifying the key characteristic of Arctic technology competencies and formulation of strategic options in the form of roadmaps. The roadmapping process applied in this project consisted of three phases combining various methods: (1) scoping (brainstorming workshops, construction of thematic mindmaps), (2) generation (technology surveys, interviews, patent analysis, roadmapping workshops), and (3) outputs (reporting and presentation of results).
The first key result of the roadmapping process was the characterisation of Arctic competence as a three-layered structure consisting of (1) competences relating to Arctic conditions, (2) Applied technology competences needed in operations in the Arctic area, and (3) Cross-sectional technology competences covering critical enabling technologies that can be applied in different application areas. These three levels together formulate a comprehensive picture of Arctic technology. Furthermore, the key results of the roadmapping process are crystallised in four strategy paths for the Arctic regions. These are: (1) Spearhead strategy: Arctic marine technology and maritime transport – a focused strategy that emphasises traditional Finnish competences in shipbuilding and the maritime industry set in the Arctic context; (2) Flying geese approach: emerging Arctic pathways – a wider strategy that emphasises a selection of strong Arctic competences; (3) Culture of Arctic experimentation – a strategy based on experimental policies and technology approaches; and (4) Snowdrift strategy: fading Arctic business – the Arctic does not form a credible focus of activities and is forgotten or set as a subordinate perspective inside some other topic.
The report provides strategic recommendations linked with the options of Finnish innovation policies and competence development. On the national level, a clear definition of Arctic expertise is necessary in order to scope the strategy and make it possible to direct R&D funding to selected key competence areas. Also, new R&D funding instruments should be developed to promote experimental development models and to guarantee long-lasting funding for R&D. Arctic element can be understood as an additional component of technology development. Therefore, it is important to coordinate the R&D funding between different strategies and research programmes to be able to identify areas where shared objectives can be found. From the theoretical-methodological perspective, it is necessary to continue methodological development combining qualitative and quantitative methods in the analysis of emerging technologies and combination of roadmapping to other, more short-term and more business-oriented analyses.

Confidentiality	Public

Espoo 26.1.2015

Written by	Reviewed by	Accepted by
Anna Leinonen, Research Scientist	Jean-Peter Ylén, Head of Research Area	Heli Talja, Research team leader

VTT's contact address
P.O. Box 1000, FI-02044 VTT, Finland

Distribution (customer and VTT)

Tekes, VTT

Preface

In this project, we have created roadmaps for maintaining and further developing Finnish Arctic expertise. The attractiveness of the Arctic region internationally has increased significantly in recent years. Behind this interest are drivers of global change such as climate change, energy demand, oil/raw material prices, tourism, new bio-economic structures, global transport, urbanisation, world population growth and development of technologies. Finland, as a country with significant parts located beyond the polar circle, has some intrinsic expertise on Arctic issues and technologies. These include, for example, competences in dealing with cold climates, long distances, and rough and varied external environments. However, in order to really benefit from the Arctic competencies calls for long term research activities and the development of competencies.

This report is an outcome of a two-year long expert process (2013–2014). The aims of the project were to identify the key characteristic of Arctic technology competences and introduce new perspectives to the national strategy for the Arctic region. VTT has collaborated closely with the University of Oulu and the Oulu University of Applied Sciences. The project was partially financed by Tekes – the Finnish Funding Agency for Innovation.

At VTT several people participated in the project group at some stage of the process. A word of thanks to Toni Ahlqvist, Henna Sundqvist-Andberg, Maria Tikanmäki, Jouko Myllyoja, Arho Suominen, Leena Grandell, Kaisa Oksanen and Hannes Toivanen for the valuable contribution, and also to a wider group of researchers who participated in the project workshops. A special acknowledgement is addressed to Senior Scientist Kari Kolari for the cover photo of this report. We would also like to acknowledge the contribution and collaboration with colleagues from the partnering organisations, especially Pekka Tervonen, Erkki Alasaarela, Eva Pongrácz, Veikko Seppänen, Petri Ahokangas, Timo Bräysy, Arja Rautio and Jari Juga from the University of Oulu; Jouko Isokangas from Oulu University of Applied Sciences; Janne Antikainen, Satu Tolonen and Mari Yli-Koski from MDI Public; and Yrjö Myllylä and Jari Kaivo-Oja from Finland's Futures Research Centre, University of Turku.

We want to thank the project's Advisory group: Kari Laine (Chairman, University of Oulu /Thule Institute), Harri Leppänen (Rautaruukki Oyj), Marjaana Luttinen (Stora Enso Oyj), Irene Isohanni (Oulu University of Applied Sciences), Johanna Kirkinen (SITRA), Jussi Manninen / Heli Talja (VTT), Martti Hahl (Barentskeskus Finland Oy), Ari Alatossava (Micropolis Oy). We also thank project's responsible officer at Tekes, Kimmo Kanto, and contact person at Oulu office, Ritva Heikkinen, for their support to the project.

Finally, we would like to thank everyone, who is not mentioned here by name, but who participated in the project's workshops or surveys, or otherwise gave one's views and valuable input to project's roadmapping process. The outcomes of the process can be read in this report, and we wish that they will have a meaningful role in the direction of Arctic competences in the Finnish research community and companies.

Espoo, 12 January 2015

Anna Leinonen

Contents

1. Introduction

The Arctic region has been attracting increasing attention in recent years. From the economic viewpoint, the Arctic region is commonly perceived as a resource reserve, which will become increasingly utilised due to global warming and the melting of sea ice and continental glaciers. The Arctic region has been commonly viewed through the lens of transportation, in which the region enables different routes to connect, for example, Europe and Asia. The melting of the sea ice also enables the logistic use of the Northeast and Northwest passages for maritime transport for longer periods. However, the complexities of the Arctic region are not captured by mere economic reasoning, rather there are also significant societal, ecological and political aspects at stake. The Arctic environment is especially vulnerable, and thus every operation should be weighed against a systematic futures perspective, balancing risks and opportunities.

The Arctic region is strongly affected by the changes in the global economic land-scape. This is visible, for example, through the impacts of climate change, e.g. withdrawing ice sheets, melting of glaciers, migration of pollutants to the Arctic that were originally produced somewhere else. It is also visible in the widely shared strategic perspective that the Arctic region is among the key sites of future industrial activities. There are also emerging geopolitical tensions that have specific relevance for the Arctic sphere. Among these issues are e.g. territorial disputes concerning the ocean floor under the Arctic ice sheet and the struggles of influence, touching upon territorial claims and rights to use transport routes, between the states that aspire to be the key future Arctic actors. These tendencies have brought the Arctic to the fore when envisioning future economic growth and competition. This structure of expectations has, on the one hand, created new international tensions regarding the Arctic region, but, on the other, it has also catalysed a surge of Arctic investments.

Technologies have significant roles in the changes in the Arctic region, as they enable the exploitation of the Arctic reserves, but also facilitate the adaptation of the Arctic communities. Technological development and related operations in the Arctic region require special attention in integrating societal, ecological, political and economic perspectives. In the project, we aim at developing a future-oriented and multi-disciplinary research approach to study the emerging technologies, and related transformation processes and domains in the context of the Arctic region, taking into account the environment and the living conditions of human communities.

Finland, as a country with significant parts located beyond the polar circle, has some intrinsic expertise on Arctic issues and technologies. These include, for example, competencies in dealing with cold climates, long distances, and rough and varied external environments. Thus, Finnish actors already have some tacit competencies that could be useful in Arctic operations. However, in order to really benefit from the Arctic competencies calls for long term research activities and the development of competencies.

This report is an outcome of an expert process that has lasted for nearly two years (2013–2014). The aims of the project have been to identify the key characteristic of Arctic competencies and how these can be defined and identified. Thus, the key meta-question of the report is the following: what is the “Arctic aspect” in the context of competence development and emerging technologies? The more practical problematic in the report is to contemplate what Arctic competencies mean in the context of different technological domains. In order to illuminate this problem, we have prepared several interrelated roadmaps on several technological domains. When combined, these roadmaps support the channelling of the Finnish innovation policies in the Arctic context. Our specific aim was to formulate strategic options – in the form of policy paths – that combine the roadmaps with the construction innovation policies.

The original aims of the project were the following:

- To analyse what Arctic competence means in the context of different technological domains
- To identify those fields of Finnish technology development that could benefit from the Arctic frame
- To construct roadmaps – that identify e.g. key solutions and applications, enabling technologies, and drivers – in those technology fields that are assessed as most potential in VTT's expert process
- To provide strategic recommendations linked with the options of Finnish innovation policies and competence development.

During the project's expert process, however, it became increasingly clear that, in order to answer these questions, we need to find a suitable balance between the two critical perspectives in the study: the technology domain-specific perspective and the necessary strategic perspective. In other words, we realised that to define the "Arctic aspect" in the context of different technologies was no simple or self-evident task. Quite the contrary: When analysing several technology domains, the "Arctic aspect" opened as a thematic that has more relevance on some analytical scales than on others. For example, an Arctic dimension in some technology might emerge through applying a technology in a specific Arctic domain or in the context of a specific Arctic application or service, but it is not "scripted" in the technology as such. This thematic can be demonstrated, for example, through biotechnology: the generic biotechnological solution could have significant Arctic dimensions when it is applied, for example, in the context extracting pharmaceuticals from Arctic berries. This line of reasoning applied to almost all technologies that we were able to consider – when studying the technologies in an in-depth technological level, the "Arctic aspect" is not a key feature. However, when adding a specific solutions and user context, then the Arctic dimension of the technologies can be understood. This means that the technology roadmaps in the report are not niche level in-depth analyses of the potential future options in the domain, but more strategic analyses of the technologies in the specific Arctic user context. Thus, this means that while our technology roadmaps are domain-specific, they do not contain everything that could be presented in the context of the particular domains. Instead, they contain the critical features that our expert process has assessed as important when positioning these technologies in the strategic Arctic user context.

The report at hand provides contributions in three directions. The first contribution is in (1) the theoretical-methodological direction. In order to analyse the complex thematic of "Arctic aspect" in the context of future competencies and emerging technological domain, it was necessary for us to tailor quite experimental methodological chains. There were two key challenges we needed to meet: the first was the question of the correct scale of analysis, and the second challenge considered the definition of the "Arctic" itself when set in the context of technology analysis. The question of the analytical scale was resolved, as is discussed in the previous paragraph, by approaching technologies not as in-depth development trajectories, but by positioning the technologies in suitable Arctic user contexts. Therefore, the question of the "Arctic aspect" in the context of emerging technologies was resolved by an exploratory mixed qualitative-quantitative methodology that combined qualitative mindmap techniques with quantitative scientometric analyses. From our perspective, the "Arctic aspect" in the context of emerging technologies is not to be understood as a function of one or two defining keywords, but it is actually an outcome of a network of functional conceptualisations across varied technological domains and with varied connections. By resolving these two challenges (analytical scale and the Arctic aspect), we were able to provide exploratory contributions that could prove useful in future-oriented technology analysis (FTA), realised especially in complex systemic settings, and for analysing the connections between "fuzzy" determinants (such as the notion of "Arctic") and the emerging technological domains. The second contribution of our report is towards (2) the direction of technological R&D development and investment organisations. Our report provides practical strategic knowledge for making strategic decisions on emerging technologies in the Arctic context, and for outlining more specific R&D choices in technological domains. The roadmaps in the report provide a basis for selecting some technological domains for deeper scrutiny, or, alternatively, the report can be used for identifying critical development steps on different temporal scales (short- term, medium-term, long-term) when making plans for entering the Arctic field. The third contribution is towards (3) the direction of national innovation policies. The report provides knowledge that complements the Finnish national Arctic strategy (2013). It also outlines a set of strategic policy pathways – with enabling technological domains – that can be used in opening new trajectories for Finnish national policies, or for developing the existing ones further.

The report is structured as follows. Section 2, after this introduction, sets the scene for the study by discussing Finland's Arctic vision, presented in 2014, the changing geopolitics in the Arctic setting, and the issues of the Arctic co-operation. Section 3 presents an outlook on foresight and the methodology. Section 4 discusses the Arctic competencies in different technological domains and through different methodologies. Section 5 presents an Arctic strategic roadmap that integrates the results of the projects in the wide strategic frame. Section 6 contemplates technology roadmaps that were realised in the context of key outcomes of strategic roadmaps. Section 7 provides a general reflective discussion and conclusions, and the final section 8 summarises key recommendations outlined on the basis of the results of the project.

2. Setting the Arctic scene

2.1 Finland's Arctic vision

Finland's location in the Nordic hemisphere has created expertise on Arctic operations and technologies. However, the Arctic competence is scattered in different technological and industrial areas. The utilization of Arctic potential requires persistent development of competences and support for high level Arctic research. The objective of the project was to create a roadmap, which can be used for supporting the formulation of Finnish industry and innovation policies in relation to Arctic competences. The roadmaps can be used in the formulation of strategy recommendations and strategy-related decision-making at the national, regional or firm level. The background to the roadmap work in the SMARCTIC project was Finland's Strategy for the Arctic Region, which was published in August 2013 (Prime Minister's Office, 2013). This document defines a vision for Finland as follows:

> *Vision: Finland is an active Arctic actor with the ability to reconcile the limitations imposed and business opportunities provided by the Arctic environment in a sustainable manner while drawing upon international cooperation.*

This vision entails an idea of Finland as an Arctic country that has shaped an Arctic identity based on nature, geography, history and experience. The strategy document also claims that Finland possesses the top-level expertise and know-how that is needed for understanding, adaptation and utilization of the change that is taking place in the Arctic. The strategy document also defines a policy that maintaining and developing a high standard of expertise and research are of primary importance, and that Finland wants to set an example as an Arctic expert both in research and in the responsible commercial exploitation of such expertise. An important aspect in the latter goal is to comply with the principles of sustainable development in Arctic operations. Another key objective, according to the strategy document, is to promote international cooperation and maintain stability in the Arctic region.

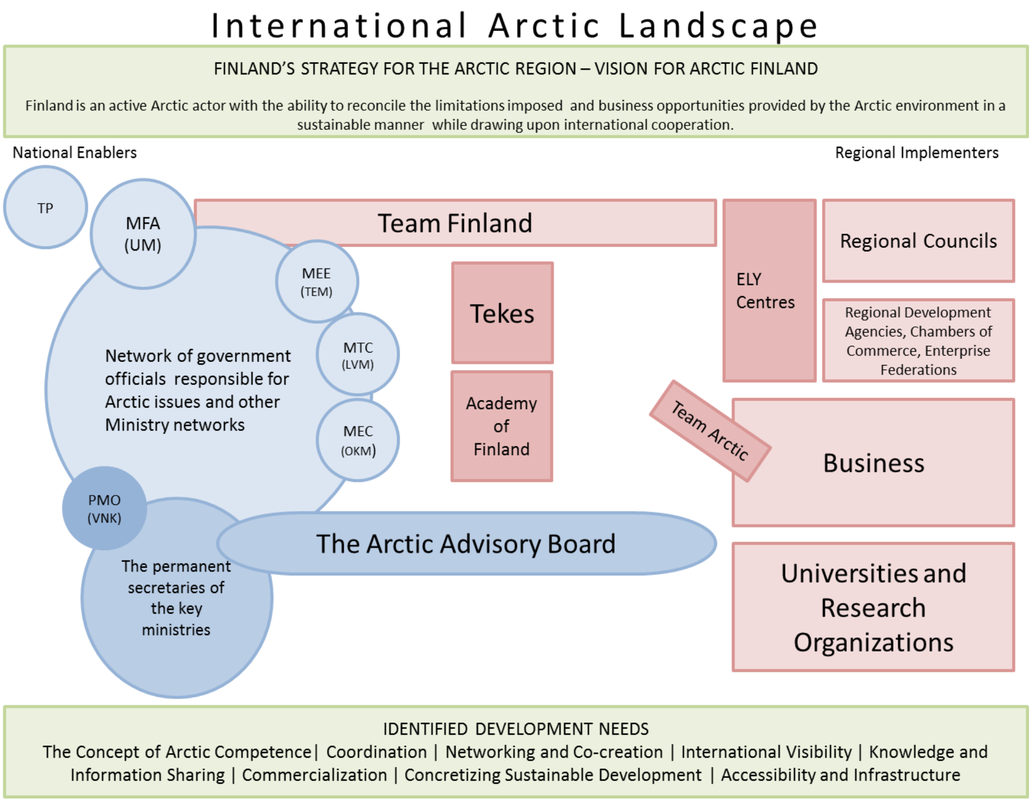


Figure 1. Arctic Innovation Policy in Finland and its Actors (Antikainen et.al. 2014).

As a part of this project, a consultant company, MDI Public, carried out an analysis of the Finnish policy process in the field of Arctic issues (Antikainen et.al. 2014). The analysis was based on interviews with 30 experts, on two surveys (1. regional actors and 2. enterprises in the field of Arctic competence and specialization), and on document analysis. In this analysis, several challenges for strategy implementation and four different paths for the implementation of the Arctic strategy were outlined. Figure 1 depicts the Arctic operational environment from the Finnish innovation policy perspective. Arctic stability (social, economic, environmental, cultural) is crucial for implementing strategies and innovation policy actions. In Finland, the Arctic operational environment is coordinated by the network of government officials responsible for Arctic issues, by the Arctic Advisory Board, and by the meetings of the permanent secretaries of the key ministries. Tekes and the Academy of Finland as research and innovation actors are also central in the landscape. Team Finland is a business-oriented initiative that unites Arctic enterprises and acts as a platform and forum for cooperation.

2.2 International cooperation and geopolitical interests

The international landscape sets the possibilities and boundaries for Finnish innovation policy and possible paths towards the concretization of Arctic competences. Table 1 presents the international bodies handling Arctic issues. Arctic cooperation has often emerged from specific needs such as dealing with the environmental impacts of oil drilling. The system as a whole appears to be fragmented and mostly uncoordinated. The Arctic Ocean and coastal areas are usually highlighted, and often land areas have been ignored. Finland and many indigenous peoples have often been excluded from the discussions among the Arctic coastal states (Canada, Norway, Denmark/Greenland, Russia and the US), but nowadays the interest in the land areas is increasing and the global influence of the Arctic Council has become stronger. (Antikainen et al. 2014).

Table 1 International cooperation on Arctic issues.

The Arctic Council (AC). The Arctic council consists of the eight Arctic States: Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and the United States. In addition, six international organisations representing Arctic Indigenous Peoples have permanent participant status. The AC is a high level intergovernmental forum to provide a means for promoting cooperation, coordination and interaction among the Arctic states and indigenous communities on common Arctic issues, in particular issues of sustainable development and environmental protection in the Arctic. The challenge of the AC is that their valuable research work does not reach the general public or gain sufficient attention.
Barents Euro-Arctic Council (BEAC). The BEAC is a forum for intergovernmental and interregional cooperation in the Barents Region. The BEAC provides impetus to existing cooperation and consider new initiatives and proposals The members of the BEAC are Denmark, Finland, Iceland, Norway, Russia, Sweden and the European Commission, and Finland holds the Chairmanship for the period 2013–2015.
European Union. The EU Arctic policy aims at protecting and preserving the Arctic, promoting a sustainable use of resources, and strengthening international cooperation. The EU supports research and channels knowledge to address environmental and climate change in the Arctic, and helps to ensure that economic development in the Arctic is based on sustainable use of resources.

Nordic cooperation. Nordic cooperation on Arctic issues is realized especially through **the Nordic Council of Ministers** that is the official inter-governmental body for co-operation in the Nordic Region.
Bilateral cooperation. Finland aims to create bilateral agreements on Arctic issues especially with Russia, Norway, Canada and the United States.
International research networks. International Arctic research and education networks are varied. Finland's Strategy for the Arctic Region emphasises the University of the Arctic (UArctic), which is a cooperative network of universities, colleges, research institutes and other organizations concerned with education and research in and about the North. UArctic is coordinated by the University of Lapland.

Through an analysis of wide range of studies and reports, Arbo et al (2013) wrap up the key geopolitical trajectories affecting the future of Arctic region. They are: (1) climate change; (2) new economic prospects; and (3) politics, and governance and security.

The question of *changing climate* is a widely studied phenomenon in the Arctic context (Arbo et al 2013: 166). The studies and reports treat this phenomenon in two ways. The first way is to collect the wisdom of latest scientific analyses, and build science-based estimations. The utilised scientific information can be e.g. measurements of ice thickness or, in the studies of logistic questions, measurements of sea temperature etc. The second way to treat the climate change is to use it as a backdrop for other purposes. This is the most common way to treat question of climate change in the Arctic context.

The question of *new economic prospects* is emphasised by majority of studies concentrating on the futures of the Arctic region. These studies usually cover three main aspects. The first one focuses on oil and gas. The question of oil and gas is covered in most of the Arctic publications, but as Arbo et al (2013: 167) assert, there are not many studies that actually forecast the reserves of oil and gas. The second aspect is Arctic mining. This refers to the underutilised potentials of Arctic mining. The third aspect is the future potential of Arctic shipping. This is widely covered aspect in the Arctic reports, and shows a clear structure of expectations.

The questions of *politics, governance and security* are also widely featured in the Arctic studies (Arbo et al. 2013). The main issues in this field are maritime issues, international relations and varied governance issues. As noted by Berkman and Young (2010), there are several governance layers in the Arctic region. The most important governance layer is the formal law of the sea, set by the United Nations Convention in 1982. The coastal states adhere to the different dimensions of the law of the sea that refers, for example, to exclusive economic zones, questions of the continental shelf and boundaries of ice-covered areas (on the complex geopolitical problematics of the law of the sea, see Dodds 2010a). The second layer of Arctic governance is informal by nature, and it is realised through the Arctic Council. The Arctic Council basically forms an arena for creating policy-oriented co-operation on the Arctic issues. An important facet in the geopolitics of the Arctic region deals with the variegated dynamics of the state boundaries, and the criss-crossing of the Arctic boundaries when viewed from different perspectives (on Arctic boundaries, see Strandsbjerg 2012).

Dodds (2010b) has made an apt summary of key tendencies that change the geopolitical role of the Arctic region. The first one is the impact of science and technology, which can be wrapped up as new knowledge about the region. Through this novel Arctic knowledge, the actors in the Arctic setting have been able, for example, to form new perspectives about the accessibility of Arctic routes and the potential locations of natural resources. The second tendency, combined with the novel scientific knowledge, is the realisation of the potentiality of the natural resources in the Arctic region. This realisation has initiated several debates and disputes in the field of international law, especially in the context of the rights of coastal states to deal with the questions of natural resources. These two tendencies, accessibility and potentiality, have led to the third tendency: the rise in the number of state and transnational actors making varied territorial claims in the Arctic region. Most of these claims are made in the name of territorial sovereignty.

3. Foresight process and methods

One definition of foresight is the following: Foresight is the process of developing a range of views of possible ways in which the future could develop, and understanding these sufficiently well to be able to decide what decisions can be taken today to create the best possible tomorrow (Horton 1999). The first important aspect of this definition is that foresight is always carried out in a process, which aims at the systematic production of future knowledge. Another important aspect is that the outcome of the process is a depiction of possible futures, not a definite prognosis or forecast of the future situation. The third important aspect to be highlighted is the purpose of foresight processes, i.e. the support for decision making. The following sub-sections present the foresight process carried out in this project, and methods which were used in the process.

3.1.1 Foresight process in the SMARCTIC project

In the literature there are plenty of models for how foresight processes should be organized. In this project, we followed a model consisting of three phases (see Figure 2): 1) Scoping, 2) Generation, and 3) Outputs and action. (For a three-phase foresight process model, see e.g. Horton 1999.) Such concepts as Arctic technology or Arctic competence are too ambiguous to be used as starting points for a foresight process. Therefore, we started the process with scoping, which aimed at defining the subject of the foresight process and directing the content of the generation phase. Generation is the phase, in which the actual generation of future insight takes place. In this project, the main goal was to generate roadmaps for the development and utilization of Arctic competences in Finland. In the final phase of the foresight process, the outcomes are reported so that the results can be utilised in decision making. This may include written or oral reporting in various ways.

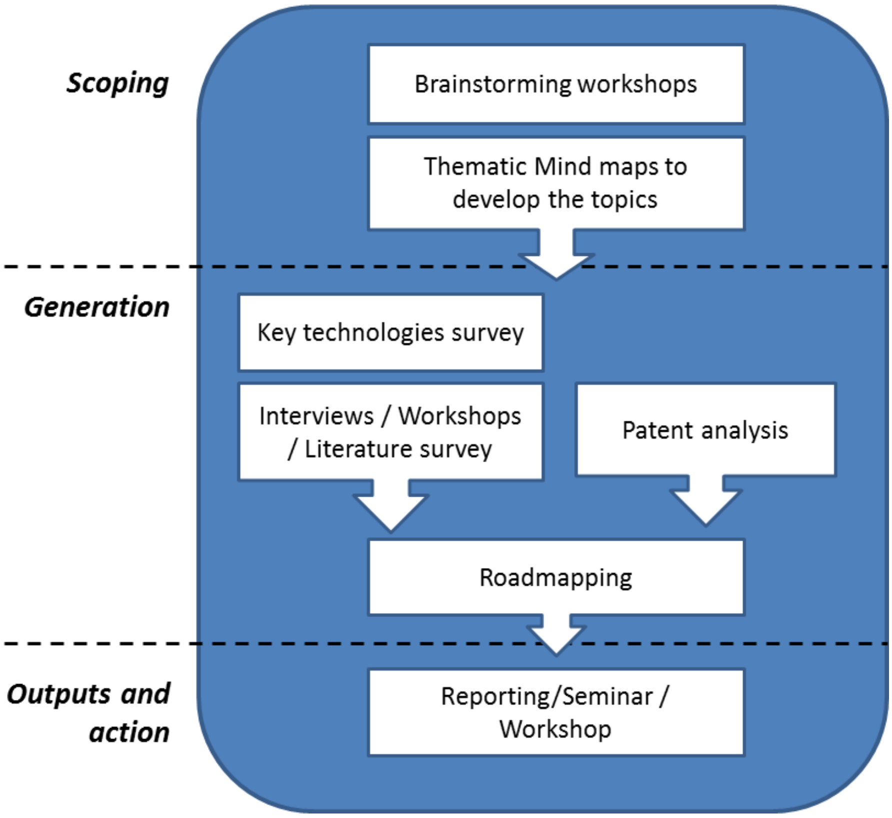


Figure 2 Roadmap process in the SMARCTIC project.

In each of the phases of the foresight process, a combination of methods is used to collect information, and translating it into futures understanding. A widely recognized model of foresight methods is the Foresight Diamond (Popper 2008).Figure 3. shows the Foresight Diamond and the methods that were used in this project. Each point of the diamond represents the type of knowledge source, or in other words, the purpose for which the method is used. The foresight methods are placed into the diamond so that the location indicates how well the method addresses the four types of knowledge source: expertise, interaction, creativity and evidence. In addition to this, the methods can be classified into qualitative, quantitative or semi-quantitative. The selection of the methods for a foresight process should be based on the contribution of each method in the context of the process as a whole, and the ways in which individual methods can be combined and synthesised to positive effect (Popper 2008). This means that one needs to consider what is the type of knowledge source that one wishes to address and how the methods selected together contribute to the aim of the process, which is in general terms to increase the understanding of futures conditions. The rectangles drawn on the Futures Diamond in Figure 3 indicate the methods which were included in the foresight process of this project. As can be seen in Figure 3, the methods are biased on the bottom side of the diamond. This means that creativity as a knowledge source was not emphasized in the selection of methods, but the other three sources (expertise, interaction and evidence) were addressed relatively evenly with the combination of methods. The selected methods and their purpose in the foresight process are explained in more detail in the next sub-section.

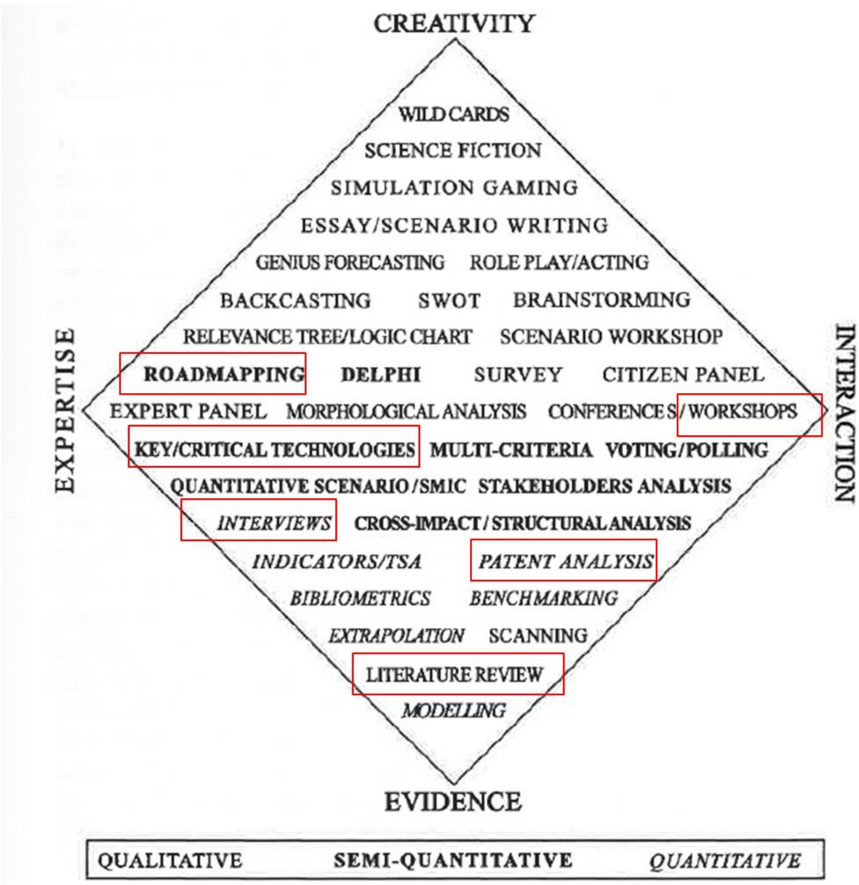


Figure 3 The Foresight Diamond (Popper 2008) and the methods that were used in the foresight process of this project.

3.2 The selection of foresight methods

3.2.1 Expertise and interaction: interviews and workshops

Interviews and workshops are commonly used methods in the information gathering of foresight processes. They are located on the opposite sides of the Foresight Diamond addressing to expertise (interviews) and interaction (workshops). This division is not black-and-white, because the participants in workshops may be selected based on their expertise, and on the other hand, interviews with individual experts may be interactive in the sense that interviewees are asked to comment on the outcomes of the foresight process. However, the main purpose of workshops is to bring different viewpoints to the same table and to create an opportunity to bring out new insight into ideas by bringing together the different views and background knowledge of participants. One could even say that the quality of experts participating in the process is a critical factor influencing the quality of outcomes of strategic technology roadmapping exercises. There are two basic principles in choosing the right mix of experts to take part in any roadmapping workshop. The first principle is variety of expertise. To the extent possible, the mix should include experts covering the most important technology fields foreseen as important for the topic under scrutiny. Obviously, it is not always possible to obtain the optimal mix of personnel at the workshop, but the process should be structured in such a way that potential gaps in the expert mix can be covered as widely as possible. The second principle is having sufficient experts with a future or long-term focus. This means that, in addition to excellent knowledge, the participants should have the capability of strategic reflection on the potential direction of their branch of expertise.

The challenge in this process was that the field of relevant technologies was not possible to define very precisely at the beginning of the process. Therefore, the first nominator of the invited experts was “Arctic” experience in research and development. At the beginning of the process, we organized two workshops, one in Espoo (19 participants; one representative from Aalto University, the Finnish Meteorological Institute and the Finnish Environment Institute, the rest were from VTT) and another in Oulu (23 participants; one representative from VTT, the Finnish Environment Institute, the Finnish Forest Research Institute, Oulu University of Applied Sciences and Lapland University of Applied Sciences, two representatives from the Finland Futures Research Centre, and the rest from the University of Oulu). The aim of these workshops was to define the content of the concepts “Arctic technology” and “Arctic competence”, and they were based on an idea that Arctic competences may arise from Arctic conditions or circumstances, on the one hand, and they are connected to some applications, on the other. The first task in the workshop was to list competences related to Arctic conditions. These competences were then grouped silently by the working group into bigger entities. The second task was to ideate ARCTIC solutions and describe them briefly in small groups. The groups were given the following definition of Arctic application:

- Applications are opportunities to implement competences, business opportunities, services, systems, solutions and technologies for Arctic conditions.

The material produced in the workshops was used in the roadmapping process to produce the understanding of the content of Arctic technology competence, and later as material for technology roadmaps.

When the content of Arctic technology took shape, the need for different expertise become evident. At this point, we either interviewed experts individually or organised meetings with a few experts. These meetings could be placed somewhere in the middle of the expertise and interaction axes of the Foresight diamond (see Figure 3), in the sense that they included elements of (group) interviews and workshops in the form of discussion and working with the roadmap template, but the participant base did not cover a wide mix of expertise necessary for full potential of interactive outcomes. These meetings produced insight for the more scoped technology roadmaps. A list of experts who participated in the roadmapping process in various phases is found in Appendix A.

3.2.2 Thematic mindmap: a tool for managing brainstorming

Brainstorming refers to a creative and interactive method used in face-to-face group working sessions so as to generate new ideas around a specific area of interest. The aim of brainstorming is to remove inhibitions and break out of narrow and routine discussions in order to allow participants to think more freely and produce new ideas. This is achieved through organising the group work in two phases. At first, the group generate ideas freely and share them with others. These views are gathered and made available for inspection, but not criticized or discussed in depth. In the second phase, all the views are discussed and clustered into categories (Popper 2008).

This kind of approach was used in the workshops organized in this project to produce an understanding of Arctic technology competences. The group work produced rich material for further use in the project. One challenge is how to manage and utilise workshop material, which is somewhat fragmented and not always well discussed or reported in a detailed manner. For this purpose we used mindmaps. Simply defined, the mindmap is a diagram used to visually organize information. The mindmap is constructed around a central concept that is located in the middle of the map. After that any associations between concepts or ideas can be visualized on the map by connecting words with lines (see Figure 4).

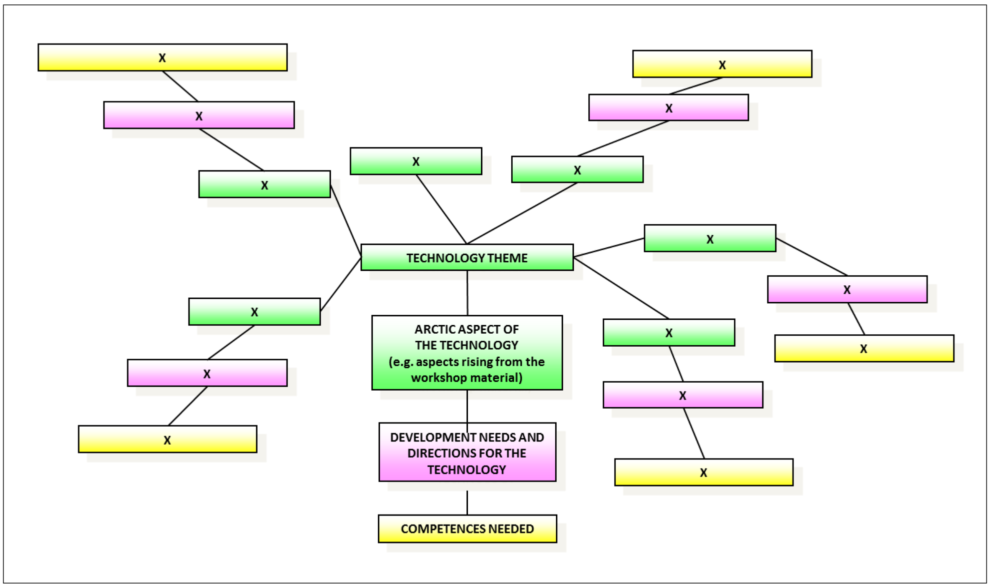


Figure 4 Structure of the mindmap used in the qualitative data management of the project.

The mindmap method was found to be very useful in the management of qualitative data of the roadmapping process due to the following characteristics of the method:

- Flexibility: The principle idea of the mindmap method can be easily applied for different purposes. It is easy to understand and adopt in workshop situations, but useful for enhancing individual thinking, as well. The mindmap can be structured in a way that it directs group thinking towards issues or aspects crucial for the process. Appendix B shows an example of this. It contains the results of a workshop session where the conclusions of the project's policy analysis were outlined.

- Visuality: The visual characteristic of a mindmap makes it useful for communicative purposes. It is possible to present a wide content and range of issues in a single mindmap. This aspect was important in the management of qualitative data, and it was utilised in the patent analysis (see the next sub-section).

- Dynamism: Mindmaps are dynamic in the sense that they are easy to expand, re-structure or combine with other mindmaps. This characteristic is especially useful in open-ended processes, such as roadmapping, where the outcome evolves throughout the process.

3.2.3 Critical technologies survey

Surveys are one possible method to gather information for roadmapping process. In this project, we made a survey of potential Arctic technologies. The selection of technologies was based on the workshop and other material collected during the process. The purpose of the survey was to prioritize the technologies and this way narrow down the scope of roadmapping. The survey was designed following the guidelines of the critical technologies method (UNIDO 2005). The goal of the method is to identify and prioritise technologies representing the driving forces in national economic prosperity and security. The results of the critical technology exercise can be used for setting national R&D priorities. The critical technology method has four steps, which are listed below. We also describe how the method was applied in our critical technology survey.

Step 1: Location and selection of experts: As the method is based on expert evaluation, this is a critical step for the outcomes of the process, especially if the goal is to set national priorities. In our case, this step included the composition of the recipient list. We attempted to have recipients from research, governance and business on our list. The base of recipients was people who had participated in the process before, especially in the preparation of the SMARCTIC project with University of Oulu and workshops of the project. We completed the list with participation lists of some events concerning Arctic issues and company listings originally made for purposes other than this project. All together, the recipient list contained approximately 260 e-mail addresses. There were some compromising aspects in this step between accuracy and efficiency, because we could not check the expertise of all the respondents due to limited resources for this task.

Step 2: Initial list of technologies: The initial list of technologies contained 15 technologies or technology applications. These technologies emerged from the discussions in workshops, interviews or other discussions during the process, and from literature. Each of 15 technologies was described briefly, and especially their connection to the Arctic theme was indicated at some level. (See the descriptions in Finnish in Appendix C.)

Step 3: Prioritization: The survey was executed using Webropol software. The respondents were asked to evaluate the technologies using two criteria: attractiveness and feasibility. Attractiveness was defined from the perspective of business opportunities and feasibility from the perspective of Finnish competences. The evaluation scale was from 1 to 5, and a verbal explanation was given for these values (see Table 2). As can be seen in the Table 2, if there were competences both in companies and research, the feasibility was valued higher. According to the evaluation scale, even a high level of research would be enough for only a feasibility level of three, if there were no companies in the field. This was a conscious choice in the survey design, because we wished to emphasize the business aspect in this project. However, it cannot be guaranteed that this qualitative valuation is transferred to the quantitative evaluation result of the respondents.

Table 2. Evaluation questions and scales used in the technology survey.

Evaluation question	***How attractive do you consider the technology application described from the perspective of business opportunities?***	***How feasible do you consider the development of the technology application described from the perspective of Finnish competence?***
5	Very attractive, because there are good business opportunities in sight in the future	Finland has very strong competences in this field, both in research and companies
4	Attractive, because there are moderate business opportunities in sight in the future	There are competences in this field, especially in companies, but there may be some gaps in research
3	Attractive to some extent: there may be good or moderate business opportunities, but their realisation is uncertain	Finnish research in this field is at a high level, but there are not any activities in companies
2	Not very attractive because of minor business opportunities	There are competences in relation to this field to some extent in Finland
1	Not at all attractive, because there are no recognisable business opportunities	The competence level is poor in this field in Finland, both in research and companies
0	I do not wish to evaluate	I do not wish to evaluate

Step 4: Final list of technologies: The two-criteria evaluation results can be plotted in a two-dimensional graph (see example in Figure 5). The points in the upper right corner of the graph are the strongest candidates for critical technologies. An interesting group is also those points in the upper left corner – as these technologies have high attractiveness but very low feasibility. These technologies should be given special attention in analysing whether they should be included among the critical technologies, and what kind of supportive activities they would require to increase their feasibility. It is important to note that the results of the critical technology exercise itself does not include decisions on the technologies, but the results formulate an expert view for decision-making. Chapter 4.2 presents the results of the technology survey carried out in this project.

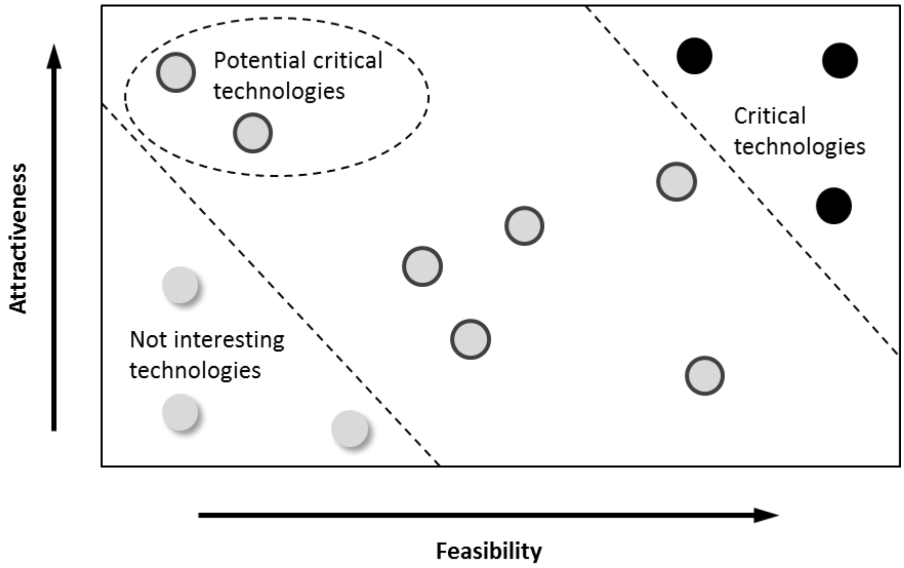


Figure 5. Ranking of technologies based on attractiveness and feasibility (adapted from UNIDO 2005).

3.2.4 Patent analysis

Patent analysis is a quantitative method sometimes used in foresight processes. It uses patent databases as a source of information, and the analysis can provide strategic intelligence on technologies, leading technology providers, or developers. Quantitative analysis utilises a statistical method to look at the number of patent registrations, assuming that increasing or decreasing registrations apparently indicate varying potential for technology developments in a specific area. A limitation of the methodology is that patent information is usually a couple of years out of date due to delays in registration processes. Furthermore, some industries make little use of patents, leaving several technological developments and lines of innovation untracked. (Popper 2008).

In this project, we wanted to use patent analysis to analyse the emerging fields of Arctic technology. Defining the Arctic technology or Arctic immaterial property rights is challenging, because inventions related to the Arctic context can be masked under whichever immaterial property rights class, and anything applied in a northern context can have an Arctic dimension. Previous studies have taken a specific viewpoint on Arctic competence, for example patent analysis on the offshore wind power (Alkærsig&Piirainen 2013), but we attempted to take a wider view of Arctic technology based on patenting. The question that we proposed to the patent data was: What is the “Arctic aspect” in the context of emerging technologies?

The “Arctic aspect” of emerging technologies is not to be understood as a function of one or two defining keywords, but it is an outcome of a network of functional conceptualisations across technologies. To meet this challenge, we developed an approach combining qualitative and quantitative methods. The starting point for the quantitative patent analysis was a mindmap (see Figure 6**Error! Reference source not found.**) that was created based on the workshops and interview material collected in the project. For the patent analysis, we wrote a Python script which deconstructs the mindmap to queries. The script analysed each abstract from PATSTAT database and identified whether the patent related to a theme in the concept map. We queried all patents applied in the United States Patent and Trademark Office (USPTO) within a time frame from 2002 to 2012, containing over 1,700,000 patents. The resulting dataset was analysed descriptively according to patent volume, technology themes and key organizations. The results of the patent analysis are discussed in section 4.3.

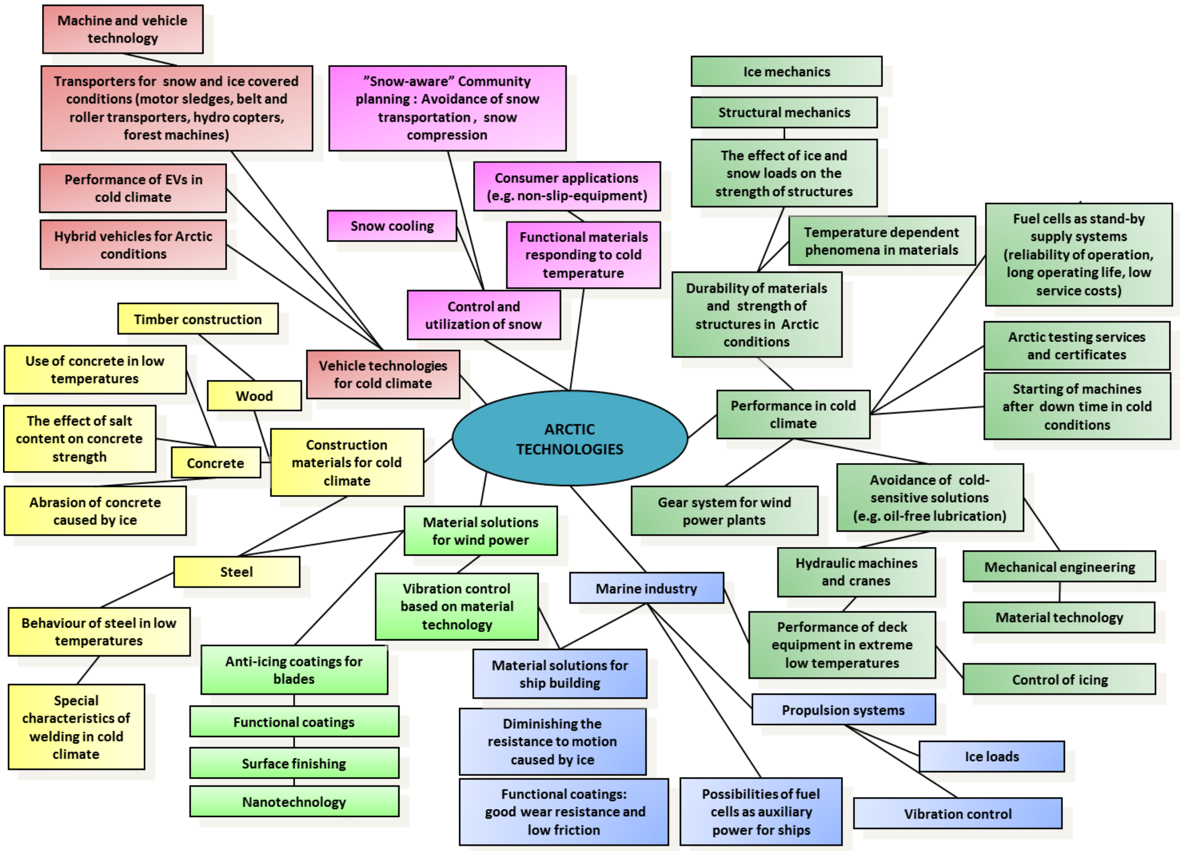


Figure 6. Mindmap used as a base for the patent analysis.

3.2.5 Innovation Policy Roadmapping

The methodological framework of this project is Innovation Policy Roadmapping (IPRM) (Ahlqvist et al. 2012). The IPRM-methodology has two levels of inspection: (1) The level of systemic transformation, which is expressed in a strategy roadmap, and (2) the level of enablers, which is shown in several technology roadmaps in the specific technology areas selected. A key aspect of innovation policy roadmapping is that it links the results of research and technology development to the systemic frame of policy-making. According to Ahlqvist et al (2012), IPRM can be applied to forward-looking policy-making in multiple ways:

1. For building of a common vision collaboratively to stimulate the commitment and embeddedness of the long-term goals among participants.

2. To facilitate systemic change by identifying the societal needs which create a potential demand for new solutions.

3. To anticipate how and when the demand could be articulated towards the emergence of a new market.

4. For visionary strategizing.

5. To identify specific innovation targets, either singular technologies or logical temporal sequences, in the roadmap structure.

In this project, the fourth alternative is the main purpose for using the methodology, as we applied the IPRM-methodology in the context of Finland's strategy for the Arctic area. The strategy roadmap crystallises the key policy and management options for the implementation of Finland's strategy in the Arctic area, and the technology roadmaps are divided according to strategy options identified in the roadmapping process. The structures of the roadmaps are shown in Figure 7and Figure 8.

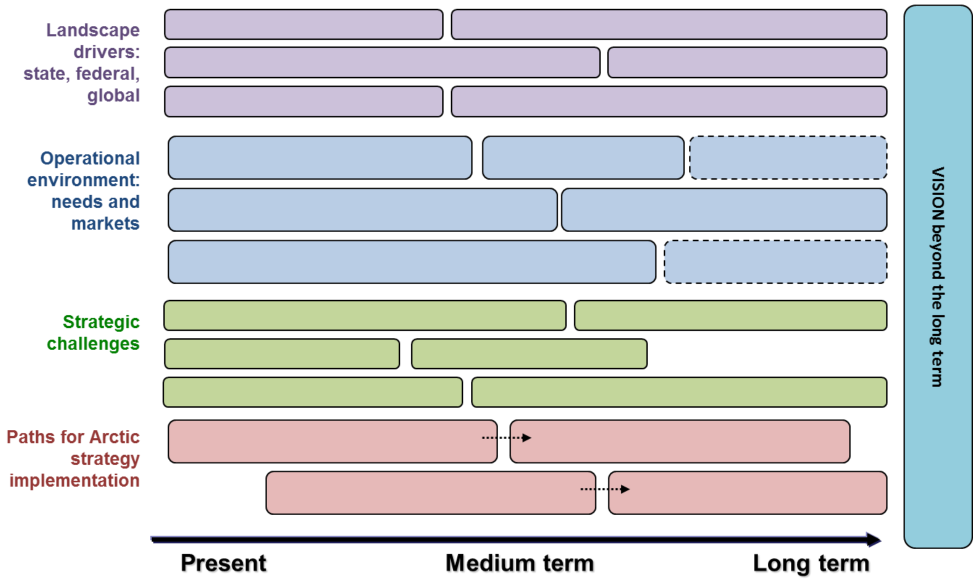


Figure 7 Structure of the strategy roadmap.

The strategy roadmap contemplates the development at an overall systemic level. The system could refer to an entity consisting of different actors, for example, the Finnish innovation system in general, including policy makers, funding organisations, research and technology organisations, companies, etc. Alternatively, the system may refer to a selected field or sector – a value network and the regulatory context of this network. The system may exist, such as a certain industry sector, or it may be non-existent and therefore formulated or defined in the source of the roadmapping process. The key idea of a strategy roadmap is to connect the development of technologies and innovations to a wider societal sphere. The aim is to support the formation of policy conclusions based on an in-depth understanding of the technological developments and their socio-economic frameworks. There are three key elements in roadmaps. The first one is an articulated vision, on the right hand side. The second one is the time line covering medium-term and long-term developments. The third element is a layered structure that outlines the wider societal context of the roadmap. The uppermost layer in a strategy roadmap (Figure 7**Error! Reference source not found.**) is *andscape drivers*. This layer depicts the key drivers and the so-called 'grand challenges' that are assessed as the most important factors structuring the roadmap topic. The second layer, *Operational environment,* covers the changes taking place in the Arctic region. The changes in the Arctic region are seen as the market area for the technology development and solution evolution. Therefore, this layer depicts the future demand for technological solutions. The third layer from the top is called *Strategy challenges* and deals with the needs and development targets identified in relation to strategizing in the field of Arctic questions in Finland. The bottom layer in our strategy roadmap crystallizes the options for strategy implementation.

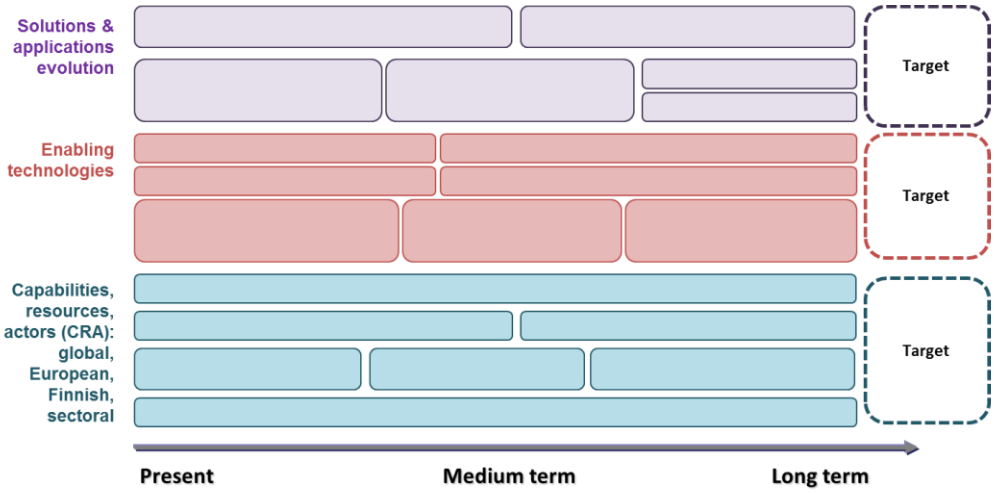


Figure 8. Structure of the technology roadmap.

A technology roadmap is basically a prospective visual depiction of key developments in a specific technological domain. The technology roadmap structure, which we used in this project, has three layers. On the upmost layer (*Solutions & applications evolution*) specific developments of technological solutions are depicted at a level that is assessed as necessary. On the second layer (*Enabling technologies*) the technologies that enable the solutions as well as the potential technological convergence are mapped. Commonly, one focuses on technologies that support the development of the solutions, but in some cases it is also possible to map the convergence of enabling technologies. The advantage of this practice is that the enabling technologies are also assessed as evolving constructs, and not as singular ‘black boxes’. The bottom layer (*Capabilities, resources, actors*) refer to various factors needed to realize the technology potential that is depicted in the technology roadmaps. At this level, the technology is set in its immediate societal context. Competencies can be described at the scale of individuals, organizations or geography. Resources refer to both material resources and social capital. Actors refer to the individuals, organizations and institutions that are perceived as important in the development of the technology.

Often, technology roadmaps also include a layer which accentuates the needs and market developments – both the market segments and geographical market regions – that are important for the technology-based solutions under scrutiny. In this process, we included market development as a part of the strategy roadmap, as the Arctic region was considered to be a sort of mega-market area for all the technology solutions. The developments in the Arctic area are the main market drivers behind the whole roadmapping process, and therefore this solution seemed reasonable from the national point of view. However, if the roadmapping was done from the perspective of an individual business or technology sector, there would be a need for more elaborate market foresight.

Roadmaps are typically developed in participative processes including technology experts and other stakeholders or interest groups depending on the goals of the roadmapping process. The challenge in this project was that the relevant stakeholder groups were not easily defined, as the topic of roadmapping was not clearly defined at the beginning of the process. Therefore, the roadmapping process was multi-phased and iterative (as explained above), and the creation of the final roadmaps was done by the project group based on the material collected in the process.

4. Scoping: Looking for Arctic expertise and emerging technologies

4.1 How to define "Arctic technology competence"?

Finland's Strategy for the Arctic region 2013 is based on the definition that Finland is an Arctic expert (Prime Minister's Office 2013). According to the document, this expertise is expressed especially in research related to northern areas, and it is a result of Finland's highly advanced education system, where its position as an Arctic country is taken into account at all levels. The strategy document also takes a position that nearly all areas of research are in some way linked to cold climate expertise and accordingly Arctic conditions, due to Finland's northern location. Technology appears in the strategy document in an enabling role. Operating in the Arctic calls for research and development of technologies suitable for cold-climate conditions, and extensive Arctic expertise possessed by Finnish companies creates an excellent basis for generating new business. Finland's strategy for the Arctic region 2013 lists the industries and expertise areas, where companies have possibilities for seizing the new business opportunities opening up in the Arctic (see Table 3).

Table 3. Areas of Finnish Arctic expertise listed in Finland's Strategy for the Arctic region 2013 in relation to Arctic business opportunities.

Areas of Finnish Arctic expertise	
Offshore industry	Construction and infrastructure
Maritime industry	Environmental technology
Shipping	Management of environmental impacts
Carriage by sea	Sustainable social concepts
Weather and ice information services	Arctic environmental expertise
Forestry	Health and well-being in the Arctic
Mining and minerals	Waste management technology
Metals	Information technology
Tourism	Public e-services
Traditional livelihoods	Innovation-driven development
Low-temperature expertise	Cold climate research
Winter testing	Bio- and nanosciences
Metrology	Risk analyses
Generation and distribution of electricity and thermal energy	Oil spill prevention technologies
	Materials technology
Energy saving and energy efficiency	Water management
Wind power technology	

The listing in Table 3 clearly illustrates the difficulty of defining Arctic expertise: it contains almost everything from scientific disciplines to technological application areas and from services or single technologies to development practices. As such, it is not a comprehensive view of Arctic expertise in relation to technologies. For the purposes of roadmapping, we needed a more coherent understanding of Arctic technology and Arctic expertise. This understanding was built in the workshop process of this project (see section 3.2.1). Figure 9 shows the resulting structure of Arctic technology competences. The structure is based on three dimensions: (1) What is the context in which the technology is used?, (2) What is the application area of the technology or for what purpose it is used?, and (3) What are the main enabling technologies that can be used in different application areas? The first question is important from the perspective of this project, because Arctic conditions set special requirements for technologies. The second question links the technologies to economic activities taking place in the Arctic area. The third level in the structure is based on an idea that there are general purpose technologies that can be applied in several application areas. These technologies are not necessarily developed from the Arctic perspective, but their advancement may have a significant effect on the possibilities of generating Arctic applications.

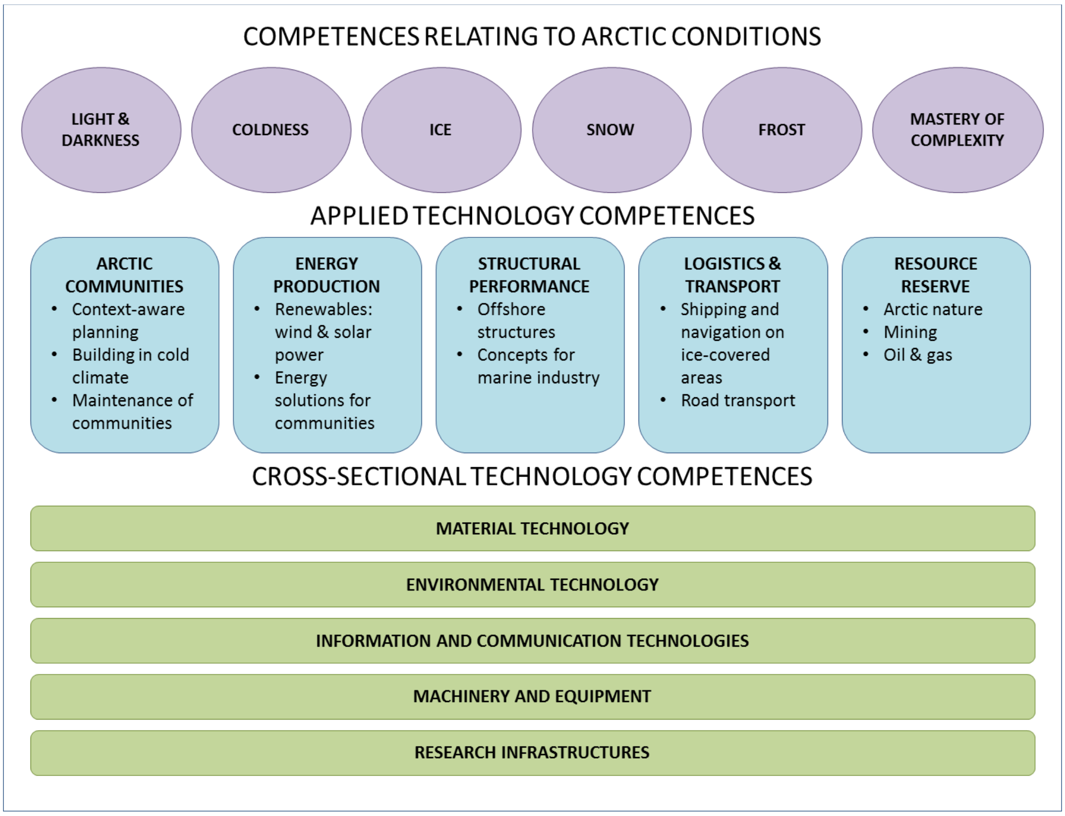


Figure 9. Arctic technology competences based on the SMARCTIC workshops.

Table 4 shows a more detailed content for the competences relating to Arctic conditions. The middle layer, applied technology competences, is presented in more detail in Appendix D. It also shows the results of a small-scale competence mapping that we carried out based mainly on online sources and concentrating on Finnish research organisations and research groups operating in the application areas.

It needs to be noted that the view of the Finnish Arctic technology competences presented in this report is not necessarily a complete picture of the topic. As information gathering was based on secondary sources and the workshop process, the result reflects the views of the participants. From this perspective, some comments need to be made. Firstly, the participants in the workshops represented a limited number of research institutes, and there was a bias in the participant base. VTT and the University of Oulu were strongly represented due to their involvement in the SMARCTIC project. This may have directed the outcome to some extent. Secondly, the SMARCTIC project approached Arctic competences from a technological point of view. Therefore, some disciplines and competences were completely absent from this process. In particular, social sciences, law or cultural studies have an important contribution to make to Arctic questions, and they would have complemented the view of Arctic competences. Thirdly, the constructed presentation of Arctic competences mainly reflects the existing competence base. As such, it does not tell us about how and in what direction competences should be developed. This is a question for the roadmapping process, and it will be discussed more in the forthcoming chapters.

Table 4. Competences relating to Arctic conditions.

LIGHT & DARKNESS	• Lightning • Mastery of operations in darkness
COLDNESS	• Low-temperature operations: Cold tolerance, protection from cold, ability to operate in cold conditions • Temperature regulation • Control of major temperature differences, sudden temperature changes
ICE	• Ice mechanics and physics: control of phase transitions, melting; variation of ice strength, ice formation and accumulation; ice friction; mechanisms of ice breaking; hoar frost (corona losses) • Sea ice: Properties (e.g. strength in the function of temperature and salt content); different forms of sea ice; mechanisms of ice block formation, ice movements on Arctic Ocean, occurrence of perennial ice • Interaction between ice and structures: Ice load analyses, formation of ice loads, management of ice loads and taking them into account in design • Modelling and simulation: Modelling of ice breaking, theories and simulation; accumulation of ice on structures (modelling and prediction)
SNOW	• Snow management and utilisation • Friction between snow and structures, management of friction • Weight and water equivalent of snow • Snow mechanics • Sublimation of snow
FROST	• Understanding of frost • Soil mechanics
MASTERY OF COMPLEXITY	• 1) Monitoring of environmental conditions (e.g. temperature and ice properties), and 2) prediction of environmental conditions (e.g. statistical models) • Climate change: Forecasting the effects and adaptation to • Analysis of complex systems • Weather and ice service systems (waves, wind, total rainfall / snow) • Management of seasonal changes (big differences in temperatures and lightning)

4.2 Technology survey: evaluating the potential of Arctic technologies

The technology survey was designed to collect insights from Finnish industry and the scientific community into the development potential of Arctic technologies and applications. Respondents were asked to rank 15 Arctic technologies and application areas (see Table 5) based on the business attractiveness and feasibility for developing Finnish know-how in this context.

Table 5. Technology survey; Arctic technologies and application areas.

SUSTAINABLE ARCTIC SOLUTIONS	
SUST 1	Monitoring and observation of environmental conditions
SUST 2	Environmental and energy production technologies for Arctic communities
SUST 3	Arctic oil spill prevention and response
SUST 4	Utilization of biomass
SUST 5	Circulation of materials and energy
SMART ARCTIC SOLUTIONS	
SMART 1	Constant monitoring and remote management of constructions
SMART 2	Development of sensor and ICT technologies for monitoring human performance in a cold climate
SMART 3	Applications for cloud service, big data, etc.
SMART 4	Satellite-based services
SMART 5	eHealth-services and telemedicine
ARCTIC TECHNOLOGY SOLUTIONS	
ARCT 1	Modelling and management of snow
ARCT 2	Cold climate machinery
ARCT 3	Development of material functional properties
ARCT 4	Arctic construction and improvement of material durability
ARCT 5	Development and utilization of fuel cell technologies in Arctic conditions

In total, 72 people took part in the online technology survey. The majority of the respondents (63%) had a research background, 26% were from companies, and 10% from the public sector. Almost half of the respondents self-assessed their Arctic experience as rather low; 23% were not working with topics related to the Arctic, 25% had 0–5 years of Arctic experience, and only 16% had more than 10 years of Arctic experience.

Figure 10 and Figure 11 present the distribution of answers. As Figure 10 indicates, the majority of the respondents rate the suggested Arctic solutions as rather attractive. The highest ranked applications are Cold climate machinery (ARCT2), Arctic construction and improvement of material durability (ARCT4), Environmental and energy production technologies for Arctic communities (SUST2) and Constant monitoring and remote management of constructions (SMART1). The least attractive technologies are seen to be Utilisation of biomass (SUST4) and Modelling and management of snow (ARCT1).

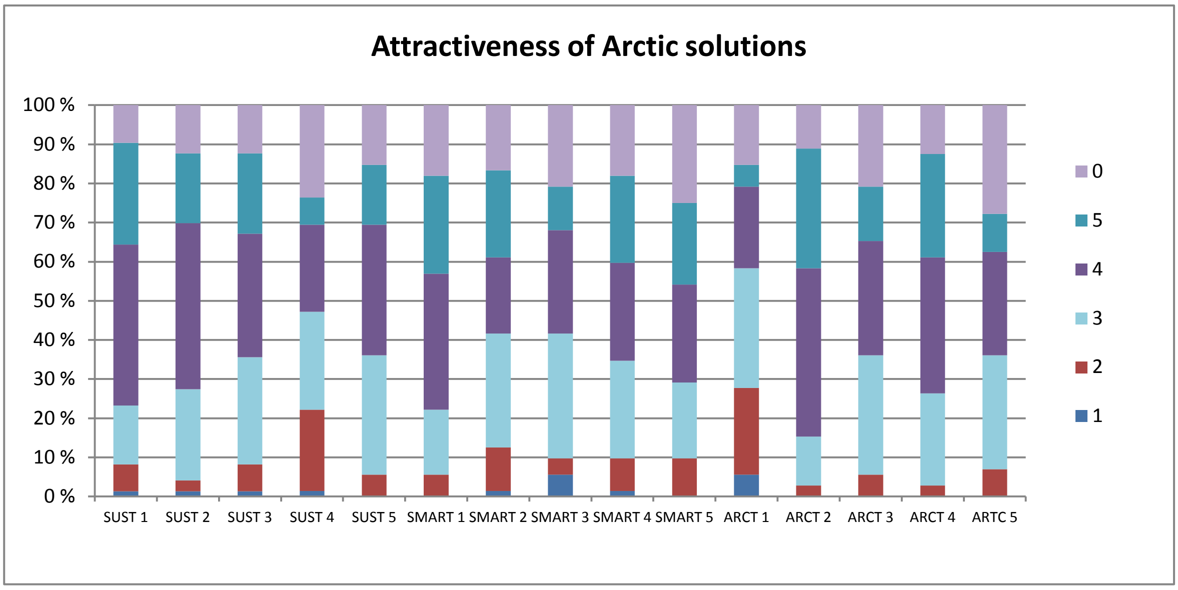


Figure 10. Distribution of answers; Attractiveness of Arctic solutions. (0 no reply, 1 not at all attractive, 2 not very attractive, 3 attractive in some extent, 4 attractive, 5 very attractive. See Table 2 for detailed description of scale.)

In general, the respondents found the suggested Arctic solutions more attractive than feasible (see Figure 11). In addition, it appears that the respondents had more difficulties in evaluating the relevant Finnish competence base than the business opportunities of suggested technologies. The strongest competence base is seen in the monitoring and observation of environmental conditions (SUST1), Environmental and energy production technologies for Arctic communities (SUST2) and Cold climate machinery (ARCT2).

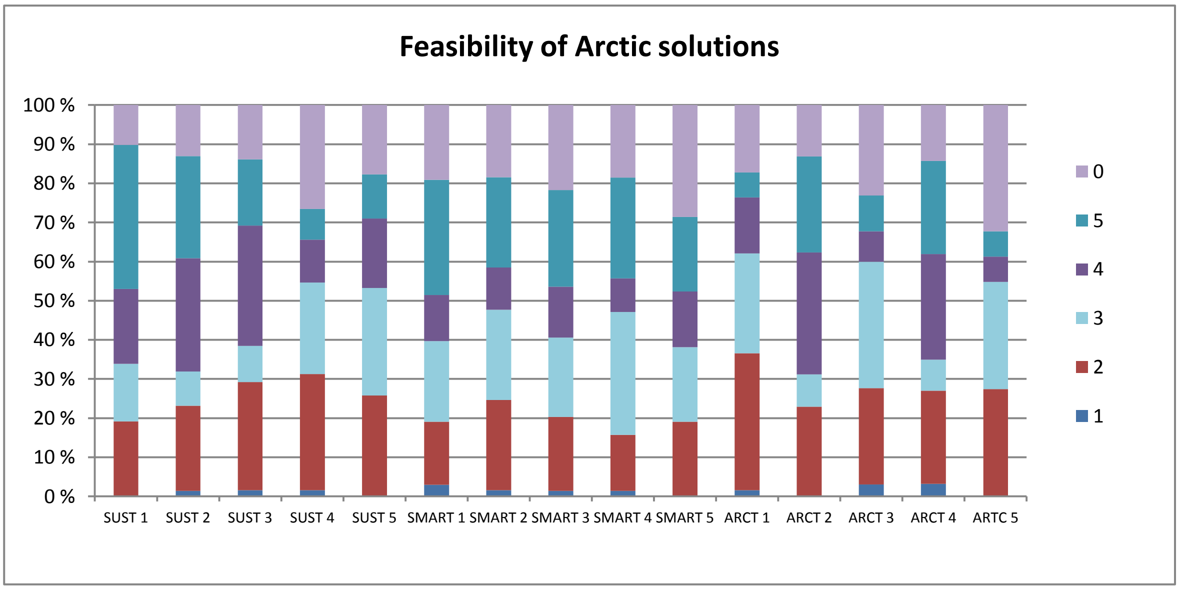


Figure 11. Distribution of answers; Feasibility of Arctic solutions. (0 no reply, 1 competence level is poor, 2 there are competences in some extent, 3 Finnish research is at a high level, but there are not many activities in companies, 4 Some competences, especially in companies, but gaps in research, 5 Finland has very strong competences in research and companies. See Table 2 for detailed description of scale.)

Average values of answers were calculated and plotted in Figure 12.The highest ranking applications were Cold climate machinery (ARCT2), Monitoring and observation of environmental conditions (SUST1), Environmental and energy production technologies for Arctic communities (SUST2), Applications for cloud service, big data (SMART3), and Arctic construction and improvement of material durability (ARCT4). The technologies evaluated least feasible and attractive were Modelling and managing snow (ARCT1) and Utilization of biomass (SUST4).

Figure 12.Attractiveness and feasibility of Arctic applications. (SUST = Sustainable Arctic solutions, SMART = Smart Arctic solutions, ARCT = Arctic technology solutions.)

Since the differences were small when all responses were analysed together, a closer look was taken at the answers of different respondent groups – research, companies and the public sector. Even though the number of respondents was not equal in each of the groups and the number of respondents from the public sector was low (7), results reveal that the scientific community, corporations and the public sector have divergent views on the feasibility and attractiveness of different Arctic solutions (see Figure 13). For example, in the case of Arctic technology solutions, Modelling and managing snow (ARCT1) was seen less attractive in companies than by other respondent groups.

It appears that in some cases the respondents with company background asses suggested Arctic technologies less attractive and feasible than other respondents. Sustainable Arctic solutions are a good example of this. On the other hand respondents from the public sector assess the potential of many of the sustainable Arctic solutions higher than do other respondent groups.

Even though the survey did not succeed in identifying the critical technologies (i.e. technologies with high attractiveness and high or relatively low feasibility) which could represent the driving forces for Arctic business development, it gave a good indication of the attractiveness and feasibility of selected technologies. Based on this survey, it appears that Finland has a rather good competence base in several suggested Arctic solutions. Many of the solutions are also seen to be quite attractive, even though uncertainly of the business potential is still present.

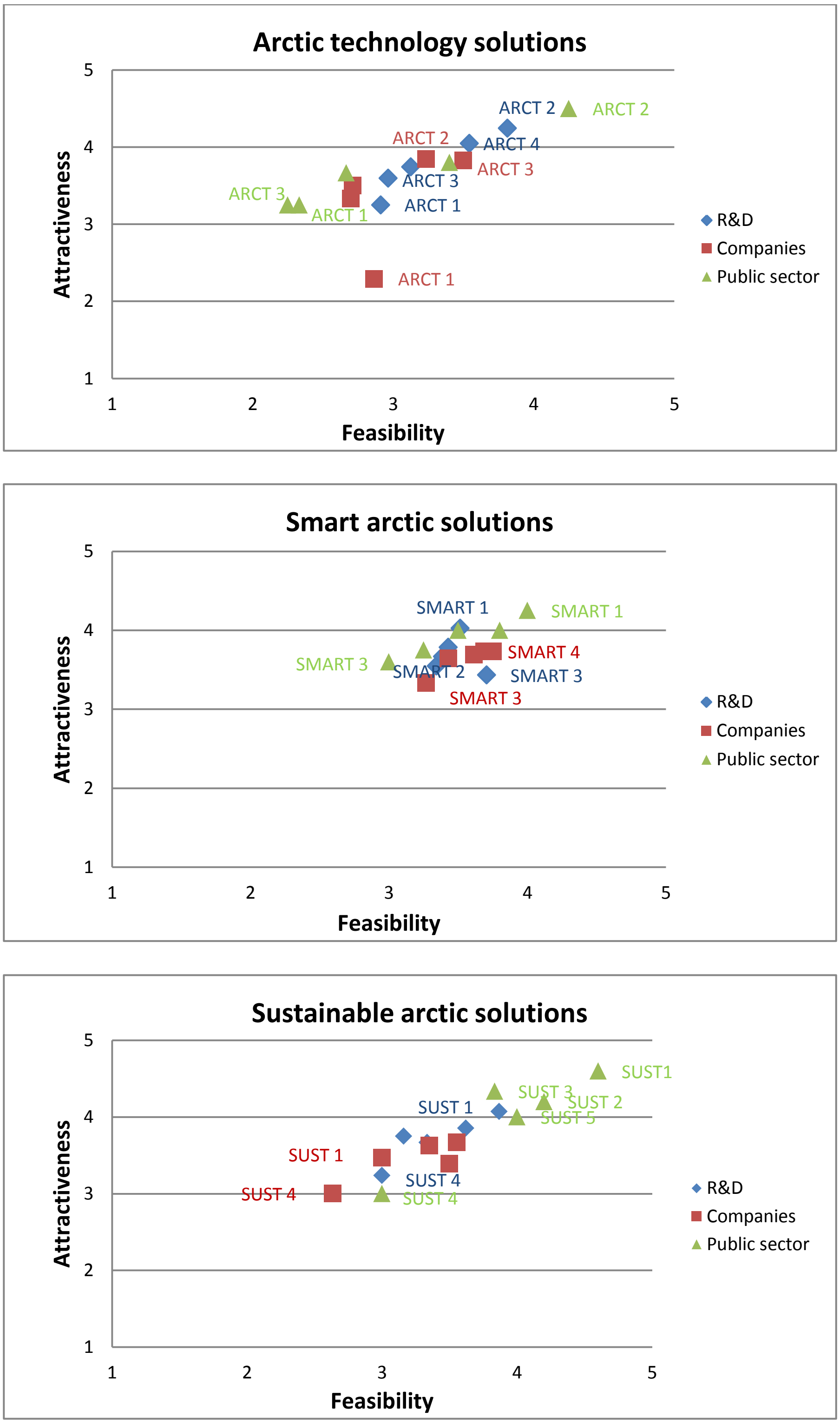


Figure 13. Feasibility and attractiveness of Arctic technology solutions, Smart Arctic solutions, and Sustainable Arctic solutions based on respondents' background.

4.1 Patent analysis: Emerging Arctic technologies?

Defining the Arctic or Arctic immaterial property rights is challenging. To an extent, patenting Arctic-related inventions can be masked under whichever immaterial property rights class, as anything applied in a northern context can have an Arctic dimension. Previous studies, looking at immaterial property rights in an Arctic context, have taken a specific viewpoint on Arctic competences – for example looking at wind power. In particular, focused analysis on patenting within the concept “Arctic” is scarce. This is most likely due to the fact that, while the term Arctic is easily grasped by humans, to a computer it represents a difficult challenge, limiting practical Boolean searches to a fairly narrow technology or domain. To better identify a more holistic competence portfolio of Arctic patenting, we have used a qualitative workshop process to aid in defining searchable query to an automated search.

In practise, using the PATSTAT database, running as a local SQL database at VTT, we queried all patents applied in the United States Patent and Trademark Office (USPTO) within a time frame from 2002 to 2011, containing over 1,700,000 patents. We then used the patent abstracts to uncover patenting area within the Arctic context based on the thematic mindmap presented in Figure 6. In practice, we created a Python script that ran several queries from the abstract of the USPTO patents, searching for different themes discovered during the mindmap process. The Python script analysed each abstract text and identified whether the patent relates to any of the thematic areas. If so, the patent was selected and its metadata was saved to a results dataset. The results data was thereafter analysed to descriptively show volume of patenting, key organizations and highlight examples of Arctic IPR in the thematic mindmap. This by no means represents all Arctic patenting, but gives an insight into the themes selected in this study.

Altogether the data search resulted in the discovery of 1,045 records in the themes identified. This allowed one record to be counted several times if the same patent fitted more than one of the themes identified in the mindmap. The records identified were there after inspected, by random inspection to identify any systematic errors in the search. Two possible systematic false positives where identified, refrigerating systems and specific medical devices. The search results were programmatically controlled for these two identified systematic false positives, clearing 76 records from the dataset. To illustrate the patenting scope of Arctic patenting, we pull examples from the themes defined in the mindmap; Construction, Marine, Wind Power, Snow and Ice Management, Vehicles and Performance, seen in Figure 14.

As Figure 14 shows, the scope of patenting within the themes is broad. The examples present both methods, such as a method for observing sea ice thickness to physical apparatuses such as railway snow removal tools. The examples used in the figure make an effort to promote the differences in Arctic-related IPR. In a sense, the Arctic can be connected to all possible aspects of human life, but as with any Boolean search based exercise, we have uncovered specific methods and applications that have made an explicit connection to Arctic.

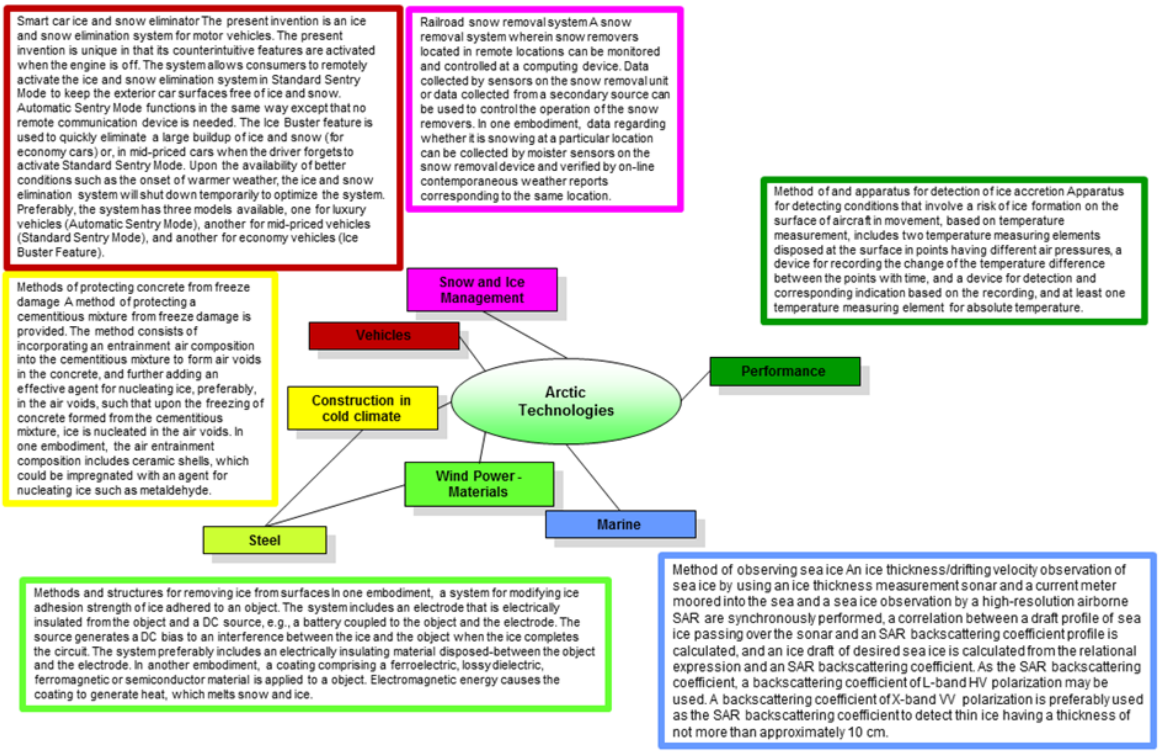


Figure 14. Examples of patents within the themes.

In addition to the examples seen in Figure 14, the results showcase industries with a long tradition of operation in a cold climate. One example is by the Bridgestone Corporation which has patented an “On-snow tire-testing method, on-snow tire-testing system, and road surface for on-snow tire tests”. Although the search does not cover winter tire development, patents, such as those mentioned before, relates to performance in Arctic environments. Performance and operations in a cold climate is one of the overall themes in the results. Examples of different technologies sustaining operation in cold climates range from “A diesel fuel delivery system that maintains optimum fuel delivery to the engine despite the presence of an ice blockage at the fuel strainer” patented by Delphi Technologies, Inc. or a “Device for indicating ice formation” by Forskarpatent in Uppsala AB and “Power distribution architecture for an ice protection system” by Rosemount Aerospace Inc. to “Snow-melting/antifreezing agents” developed by ABC Research Laboratory for Building Materials Co.

In addition to performance related patents, much of the results focus on motor vehicles and specifically snow mobiles. IPR such as Yamaha’s “A snow lubrication device” that improves operation of the snowmobile if it strikes a stone is a practical technology, and several internal combustion engine related inventions look at the operation of vehicles and engines in cold climates. Often, the technologies’ relevance to cold climates is not explicit but rather implied by the application area defined in the patent.

The final dataset was drawn as a time series by the themes identified in the mindmap. Seen in Figure 15, the narrow confines of the analysis produced a scarce amount of patents per theme; thus the results are presented as a sum of all themes, allowing latent patterns to emerge more clearly. The volume of patents is relatively low when compared to the volume of new patents published annually – total patent grants by the USPTO being in 2011 247,713 patents. Within the time period studied, USPTO has had an annual increase in patent applications, while Figure 15 shows a decrease in patenting volume. There is clearly a trend of decreased patenting, made more significant with the increase in overall patenting. This suggests a strong decrease in patenting, but this observation is limited by the overall narrow scope of the search.

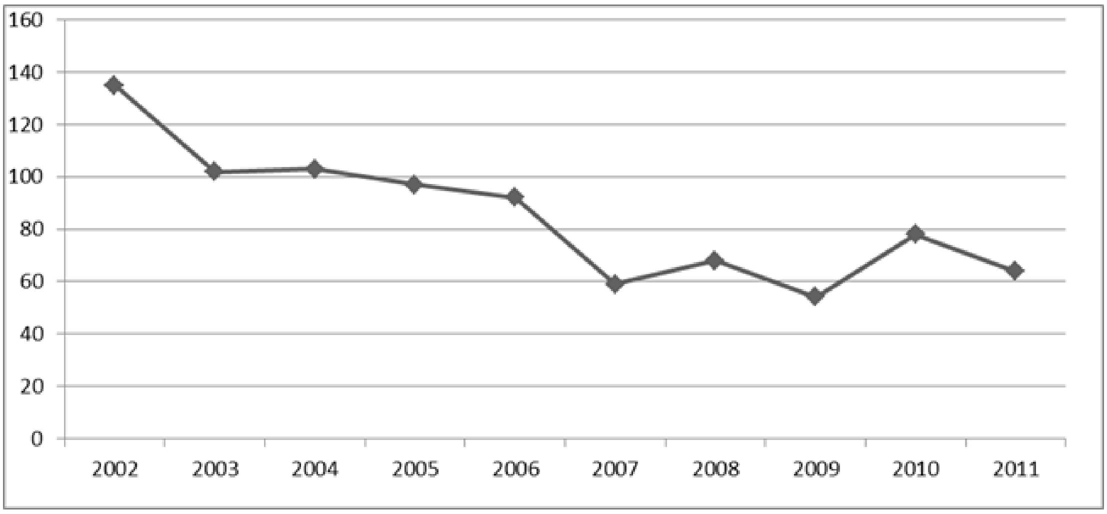


Figure 15. Patenting activity as a time series all themes.

To further uncover the linkages of the themes, we used the metadata on the IPC classification assigned to each of the patents. We created a network diagram of co-occurrences of IPC classification between the themes seen in Figure 16. This Figure gives a view to the limited interconnection between the themes and similarly in part explains the challenges of defining the Arctic. As noted before, Performance is the overarching theme in patenting. Patents identified as belonging to the theme Performance share the most IPC classes with other themes in Figure 16, while there are little or no co-occurring classifications with the other themes. Figure 16 also shows that by volume the themes Performance and Motor Vehicles are the largest in the results. Although these results only show the structure of Arctic technologies based on the scope selected for this study, we see that there are clear technology areas which have had a high incentive to develop technological solutions to sustain operations in cold environment – such as in the vehicle industry. Figure 16 represents the Arctic as we would expect it. The label “Arctic” can be attached to a number of technological areas and while we see a shared technological frontier, the technologies also remain separate and connected to their core knowledge.

In practise, Figure 16 explains the challenge of searching for Arctic IPR. A simple search carried out in the USPTO online terminal for the keyword “Arctic” would, for example, have resulted in a patent titled “Transgenic mouse expressing Arctic mutation E693G” covering the method of producing a transgenic animal. The search would also be crowded with patents on for example “Mooring system for drilling hull in Arctic waters” and “Arctic dredging and pipelining”, although much of this has been protected by patents in the 1970s and 1980s, thus falling outside the scope of this study.

The search based on the mindmap produced a different picture of Arctic patenting, drawing out patents such as “Ocean oil spill and contaminated sea ice containment, separation and removal system”, “a method for containing and cleaning up oil or other contaminants from an area of water containing mixture of ice and water is disclosed.”, “a method for inhibiting the formation or accumulation of ice on a solid surface and for reducing the salt out temperatures” and “Cold weather hydrogen generation system and method of operation” and “Vibration engine monitoring neural network object monitoring”.

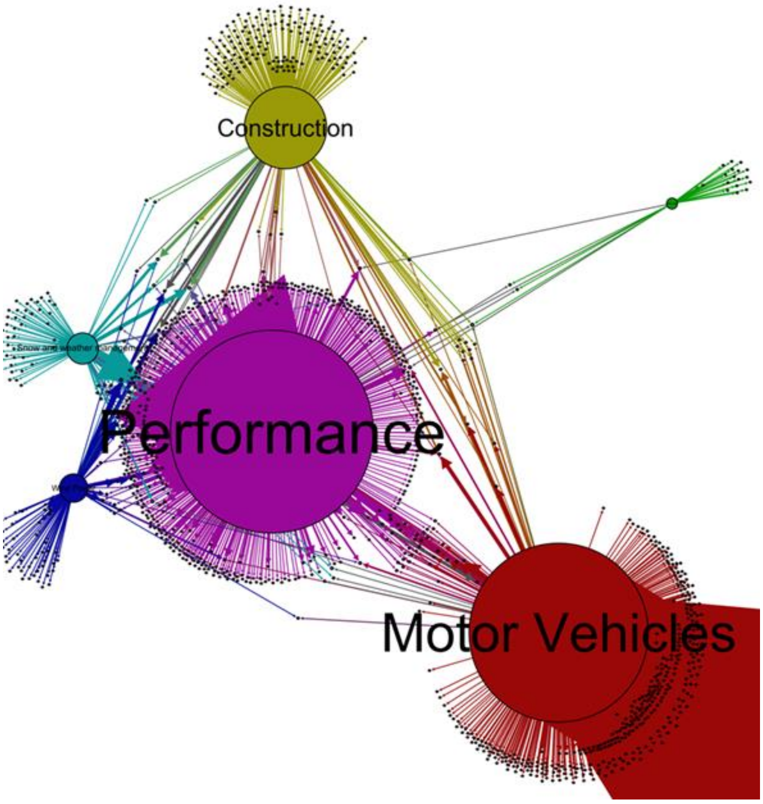


Figure 16. Themes connected to IPC classes. The figure shows the interconnection of themes as the themes are categorized to the same IPC classes.

The thematic areas are connected to each other by IPC classifications made to individual patents. Figure 16 shows in detail the linkages between the themes to the extent individual patents share specific classes in the IPC classification system. Figure 16 is used to look at whether the search results have a shared intellectual base, or whether the themes are separate with narrow links between them. Ultimately, if all related patents within the search results were to share one classification; this could be used to identify the patents relevant. However, as seen from the figure, the themes are scarcely connected with some interconnected IPC classes among the themes existing.

In Figure 16, the performance- and operating machinery-related topics, understandably, are more closely connected. Themes such as Construction and Snow and Ice Management remain more loosely connected. The selected technologies are shown here as separate entities with limited shared intellectual background. Arctic-related IPR remains challenging to distinguish with a narrow keyword search, and by looking at the results through selected IPC classes also makes for a significant selection bias.

Looking at the thematically selected areas, we can link the IPR to companies. As seen from Figure 17, the data is dominated by large Motor Vehicle and specifically snow mobile manufacturers. This is understandable, as it is seen in Figure 16 that the Motor Vehicle and Performance themes are by volume the largest in the results. Looking beyond the strong role of Motor Vehicles, it is noteworthy that there is a significant number of outliers, companies and IPC classes existing in the dataset once or twice within the scope of the study. In this search, the IPR is a mixed collection of patents within a relatively broad scope focusing significantly on only a few general patent classes such as “Basic electrical elements”, “Cements” and “Dyes; Paints; Polishes; Natural Resins and Adhesives”.

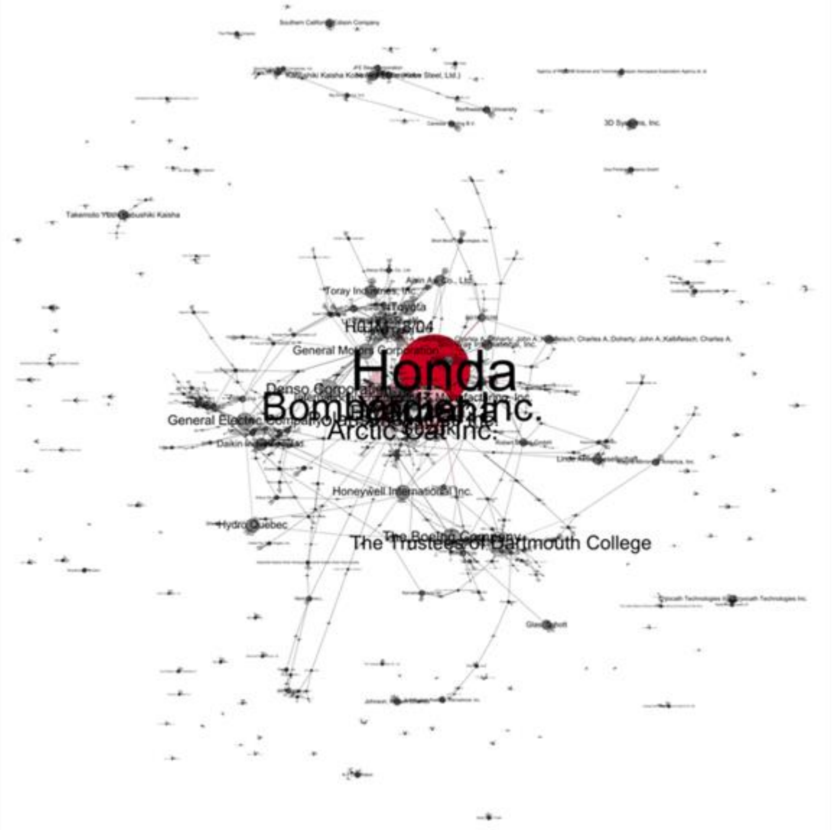


Figure 17. Companies connected to IPC classes.

To summarize, it is relatively challenging to narrow down Arctic patenting with a simple Boolean search. Also, even with a relatively large sample, we are unable to find IPC classifications creating a practical window into analysing Arctic patenting. Using an approach integrating a qualitative workshop-based mindmap, where after searches are made, this produces a window on to a specific selection of Arctic technologies that might result in significant latent pattern emerging. This can result in a more holistic understanding of what should be studied in greater depth when analysing Arctic technologies.

Within the scope of the search, we see that 1) the search carried out is able to grasp a fairly confined technological area, and 2) the selected thematic areas in this study decrease in volume although the overall trend in patenting is the opposite. This development might be in part explained by the narrow scope of the study, which is prone to variation, but arguably this limitation can only explain the behaviour in parts. 3) Looking at the companies active in the field, we identify large Motor Vehicle companies crowding the core of the network, while there is an abundance of smaller actors creating a sparse network in specific areas. As a conclusion, the results show the broad nature of Arctic technologies. Volumes of actors spread onto a large number of technological domains which are hard to grasp by Boolean searches.

5. Strategic roadmap

Figure 18 shows the roadmap that was created in the SMARCTIC project. This roadmap is a general strategic roadmap based on the literature and the policy survey carried out in SMARCTIC project. The purpose of this roadmap is to outline the developments taking place in the Arctic operational environment. There are four levels in the roadmap. The top level (Landscape drivers) describes global changes and developments affecting the Arctic area. The second layer from top (Operational environment) describes the economic activities in the Arctic area. This layer is needed to anticipate the potential markets and application areas for Arctic technologies. The two layers at the bottom view Arctic development from a national perspective. The strategic challenges layer describes the challenges that were identified in relation to the implementation of Finland's strategy for the Arctic region, and the bottom layer (Paths for Arctic strategy implementation) identifies the possible strategy paths in relation to Finnish Arctic competences. The suggested timescale of the roadmap is fifteen years, but the time axis is intentionally left open, because the roadmap is not intended to describe future development as a definite series of events bound to certain points in time. Rather, it is – in compliance with strategic roadmapping tradition – a collection of possible developments that are intended to take place in the course of time. The roadmap outlines the complexity of the Arctic context, and mark out the path to the Finland's Arctic vision. In the following sub-sections, the various parts of the roadmap are discussed in more detail.

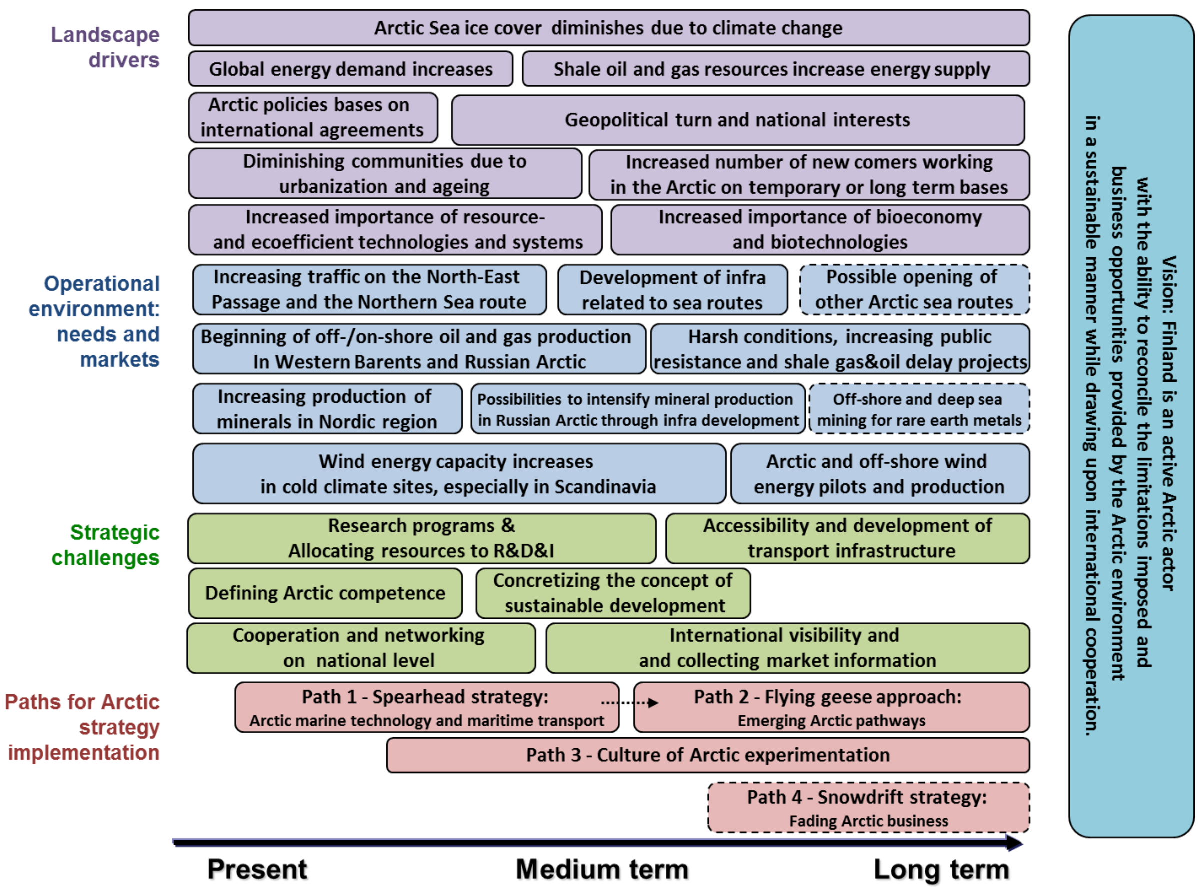


Figure 18. Strategic roadmap for Finland to utilize and develop Arctic competences.

5.1 Vision

The roadmap **vision** is taken from Finland's Strategy for the Arctic Region (Prime Minister's Office, 2013):

> *Finland is an active Arctic actor with the ability to reconcile the limitations imposed and business opportunities provided by the Arctic environment in a sustainable manner while drawing upon international cooperation.*

This vision entails an idea of Finland as an Arctic country that has shaped an Arctic identity based on nature, geography, history and experience. The strategy document also claims that Finland possesses top-level expertise and know-how that is needed for understanding, adaptation and utilization of the change that is taking place in the Arctic. The strategy document also defines a policy that maintaining and developing a high standard of expertise and research are of primary importance, and that Finland wishes to set an example as an Arctic expert both in research and in the responsible commercial exploitation of such expertise. An important aspect in the latter goal is to comply with the principles of sustainable development in Arctic operations. Another key objective, according to the strategy document, is to promote international cooperation and maintain stability in the Arctic region.

5.2 Landscape drivers

Landscape drivers are trends or developments that exist in the world and that have an impact on the possibilities of the vision becoming reality. Fundamentally, drivers are factors that support or promote the development towards vision, for example by creating a demand for certain solution. However, the positive effect of a driver may end at some point in time, or the trend may turn into more of a hindering factor. We selected the key drivers in the roadmap on the basis of the trend analysis carried out in the SMARCTIC project (Myllylä & Kaivo-oja 2013) and literature survey. They are discussed briefly below.

Climate change: Over recent decades, the average temperature in the Arctic region has risen almost twice as fast as the global temperature on average. Climate change is expected to have significant changes in the Arctic region in future, and some of these processes are already ongoing. Often, even the same change can be considered to be either negative or positive, depending on one's point of view or interests. Melting sea ice is a good example. At the same time that it enables planning new logistical routes for transporting goods and the acquiring of resources, it can have drastic, negative effects on local ecosystems and accelerate changes in global climate. Negative effects of climate change are also seen on the Arctic territory, where the melting of the permafrost creates major challenges for human built infrastructures.

Energy demand, oil/ raw material prices: Arctic oil, gas and mineral resources are becoming more interesting due to increased demand and decreasing resources elsewhere. The harsh Arctic conditions make it more challenging to utilise these resources. Therefore, it is crucial how oil and raw material prices are changing. Other possibly less well known resource reserves, e.g. in Africa or shale gas reserves in Northern America, are therefore competing areas of interest to the Arctic region, and any changes in these areas can have significant effects on the feasibility of the Arctic projects. Also, public resistance to the exploitation of Arctic natural resources may increase over time, especially if any environmental damage occurs and gets out in public knowledge.

Cooperation policy & geopolitical turn*:* In recent years, the predominant discourse concerning the transformation in the Arctic has been based on the paradigm of "Arctic cooperation". The Arctic states have recognized the importance of cooperation, and international law has been accepted to guide agreement (e.g. the United Nations Convention on the Law of the Sea). Therefore, the risk for any conflict inside the Arctic area has been considered to be small. However, the Arctic area is not shielded from global dynamics and political crises. The political scene has changed significantly since the start of SMARCTIC project due to the ongoing crisis in Ukraine. The relations between Russia and the West have turned colder, and this may have profound direct and indirect effects on the cooperation in the Arctic context in the long run. Even if the need for western technological know-how in the offshore megaprojects in the Russian Arctic Ocean still exists, the crisis may increase the overall risk levels of international investors, and these indirect effects will affect capital intensive and long-lasting projects.

Demographic changes: The demographics of the Arctic area is characterized by two trends: urbanisation and ageing. Since the 1960s, most of the population growth in the Arctic has occurred in urban centres tied to industrial activities, social services and public administration. Urban areas attract people by providing better opportunities for work, education and a better standard of living. At the same time, cities are often characterised by social stratification. While they can be viewed as hubs in the economic development of their regions, they also potentially foster social inequality. Ageing is a consequence of several demographic trends, including longer life expectancy, decreasing birth rates in the Arctic communities and a decline in the younger age groups due to migration out of the area. The share of the population aged over 65 years is especially high in the northern parts of the Nordic countries. The general trend of ageing will become a potentially significant economic challenge in the whole Arctic area in the years to come due to the increases in dependency ratios. However, the demographic development is difficult to anticipate, as the labour markets have increasingly interacted with labour markets outside the Arctic. In the European Arctic, male workers arrive from East European countries and Poland in particular. In Russia, Canada and Alaska, the new males come from the “south”. In terms of female workers, the majority come from Thailand and Indonesia. This creates a much higher level of diversity in community structures. There is also a need for management approaches able to cope with more diverse social situations including questions of indigenous/nonindigenous and permanent/temporary inhabitants. (Megatrends 2011).

Technological trends: Increased industrialization and population growth have created concerns about the carrying capacity of the Earth. Therefore, concepts like resource and eco-efficiency has been introduced into the public discussion and as guidelines for economic or business activities. Eco-efficiency refers to a principle of creating more goods and services while using fewer resources and creating less waste and pollution. Similarly, resource efficiency is a way to deliver more with less (natural resources). It increases aggregate economic value through a more productive use of resources, taking their whole life cycle into account (ECN 2013). These principles should also be implemented in technological development so that new technologies and solutions are designed to meet the resource and eco-efficiency requirements. While eco-efficiency has appeared on the political agenda since the 1990s, bioecononomy (or circular economy) is a more recent concept. Bioeconomy refers to a new way of seeing industrial activities as part of the natural system and biosphere, and it entails the following principles (Kuisma 2011): renewal natural resources substitute for non-renewable ones, sustainable use of natural resources, and closed loops in material and energy circulation. Finland has great potential in the bioeconomy due good biocapacity, i.e. profusion of natural resources, such as forests, high level of competences and technological know-how, as well as industrial activities in the field (TFBS 2014).

5.3 Operational environment

The operation environment of the Arctic business scene was scanned, with special emphasis to identify the short-term and longer term opportunities for high technology Finnish enterprises aiming to create international Arctic business. Two recent Finnish studies estimate that the Arctic business potential is high (Pokela 2014, Rautajoki 2014). According to Pokela (2014), the Arctic business opportunity is estimated to be of €240 billion by 2020 (see Table 6). Arctic Business Forum Yearbook (Rautajoki 2014) sums the investment potential of the European High North: Russia (Arkhangelsk, Murmansk), North of Norway, Sweden (Norrbotten, Västerbotten), Finland (Kainuu, Oulu, Lappland) to be up to €144 billion by the year 2020. However, the global financial crisis has slowed down the investment projects in this the Arctic area.

Table 6. Sector specific investments to the Arctic region by 2020 (€ billion) (Pokela 2014).

	Energy	Mining	Maritime transport	Construction and infrastructure	Telecommunications and information services	Total
Finland	8.8	8.3	0.1	2.2	0.025	**19.4**
Sweden	15.0	6.7	N/A	2.7	N/A	**24.4**
Norway	26.0	0.3	0.003	5.3	N/A	**31.6**
Denmark	15.6 [a]	3.4	N/A	N/A	N/A	**19.0**
Canada	1.8	9.3[b]	25.0	0.08	0.4	**36.6**
USA	54.9[c]	5.4[d]	N/A	N/A	2.3	**62.6**
Russia	20.9	2.2	6.2	16.8	N/A	**46.1**
Total	**143**	**35.6**	**31.3**	**27.1**	**2.7**	**239.7**

a Suggested implementation in 2040. b Projected mining investments between 2012 and 2031. c Trans-Alaska pipeline as main investment (2021-2022), d projected mining investments between 2012 and 2031

5.3.1 Development of global logistical routes

Arctic Sea routes: Global warming and the enormous deposits of natural resources will make sure that the Arctic is important in the future. Its central location in geographical terms and the short direct sea routes to the main population centres of the globe, still predominantly located in the northern hemisphere, are a significant asset. (Megatrends 2011)

The North-East Passage (NEP) along with the Northern Sea Route (NSR) is considered to be the most potential global logistical routes in the Arctic. These routes are also more vulnerable to global and national economic conditions than alternative shipping routes. (Jørgensen-Dahl 2010). The transit traffic on the Northern Sea Route is still small, and the Russian regulations and legislation needed for the use of the sea route are being developed (Rautio & Hahl 2013). In 2012, the number of vessels traversing the Northern Sea route was 46 (Arctis 2013). Some estimate, that ship-ping along the Northern sea route will grow more than 30-fold over the next eight years, which could account for a quarter of the cargo traffic between Europe and Asia by 2030 (Koranoy 2013). While others predict that the Arctic shipping along the NSR is likely to continue at the same level in the near future (Jørgensen-Dahl 2010).

The transit rate on the North-East Passage is bigger; in 2013 Russia granted permissions to 635 ships to access the North-East Passage (Helsingin Sanomat 2014). Though the number of vessels on the Arctic sea routes has been increasing, Arctic shipping is still highly seasonal and depends on ice conditions, which vary from year to year. Since the Arctic operation environment is highly unpredictable, it is challenging to predict when the passages will be open. (AMSA 2009) This makes “just–in-time logistics” impossible, but opens new opportunities for bulk cargo transportation (Brigham 2011).

The Northwest Passage (NWP) has been discussed, but it is considered to be more challenging due to its ice conditions and limited shipping infrastructure. If the reduction in ice coating continues, there may also emerge the possibility to open new route, the so- called Trans Polar Passage (TTP), over the North Pole. (Myllylä & Kaivo-oja 2013)

There are factors that favour the North-East Passage and the Northern Sea Route over NWP and TTP in the future; both routes go along parts of the Arctic abundant with natural resources (onshore and offshore); the extraction of these natural resources produces cargoes; infrastructure related to sea routes exists (NEP) and is planned to be developed; also ice conditions are less severe and the transport season is longer during the summer season. (Jørgensen-Dahl 2010).

In addition to energy export and mining, also tourism and the fishing industry are likely to increase the economic activity and importance in this region. Though the NEP and NSR are better developed in comparison with other Arctic sea routes, there are still severe gaps in the infrastructure necessary for safe passage; such as a lack of search and rescue capabilities, ice-management capabilities, salvage points, sea ports, and communication infrastructure. (Brigham 2011).

On the existing routes, the amount of the traffic routes will probably increase and the length of the summer season is expected to be extended. This in itself will contribute to the increase of travelling and marine transport. (Acia 2004). Even though the ice cover continues to decrease, the Arctic sea routes are not likely to be available for year-round transport during this century, at least not without ice-strengthened polar Class ships and / or with ice-breaker assistance, which increases the costs of year-round Arctic shipping making it economically infeasible. (Mikkola & Käpylä 2013).

Infrastructure related to development of logistical routes*:* Besides acting in an enabling role for opening new logistical routes, climate change also has negative effect on arranging logistics. Melting (perma)frost already disturbs land transportation and pipes. Drilling for oil and natural gas, as well as the forest industry, are facing challenges through a shortened transportation season on frozen tundra and ice roads. Difficulties in transportation also affect communities through the changes in accessibility of commodities. (Acia 2004)

Excluding the Nordic states, the infrastructure in the Arctic is underdeveloped. Road systems are sparse, unpaved, and not maintained. Rail systems are limited. Airports are regional, with the commercial hubs to the south. Seaports and inland waterways are developed in accordance with the states' reliance on resource exports (Knell 2008). Consequently, large-scale development of road, rail, air transport and port infrastructure (aerodromes, airports, ports, wave breakers), is needed.

Crystallizing the key dynamics from the logistical point of view, it can be concluded that the Northern Sea Route project impacts very much on the general development of transport infrastructure in the Arctic. Both oil and gas projects and scaled logistic projects will generate a fast growing demand within all major industrial sectors: construction, logistic, energy, environmental and general safety, IT and communication, etc. In mentioning the Northern Sea Route, it cannot be omitted that the successful use of this resource depends much on the shelf and shore extraction of hydrocarbons in the Arctic. (Finpro 2012)

One of the largest infrastructure development projects in Barents Sea region that is related to the use of Northern Sea Route is the "Complex Development of the Murmansk Transport Hub" project. The project aims to create of a year-round marine hub for processing container and liquid cargoes and transhipment of coal and mineral fertilizers. It also provides development for the Kola Peninsula's sea, rail and road transport infrastructure. The total funding for this project is €3.2 billion. The Murmansk Transport Hub project was planned to be implemented as a private-public partnership before 2018, but it has been postponed from its planned timetables, and is now being expected to begin in 2014 (Rautajoki 2014).

Arkhangelsk (Archangel) Deep Sea Port, Onega sea port and related Belkomur project are the key development projects in the Russian Arkhangelsk region. The ongoing Belkomur transport infrastructure project focuses on the construction of the rail line from Solikamsk-Syktyvkar-Arkhangelsk. The Belkomur project acts as a gateway for the Arkhangelsk Region and industry by connecting the region with Trans-Siberian Railway. One of the industries benefiting from this €3 billion investment is the Russian forest industry. The Belkomur project is likely to speed up other investment projects in the area, such as the construction of the deep sea port. Though the implementation of a port infrastructure project is still at the planning phase and is expected to begin after 2020. The €3,2 billion investment project at Onega Seaport likely to begin even later, closer to 2030 (Rautajoki 2014).

Another significant port infrastructure project in Russian Kara Sea region is the development of resource- rich Yamal Peninsula and the port of Sabetta. The sea port construction is closely linked with the Yamal LNG project, which includes the creation of facilities for the production, storage and shipping of liquefied natural gas based on Yuzhno-Tambeyskoe field (Arctic info 2013). The construction of the port began in 2012 and the first phase of the development is planned to be finalized in 2014 (The Siberian Times 2012).

In comparison to Russia, Norway has well developed transport infrastructure in the Arctic region. The country has also plans to further develop the infrastructure. The main projects planned to start first are the railway connecting Narvik with the Swedish border (€1,2000 m), Gimsøy and Helgeland airports (€450 m), road and bridge projects (€740 m), and the development of port and terminals; including Narvik, Tromsø and Kirkenes (€565 m). The port of Kirkenes, which is already an iron ore export port, has great potential to become a transfer port for raw oil coming from Yamal and the Kara Sea and could even become a competitor to the Russian port of Murmansk (Rautajoki 2014).

The development of the port of Kirkenes and the Finnish Arctic Railway (Rovaniemi (FI) – Kirkenes (NO) is seen as an attractive opportunity for Finland to gain access to Arctic sea routes, such as the North-East Passage and Barents regions natural re-sources (Raunio 2012). The first phase of the railway (Rovaniemi–Sodankylä) could be constructed by 2020, and the second stage (Sodankylä–Kirkenes) by 2030 (Raunio 2012). The total investment in Finnish side would be €1,900 m, though no investment decisions are so far done in Finland. In Norway € 1,000 m investment in the Finnish Arctic Railway is also on hold due to Finnish Transport policy. (Rautajoki 2014) There are signs that the general interest in the development of the Finnish Arctic railway is slowly increasing (Lapin Kansa 2014).

5.3.2 Investments in the utilization of natural resources

Arctic Oil and Gas field projects: The recent oil and gas field projects in the Russian Arctic focus on onshore projects, such as the Yamal development, and offshore projects in the Barents, Pechora and Kara Seas. According to Gazprom (2014a), oil and gas production in the Yamal region is estimated to grow significantly (see Table 7). In the first phase, the production focuses on the Yamal Peninsula, and the developments at offshore sites in the Kara Sea are projected to start after 2025.

Table 7. A forecast for gas production in the Yamal Peninsula and adjacent offshore areas (Gazprom 2014a).

Year	2011*	2015	2020	2025	2030
Gas production (bcm)	7.9	75–115	135–175	200–250	310–360

The offshore projects are riskier and have often taken the form of joint-ventures be-tween Russian and international energy corporations (Mikkonen & Käpylä 2013). The Shtokman gas and condensate field development project, which is one of the largest development projects in the Barents area, is a good example of a risky offshore project. The field is located on the Barents Sea shelf 600 kilometres northeast of Murmansk (Gazprom 2014b). The project, that was initiated together with Gazprom, Statoil and Total, has faced severe uncertainty, due to the North American shale gas boom and rising costs. Statoil has withdrawn from the project in 2012, which led Gazprom and Total to postpone the project (Barents Observer 2013). Since then, the project has been continued (Ernst & Young 2013).

Other key offshore projects, like the Prirazlomnoye oil field, have also faced difficulties (Mikkonen & Käpylä 2013). In April 2014, Gazprom announced that it had loaded the first cargo of oil produced from the Prirazlomnoye field, which is still the only Russian project for hydrocarbons development on the Arctic shelf (Gazprom 2014c).

Another large-scale international investment project in the Russian Arctic is the Sa-khalin-1 project, which is an international consortium project comprised of the following participants: Exxon Neftegas Limited, a subsidiary of US-based ExxonMobil, the Russian oil company Rosneft acting via its affiliates RN-Astra and Sakhalinmorneftegas-Shelf; Japanese consortium SODECO; and the Indian state-owned oil company ONGC Videsh Ltd. The project is developing three oil and gas fields, Chayvo, Odoptu, and Arkutun-Dagi, located off the north-eastern coast of Sakhalin Island in the Russian Far East. Another major phase of the project will develop the Arkutun-Dagi field, just east of Chayvo. Production is anticipated to begin in 2014. Future project plans call for the expanded development of Chayvo natural gas resources (Sakhalin 1 2014).

So far there are no ongoing offshore drilling projects in Alaska, Canada or Greenland (Ernst & Young 2013). Statoil has estimated that Arctic offshore drilling in harsher areas will start at the earliest by 2030, but most likely closer to 2040 or 2050 (Kauppalehti 2013). The situation in Northern Norway has been described as resembling the Russian Shtokman project and the planned projects, like the Johan Castberg oilfield (€12,000m) is still waiting for better times. If the Norwegian offshore projects are postponed, the development in the region will slow down. (Rautajoki 2014)

Even though the Norwegian Snow White gas field is producing gas for the Menköya LGN-plant and production is likely to be increased (Rautajoki 2014), and the Prirazlomnoye oil field has managed to start oil production, many other Arctic oil and gas drilling projects have been cancelled or postponed. The reasons mentioned include the harsh Arctic climate conditions, high costs and heavy regulation (Kauppalehti 2013). The success of shale gas and oil in the USA has also reduced the profitability of oil wells and gas in Barents Sea (Rautajoki 2014).

Apart from financial reasons, the environmental concerns of the general public, environmental organisations and governments is expected to slow down hydrocarbon development projects in the high Arctic region.

Wind energy*:* The deployment of wind energy in cold climate areas is growing rapidly. There are several reasons for this development; cold climate sites often have favourable wind conditions, and are sparsely populated; technological innovations improve the technical performance of wind turbines in cold and freezing conditions and the trend towards renewable and clean energy is getting stronger. Not all cold climate wind turbines operate in freezing conditions, though it has been estimated that approximately 60% of the new capacity added to cold climate areas would operate in freezing conditions. According to The BTM wind report, World Market Update 2012, 45–50 GW of new wind energy capacity will be added to cold climate sites by 2017, leading to €75 billion in investments. (Navigant research 2013).

Investments in wind energy have increased in Northern Europe, and several wind parks are being planned be built in Northern Sweden (€12,000 m investment) and Norway (€15,921m investment) in the future. The size of the investments is significant. Hydrocarbon and bio-based energy are more established in Arctic Russia, and wind energy has not yet gained a significant role in that region, though there are plans for smaller investments, such as a €320 m investment in wind energy in the Murmansk region, though, this investment is not likely to occur soon. (Rautajoki 2014)

While wind power capacity is estimated to increase, the global economic recession creates pressure to wind energy investments especially in Europe, where the governments subsidize wind energy production and investments. This may lead to postponing of large onshore wind park projects in Europe. Off-shore wind energy is still at an early stage of development, and the first floating wind turbine was developed and piloted in 2010 by Statoil. Arctic climate conditions create additional challenges to onshore and off-shore wind energy production in comparison with cold climate wind energy production. Despite recent developments, offshore wind energy is seen as a developing market with growth potential in the medium to long term (Valor 2013).

Mining: An increased global demand for mineral commodities has in recent years created an increased deployment of existing mineral resources into new mines. One of the areas with high potential to develop economical mineral resources is the Arctic region, such as the Barents region.

In the Western Barents region (Northern parts of Norway, Sweden and Finland), a considerable increase in product volumes is seen in both the shorter and longer perspectives. The product volumes in the region are estimated to increase from today's 75 Mt/year to 106 Mt/year in 5 years' time and 118 Mt/year 10 years from today. The increased production, mainly in Norrbotten in Northern Sweden (currently 32 Mt/year, 50 Mt/year in 5 years' time and 61 Mt/year 10 years from today), require investments in both production infrastructure and new transportation solutions in Sweden and Norway (Lindberg et al. 2014). In the Norrbotten region, the investment potential for the mining industry is estimated to be €5,900m between years 2014 and 2025. In Finnish Lapland, the fastest growing sector has been the mining industry. The growth is estimated to continue after the financial crisis, and the investment potential (€6,980 m) is high for the mining projects on hold. The growth in the mining industry will affect the development of transport infrastructure, including the realization of the Arctic rail project (Rautajoki 2014).

In the Russian Arctic region, the main mining centres are located on the Kola Peninsula, around Norilsk and Murmansk. There are about 25 mines operating in Arctic Russia, the majority producing nickel and copper, and also significant amounts of tin, uranium and phosphate. (Arctic info 2013b based on Lloyd's). Finnish companies already involved in mining projects in the Murmansk region include companies such as Metso, Pöyry, Ahma Insinöörit Oy, Firote Oy and Paakkola Conveyors Oy. The in-vestment potential in the Kola Peninsula mining project is estimated to be €4,090m, and the mining projects are expected to be implemented within this decade (Rautajoki 2014).

Arctic offshore mining is still in an early phase of development. The increasing demand for valuable minerals may trigger the development of the deep sea mining technologies. Apart from technology, and the profitability of deep sea mining, environmental concerns and legislation have also prohibited the excavation of deep sea minerals. In the spring of 2014, a Canadian mining company finalized an agreement to start digging up an area of seabed in Papua New Guinea. This will be the first attempt to extract ore from the ocean floor (Shukman 2014).

Finnish offshore industry, defined as businesses conducting or supporting offshore oil and gas exploration and production as well as other production and related activity in the sea (e.g. offshore wind and wave energy and seabed mining), has experienced a rapid growth with annual growth rate of 13%. The industry's export value is expected to exceed 1.6 billion euros in 2013. (Valor 2013)

The capital intensive investments rely strongly on opening the Arctic seaways and utilization of areas natural resources. Table 8 summarizes the development from that point of view.

Table 8. Summary of the operational environment development.

	Present	Mid-term	Long-term
Artic sea routes	< 700 vessels annually traversing the North-East Passage (NEP) < 60 vessels annually traversing the Northern Sea route (NSR)	> 1000 vessels traversing NEP 100 - 1500 vessels traversing the NSR	Depending on overall development as much as a quarter of cargo traffic between Europe and Asia could pass through the NSR. Opening of other sea routes.
Infrastructure development	Barents and Yamal regions	€10 billion investments in Western Barents €17 billion in Russian Arctic (2014–2025)	Arctic railway Finland–Norway
Mining	Annual production of minerals in Western Barents region increase from 75 Mt (today) to 106 Mt (2019) €4 billion investment potential in Eastern Barents region	Annual production Western Barents region reaches 118 Mt (2024) Increased production in Eastern Barents region	Off-shore and deep sea mining for rare earth metals.
Arctic oil and gas	< 4 off-shore oil and gas production zones Onshore gas production in Yamal Peninsula (< 10 bum production)	> 4 offshore oil and gas production zones in Western Barents and Russian Arctic Onshore gas production in Yamal Peninsula (<150 bcn production)	> 10 offshore Arctic oil and gas production zones, also in Alaskan artic Onshore gas production in Yamal Peninsula (<360 bcn production)
Wind energy	45–50 GW new wind energy capacity will be added to cold climate sites by 2017, leading to €75 billion investments	€30billion investments in Arctic and cold climate wind energy in Scandinavia.	Arctic and off-shore wind energy piloting and production.

5.4 Strategic challenges

The innovation policy analysis carried out in this project (Antikainen et. al. 2014) disclosed six main challenges that experts interviewed and regional actors and entrepreneurs surveyed wished to be managed. The challenges are linked to the implementation of the Arctic strategy.

In the short term, adequate *research funding and allocation of resources to R&D&I* are central challenges. Concrete development projects are needed for allocating the funding for business-oriented R&D&I action, in which SMEs may also participate. Overall, the funding should be directed to R&D near the customer and the implementation end of the innovation cycle. In research, the Arctic research programme of the Academy of Finland and the EU funding schemes are important instruments for increasing understanding of Arctic issues. Developing and maintaining research infrastructure (laboratories, measuring technology, simulators, etc.) should also be ensured. Among Arctic technologies, new business models, standards, networks, markets etc. should be studied and developed. Arctic issues should be recognised in university and school curriculums. Arctic employment is often seasonal and varying, thus it needs flexible and experimental development.

In the longer run, *accessibility and development of infrastructure* become increasingly important issues. Solutions for transport and logistics are crucial for Arctic business. Government guidelines are awaited regarding the transport policies. We need a clear vision about what kind of logistics is wanted in the Arctic region; this also includes the digital services and ICT solutions needed. New logistics routes are opening and this requires dialogue, especially with Norway. Finland's role as an Arctic region window onto the EU needs strengthening and discussion. Different strategy processes and projects related to transport and logistics are in progress (e.g. Development overview of the regional structure and traffic system ALLI (Ministry of Environment), the Joint Barents Transportation Plan, strategies by the Regional Council of Lapland, etc.).

To increase the societal impacts and visibility of Arctic research, a clear *definition of Arctic competence* and *concretizing of sustainable development in the Arctic context* is needed. The interviews and surveys carried out by MDI show that Arctic competence is not a well-established concept, and the experts, technologies and markets of the area are not fully recognized. The obscurity of the concept complicates coordination, cooperation and implementation of the strategies. A comprehensive definition would clarify the resources of Finnish Arctic competence and reposition them in the international landscape. A clear definition and commitment also supports the possibilities of developing the Arctic competence as a Finnish spearhead. Arctic competence links together Arctic land and sea areas, maritime industry and services, environmental technologies, ICT and even space technology. Sustainable development is one of the key requirements of Arctic cooperation and business. It includes both the inclusion of local people and the sustainable use of raw materials. Finland can act as an international forerunner, for example in combining new business solutions and improving the livelihood of indigenous people. Sustainable mining (Tekes green mining, Nordic NordMin, etc.) is one of the openings that await national insights. This also requires transparent public dialogue about Arctic environmental issues.

Cooperation and networking is essential for strengthening the Arctic competence and for utilizing business opportunities. The Strategy for the Arctic Region emphasizes that the whole of Finland belongs to the Arctic region. Arctic organization is new, and the actors do not know each other or recognize themselves as Arctic actors. Overall, the on-going development related to Arctic competence is scattered and not recognized, and Arctic actors need to be mapped on different levels both horizontally and vertically. Cross-regional networking is important and requires active enterprise federations. Large and small companies should work together in order to create globally attractive business (e.g. infrastructure solutions). Similarly, cooperation between research organizations and business needs to be enhanced. Different projects concerning Arctic themes need mutual dialogue, and they could be linked to larger issues such as INKA, the Innovative Cities Programme. Cooperation between Tekes, the Academy of Finland and the Ministry of Employment and the Economy improves the coordination needed, and the Team Finland process helps to clarify the roles of different actors and processes.

International visibility and collecting market information are longer term challenges. Finland aims to be an active Arctic actor in global arenas and connect to international customers.

International cooperation and increasing Arctic business requires long-term orientation and continuity; the cooperation should be based more on wide networks than on direct technology-oriented business. Here the Team Finland process seems to be crucial. At the moment, the most important partners are Norway and Russia, with whom a continuous discussion, market knowledge collection and sharing, and utilizing opening investment opportunities is required. In addition, Sweden and maritime issues related to the Baltic Sea is interesting. Overall, the Arctic region and environment should be considered widely. Similarly, business opportunities should not be limited to large-scale operations such as gas or oil markets, but include small local imports and SMEs. At the moment, many Arctic SMEs feel that they are not given enough information about the market possibilities. Regional knowledge sharing should be strengthened; local Chambers of Commerce and the Centres for Economic Development, Transport and the Environment a key actors in this.

5.5 Paths for Arctic strategy implementation

The bottom layer of the roadmap covers four possible paths for the implementation of Finland’s Strategy for the Arctic Region. These paths combine the Arctic operational environment, competences and innovation policies. They are not alternatives in the sense that one would exclude other ones, but they differ in breadth of scope (paths 1 and 2) and in the means of applied innovation policy (path 3). A more detailed content of the strategy paths is reported elsewhere, but a brief content of each path is presented below.

Path 1 – Spearhead strategy: Arctic marine technology and maritime transport

This path is based on a hypothetical strategy that Finnish actors would focus their perspective on Arctic futures entirely through the lens of marine technology and maritime transport. In short, it would be a focused and narrow strategy emphasising Finnish traditional competences in ship building and the maritime industry, but now set explicitly in the Arctic context. On the other hand, this path can be seen as the one that has already started, for example in the form of Tekes program on Arctic Seas.

Path 2 – Flying geese approach: emerging Arctic pathways

The second path widens the scope of Arctic research and business opportunities from the Arctic area and Arctic sea to the near-by markets. Living and everyday life in the North is an important starting point for technology development in this path. Therefore, also emerging technology areas are sought in addition to marine technology and maritime transport.

Path 3 – Culture of Arctic experimentation

The third path does not focus on any specific Arctic technology but on creating infrastructure, tools and innovation policy that support experimentations leading to faster commercialization of new technologies and services of Arctic applications in traditional and emerging sectors. The third path leads to Arctic futures via agile experimentations, such as living labs, pilot environments, and fast prototyping, cross-breeding of sectors and ideas, and test beds. Living labs are considered to be user-centred open innovation environments, while test beds are seen as platforms for experimentation in large development projects.

Path 4 – Snowdrift strategy: fading Arctic business

The fourth path is based on the supposition that Arctic business potential remains unrealized. In these circumstances, it is reasonable to forget the Arctic context as a focus area. In this path, Arctic conditions are not the starting point of competence development, but rather an additional element of or approach to the competence development on other fields. The needs for competence development may arise from local or regional needs. In the end, Finland is still situated in the Northern hemisphere, and there is a need for solutions for cold climate in construction, energy efficiency or human wellbeing. On the other hand, our location provides possibilities for local businesses, e.g. in relation to tourism. Another alternative in this path is to broaden the concept of Arctic competence also to cover other areas with some element of “extreme conditions”. In this case, Finnish actors in R&D or companies could provide solutions for extreme conditions to the global market. Such a market could be found e.g. in the tropics, in mountainous areas or in sparsely populated areas.

The chapter following presents the detailed technology roadmaps for the strategy paths.

6. Technology roadmaps for the policy paths

6.1 Path 1 – Spearhead strategy: Arctic marine technology and maritime transport

Targets

The target of path 1 is based on a hypothetical strategy that Finnish actors would focus their perspective on Arctic futures entirely through the lens of marine technology and maritime transport. In short, it would be a focused and narrow strategy emphasising Finnish traditional competences in ship building and the maritime industry, but now set explicitly in the Arctic context (Figure 19).

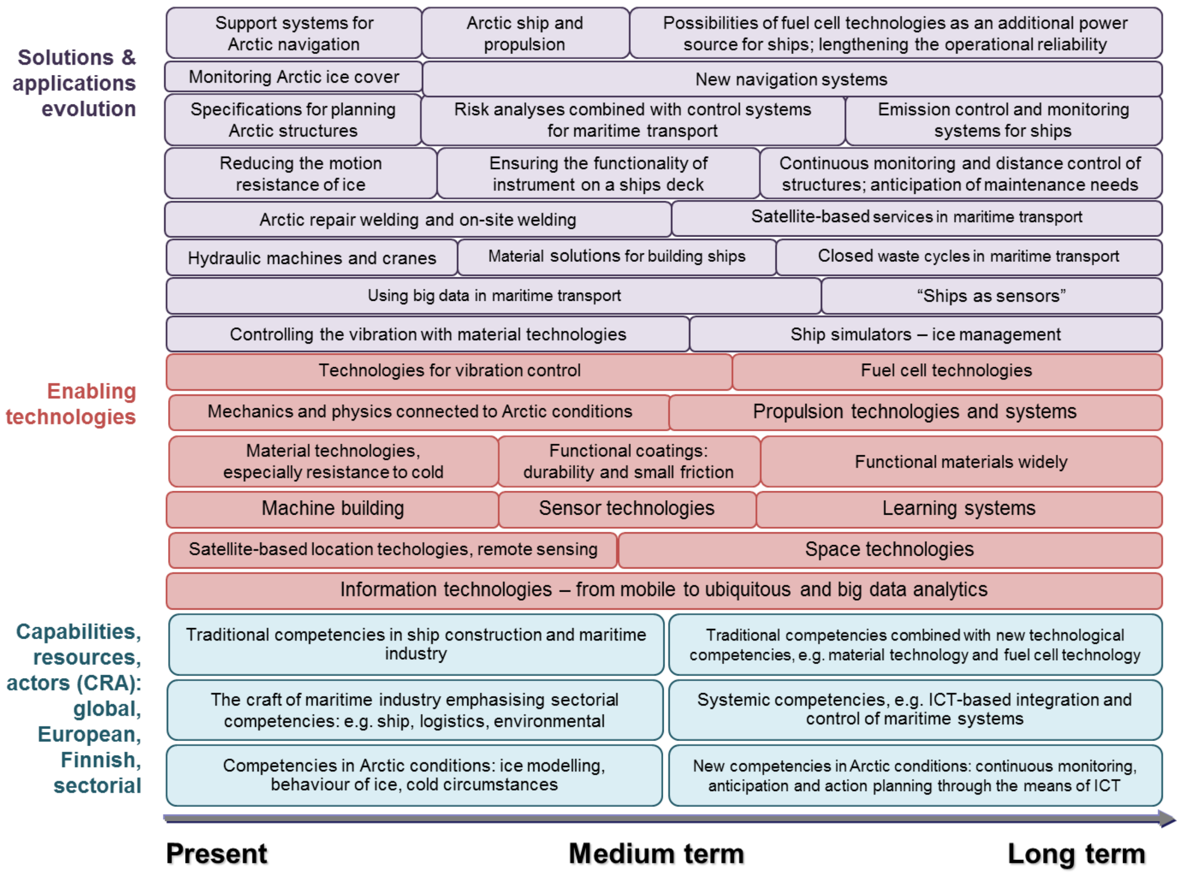


Figure 19. Path 1 — Arctic marine technology and maritime transport roadmap.

Present state of the technology (1-3 years)

Solutions & Applications evolution: At the present and in the short term, the solutions emphasise different kinds of support systems for Arctic navigation. These systems support navigating ships in harsh environments and in the constant physical stress caused by the Arctic conditions. For example, in this case monitoring of Arctic ice cover is an important state of the art solution. This monitoring function could be combined with Arctic navigation systems so as to widen the coverage of such monitoring systems. In addition, there is an increasing need for specific planning procedures and directions on how to construct structures in the maritime industry that would endure in the Arctic conditions. This procedure would include all the functions related to the activities in the maritime industries: the ship itself and its different systems; the control of logistic systems; monitoring of the environment and so on. These directions would be important, for example, in reducing the motion resistance of the ship when moving in ice. There are already different planning, direction and implementation procedures for Arctic repair welding and on-site welding. These are increasingly important in order to maintain the functionality of ships in Arctic conditions. The same also goes for another solution, that is, hydraulic machines and cranes. Currently, it is already possible to use different kinds of big data- based analytics to support maritime transport, but the real applicability of these solutions will increase as new kinds of ship technologies and navigation systems become more common. Also, today it is already possible to control the vibration of ships with different kinds of material technologies.

Enabling technologies: There are several technologies that enable the present state of the art in the roadmap path 1. There are different kinds of technologies for vibration control based, for example, on static, dynamic and thermal analysis; structural design and optimization; vibroacoustics; computational fluid dynamics; and heat transfer. There is also a lot of on-going research activity focused on mechanics and physics connected to Arctic conditions. Material technologies, emphasising especially the resistance to coldness, are a focal area under scrutiny. These include, for example, new kinds of coatings to be integrated with the steel structures of the ships, and also novel technologies that could, for instance, produce light-weight composites. There is also state of the art development in machine building, such as the development of more ecological diesel engines. Satellite-based location technologies, enhanced with remote sensing, are already today's state of the art. Information technologies are an advancing technological frontier also in maritime transport.

Capabilities, resources and actors: The present state of the art emphasises traditional competencies in ship construction and the maritime industry. This means that marine technologies are still based on a long tradition and key tools that have been important across the history of ship building. It could also be formulated that the present craft of the maritime industry emphasises sectorial competencies, for example a division of knowledge between the ship, its logistics, and its connections with the external environments. Also, competencies in Arctic conditions, such as ice modelling, knowledge of the behaviour of ice and cold circumstances, are particularly important.

Developments towards the medium and long term (3-15 years)

Solutions & Applications evolution: The medium and long term possibilities include the development of a more capable Arctic ship with the proper propulsion technology fit for Arctic conditions. There are also promising possibilities of using fuel cell technologies as an auxiliary power for ships. The fuel cells would lengthen the operational reliability of ships when in the Arctic environment. There are also emerging risk analyses and related procedures that could be combined with maritime control systems. Important emerging features are different kinds of emission control and monitoring systems for ships operating in demanding environments. This also calls for ensuring the functionality of instruments on a ship's deck. The emerging possibility, currently under heavy research and development in the fields of aeronautics and space technologies, are materials and structures that could be continuously monitored from a distance. There is an option that these materials could even be developed to become self-monitoring and, at least to a certain extent, self-repairing. Thus, the ships operating in the Arctic region could constantly anticipate and react to the emerging maintenance needs, and thus considerably lower the risk of wider environmental catastrophes. The satellite-based services in maritime transport are heavily on the rise. This includes all sorts of environmental data analytics that could be accessed through ships' multiple sensors and measurement devices. The targets of measurements could, for example, be movements of ice sheets, navigation-related questions and emission monitoring. In the more long-term future, the development could even lead towards the direction in which the entire ship could act as a “sensor”. This means that different kinds of sensor technologies are so integrated into the basic structure of the ship and on its surfaces that basically every part of the ship can collect data and monitor its surroundings at different levels. There are several emerging material technologies that could be pivotal in shipbuilding. These include novel composite technologies and new layered technologies to gain different kinds of properties. These new materials could be produced with traditional layered welding technologies, but, in the future, also through the means of additive manufacturing. In the future, it would also be crucial to develop different kinds of solutions for closed waste cycles in maritime transport. This is especially important when operating in a region of such vulnerability as the Arctic. The big data types of analytics will be used in all control functions of the ship. Ships will thus be “aware” of their environments, at least as it comes to monitoring the interface of a ship’s surfaces and its immediate surroundings. There will also be ship simulators that are used in developing novel solutions for ice management.

Enabling technologies: Some technologies that enable the developments described above are fuel cell technologies. Also, novel propulsion technologies and systems will be crucial. Functional coatings will be used to gain durability and to lessen the friction caused mainly by ice. Different kinds of functional materials, for example those used in space technology development, and sensor technologies will play a key role, especially if and when Arctic ship technology develops towards a “ship as a sensor” type of entirety. This development is also enabled by using different kinds of learning systems and ICT, ranging from mobile to ubiquitous and big data analytics, as a backbone of the information structure of the Arctic ship. Thus, the ship will become even more complex socio-technical network than it is today. However, the key advantage in this development is that the ship is not just able to monitor and anticipate the changes in its structures and in its environment, but is also capable, at least to some extent, of taking action and hence maybe capable of preventing major catastrophes that could be fatal in the Arctic region.

Capabilities, resources and actors: In the future, the traditional competencies in ship construction and maritime industry will be combined with new technological competencies, for example with competencies in material technology and fuel cell technology. There will be increasing needs for so-called systemic competencies, for example by combining sensor-base ICT solutions and general ship control. New competencies in Arctic conditions will also be highlighted. These include continuous monitoring, anticipation and action planning through the means of ICT.

6.2 Path 2 – Flying geese approach: emerging Arctic pathways

The second path widens the scope of Arctic research and business opportunities from the Arctic area and Arctic sea to the near-by market. Living and everyday life in the North is an important starting point for technology development in this path. Therefore, also emerging technology areas are sought in addition to marine technology and logistics. In the following, we present the themes and roadmaps for the second path developed in the workshop process of SMARCTIC project.

Figure 20 shows the themes that were identified in the project and included in Path 2. These themes were developed into roadmaps in a varying level of detail. These roadmaps are discussed in greater detail in the following sub-sections.

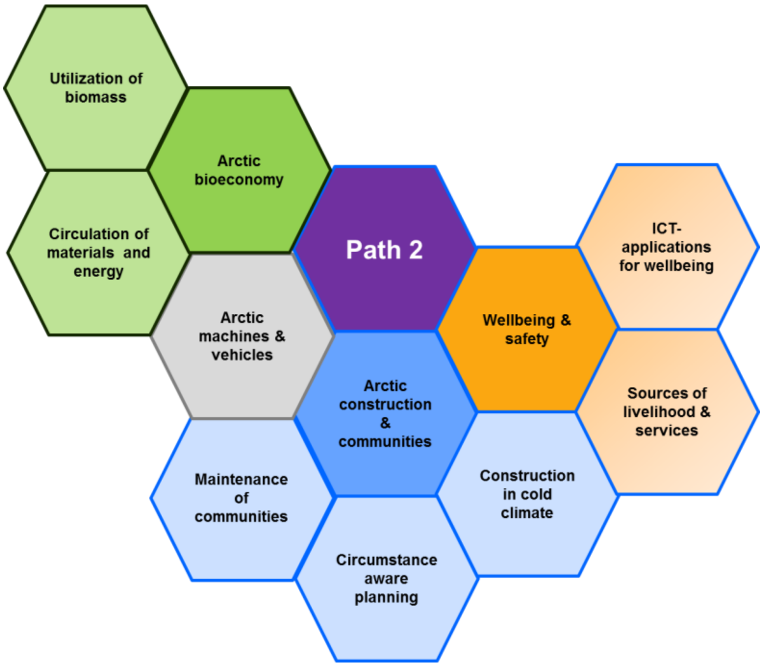


Figure 20. Technology themes included in Path 2 cover Arctic communities and construction, wellbeing and safety, Arctic machines and vehicles, and bioeconomy-related developments.

6.2.1 Roadmap for Arctic communities and construction

Targets

Figure 21 shows the roadmap for Arctic communities and construction. Increasing economic activities in the Arctic region will increase the need for solutions for construction and community development. Challenges related to sustainable development have increased the pressure to create resource and eco-efficient technologies. The Arctic is characterised by a sparse population with scattered communities and long distances. The harsh Arctic climate sets special requirements to the built environment and energy systems. The target in this field is to develop solutions for closed-loop and to some degree self-sustaining Arctic communities. This requires development of decentralized technology concepts for living, construction and the energy sector based on improved capabilities and integration of competences in selected areas. In this roadmap, special attention is laid to energy systems in the Arctic.

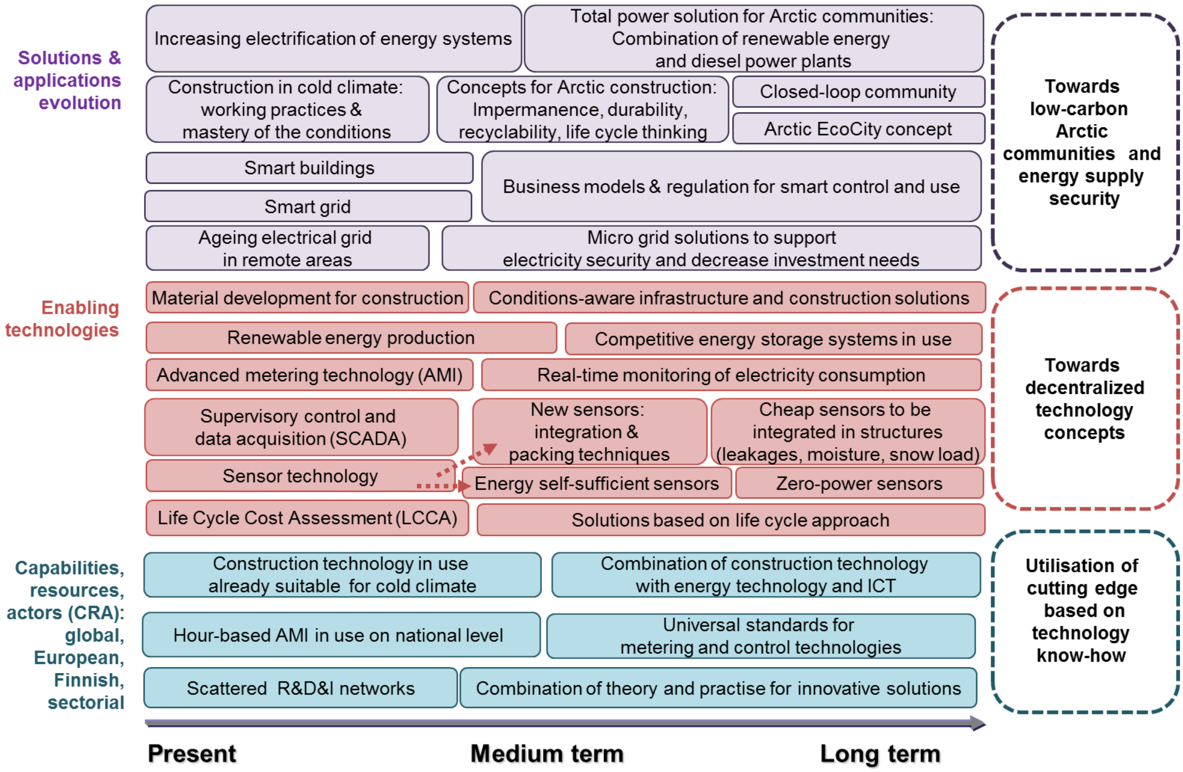


Figure 21. Roadmap for a theme "Arctic construction and communities".

Present state of the technology (1–3 years)

Solutions & Applications evolution: In the present situation, a strong dependency on fossil fuels in energy systems is characteristic of the Arctic communities. Construction in a cold climate requires special attention to energy efficiency and working practices. There are significant needs to modernize the existing housing stock from the points of view of energy efficiency and aesthetics. An interest in innovative solutions for e.g. the outer layer of buildings (walls, façades) as well as in the areas of ventilation, air recirculation and air recovery inside buildings will be high. Building automation systems (BAS) represent another interesting, emerging area. It has the goal to monitor and control the building with respect to fire and flood safety, lighting, security, HVAC, humidity control and ventilation. BAS leads to an increase in living comfort and personal safety. One of the most important areas in building automation is BEMS – building energy management systems. It is a practical tool to implement energy demand side management in the building sector, and as such it functions as one important element in the smart grid.

The smart grid is a next generation electrical power system. It is a means of delivering electricity from producers to consumers using ICT technology to control consumption load in order to enhance energy savings, reducing cost and increasing reliability. Elements of the smart grid include distributed generation, virtual power plants (VPP), active demand in consumer networks, demand side management (DSM), electricity storage technologies, advanced metering infrastructure (AMI) and supervisory control and data acquisition (SCADA) (Hasmi 2011).

In the present state, the energy system is characterised by fuels, fossil energy carriers and energy dependency on imports. The Northern areas are part of the national grid with centralised electricity production patterns. However, there is a clear motivation to shift the energy sector to a low-carbon, self-sustained system with a high level of energy efficiency. The motivating factors are climate change and energy security reasons. In this change, use of fuels will decrease and electricity will increase its' importance. In the North, the electricity grid is aging and needs maintenance and investments in new infrastructure. Due to the long distances, the need for investments is high. However, this can be avoided to some degree by the microgrid concept, which is a small local grid connected at one point to the national grid. It is able to operate on an autarchy basis. The microgrid consists of decentralised technology in buildings and the energy system.

Enabling technologies: The cold conditions in the Arctic area set high requirements for the construction materials, and therefore the temperature-dependent phenomena in the materials need to be known. For instance, a need for Arctic building materials suitable for permafrost and produced from mining and timber industry waste¸ as well as life sustainable and energy-efficient building techniques will be high. There will also be a demand for quick build and mobile buildings with independent support and security systems (Finpro 2012). The increasing human activities in the Arctic require more environmental monitoring studies to assess the change, and to monitor and maintain a balance between Arctic ecosystems and urbanization. Continuous condition monitoring can bring remarkable advantages in the Arctic area, as it may be to impossible carry out unplanned maintenance or repair activities due to the difficult accessibility of the area. Sensor technology is a key technology for integrated condition monitoring. In general, the life-cycle approach is an important aspect in the development of solutions for the Arctic area. In addition to environmental issues, costs should also be included in the development and assessment of the solutions.

For Arctic energy challenges, several technological approaches already exist. Elements of the smart grid and building automation concept can roughly be allocated in four groups: decentralised energy generation technologies, energy storage technologies, metering applications and ICT solutions for smart communication and control of the various parts of the smart grid. Several of the technologies are already in use in Finland such as advanced metering technology (AMI), which allows for two way communication and hourly end-user electricity load measurements. In the current system, the consumer is able to receive their own electricity consumption profile with a time lag of one day. Apart from that, building automation systems make use of various other detectors such as gas and smoke detectors, heat sensors, fire protection systems, breaking glass detectors or water leakage detectors (READY4 Smart Cities 2014). Automated distribution grid management is provided by SCADA, a supervisory control and data management system, which includes a self-healing system. Various means of energy storage are on the market: heat storage (warm water storage in households) and batteries (Li-ion, NiMH). Distributed renewable energy production technologies are in some cases already in the current state competitive (small-scale hydro, biomass), whereas other technologies need further R&D investments (solar electricity, wind mills).

Capabilities, resources and actors: Key competences that need to be developed in the construction sector: material technology, soil mechanics and frost, infrastructure planning, construction in a cold climate. In the smart grid/ building automation sector, key competences include: ICT technology, metering and sensor technologies, integration of ICT in metering and energy technologies. The research and innovation system in the field of construction is scattered today, and there are needs for an improved combination of theory and practise and cooperation bridging different sectors. Finland's strengths in the field are experience of construction operations in cold climate and snow, and a nationwide use of advanced metering infrastructure (AMI).

Developments towards the medium and long term (3–15 years)

Solutions & applications evolution: In the medium and long term, concept thinking is implemented increasingly in Arctic construction. Construction in the Arctic should be considered as a temporal action which is dependent on the economic and political changes.

Therefore, new Arctic construction solutions are modular, adaptable, portable and recyclable. Arctic conditions are a foundation for concept development including such characteristics as impermanence, durability, recyclability and life-cycle thinking. Re-inventing the modernist idea of the minimum space required by each function to find lightweight and environmentally friendly solutions should be also considered. The use of imported artificial materials on their behalf should be minimized and local natural materials favoured (Varjus 2013).

Several of the technologies and applications needed for a functioning smart grid or microgrid exist already in the current state. However, more R&D is needed to enhance the cost effectiveness of the technologies and therefore help their market penetration (energy storages and electric vehicles). Further R&D is related to modelling the market including: various business models, the impact of varying electricity pricing on demand response and energy storages, dynamic tariff models, various business models related to active end-consumer, automatized active end-user, price elasticity of demand, load models, heat storages acting as electricity storage, microgrid operation (year round) (Joy et al. 2013).

The renewal of the ageing electricity grid of Northern areas becomes topical in the long term. Due to a scarce population and large distances in the Arctic, this will be costly. A microgrid can be a cost effective alternative to the renewal of the existing aging macrogrid infrastructure. A microgrid is a local grid with electricity generation, storage capacity and electrical loads. In normal operation, the microgrid is connected to a larger macrogrid at one point. However, this connection can be interrupted and the microgrid is fully functional as a stand-alone entity.

Enabling technologies: In the middle and long term, the development of construction materials, energy and environmental solutions is integrated to the development of decentralized solutions for cold climate. Another line is to develop conditions-aware infrastructure and construction solutions for a cold climate. This development requires development of sensor technologies. In the middle term, this means new integration and packaging techniques, and the development of energy self-sufficient sensors, and zero-power sensors in the longer run. The goal is to be able to produce cheap sensors to be integrated into structures in order to detect water or heat leakages, moisture, or load caused by snow.

To enhance the functionally of the smart grid concept, metering technology has to be developed further so as to provide real-time monitoring data on minute basis. The consumer would then be able to monitor their own electricity load in real time and act accordingly. A real time consumption load will generate large amounts of data. This raises critical questions for development. Who is allowed to use the data and take financial advantage of it? Cyber threats are real for big data; therefore, IT cyber security authentication and encryption technologies are needed for protection. Energy storage is a vast area with R&D potential: supercondensors, vanadium redox flow batteries, fuel cells with associated electrolysis. Plug-in electrical vehicles are one special application serving as electrical energy storage (Joy et al. 2013).

Capabilities, resources and actors: Universal ICT standards need to be developed for metering and communication devices for smart grid solutions, since currently a lack of interoperability between ICT functions delays creating a common network between building automation and the smart grid. This requires the involvement of standardisation institutions and cross sectorial cooperation. Key capabilities that enable the development include the harmonising of standards for metering and control technologies, development of business models for the building and energy sector and R&D in the energy storages and electric vehicles.

6.2.2 Roadmap for ICT-solutions for well-being

Targets

The target for solutions and applications development is to enable and increase co-creation so as to ensure the usability and usefulness of well-being services. Also, in the long term the improvement of availability and contextualisation of services in the Arctic area is aimed at. The enabling technologies for this development require reliable and energy-efficient data networks and functional sensor systems. Central resources for this development are capable people, cross sectorial cooperation, and a national service bus, which enables flexible communication between service applications. The target in this field is desired data transparency from different data sources (Figure 22).

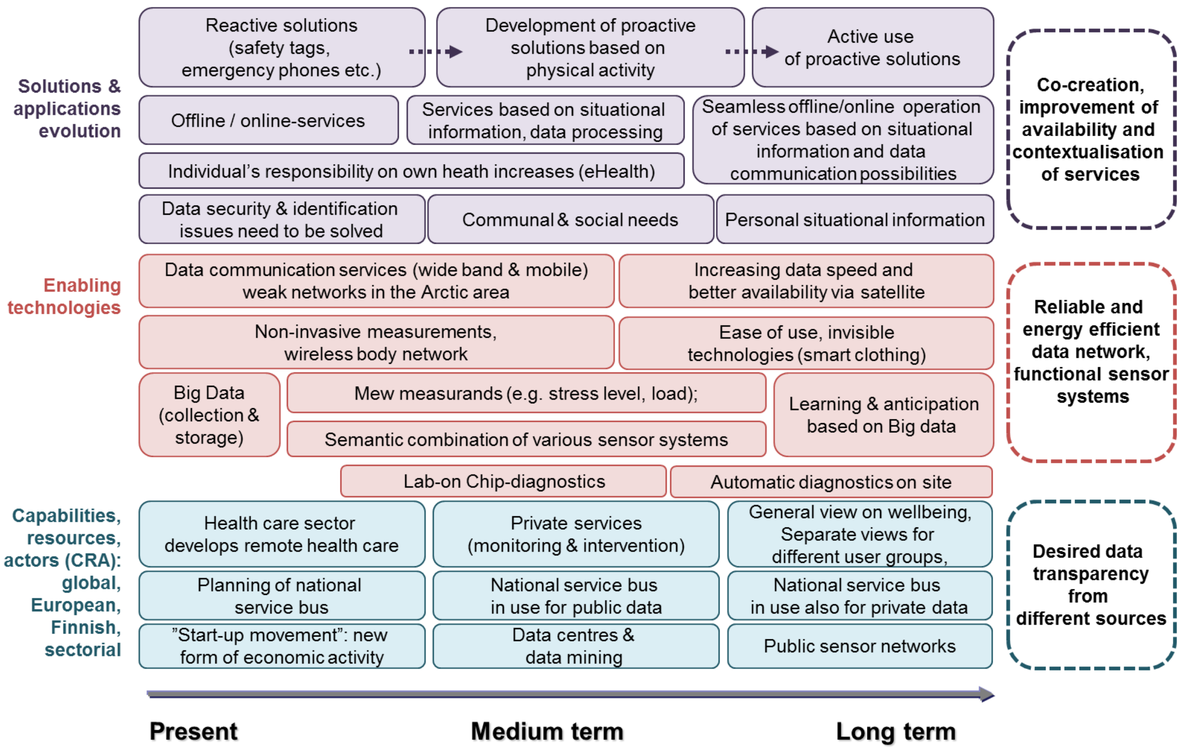


Figure 22. Roadmap for ICT-solutions for well-being.

Present state of the technology (1–3 years)

Solutions & Applications evolution: The state-of-the characteristics of the ICT-solutions for well-being can be described to be *reactive*, as there are such solutions as safety tags and emergency phones on the market. Also, the services are not dynamic, as they operate either on offline or online modes. Socially, the prevailing trend is that the individual's responsibility on his/her own health is increasing, and this tendency will be greater in the future. For this purpose, various eHealth technologies and services have been developed. eHealth technologies refer to electronic personalised health systems for citizens, and also to tools for authorities and professionals, to be used for assisting in better heath monitoring, and the more effective operation of the health care system. A bottleneck for the development of such services is data security and reliable identification of users. These issues need to be resolved before wide-scale development of services is possible. Remote and eHealth services are especially important in the Arctic context, because distances are long and population density is low in the Arctic area.

Enabling technologies: A prerequisite for ICT-solutions is workable data communication services, i.e. wide band and mobile networks. In the Arctic area, data speeds are low due to weak networks. The possibilities of Big Data applications are also promising. However, the present technologies in this field concentrate primarily on data collection and storage, and application development is less frequent. As mentioned above, the data security and identification technologies also need to be developed.

Capabilities, resources and actors: In order to be successful in health and well-being-related application development, cooperation between various fields, as well as, public and private sectors need to be promoted. At the moment, the health care sector is the primary developer of remote healthcare solutions. To accelerate digital service development, the national service bus needs to be implemented. National service bus is a concept for data transfer that aims at standardized data transfer practices and therefore promotes flexible communication between different service applications. The general architecture of the national service bus has been planned (Valtiovarainministeriö 2013).In general, the development of new ICT-solutions and services requires a new kind of economic activity – “a start-up movement” – that introduces new actors in the field. There is a good opportunity for such a movement, as the downshifting of mobile technology development in Finland released plenty of capable people and relevant competences onto the market. Some of these resources can be harvested into ICT development in relation to health care and well-being, also in the Arctic context.

Developments towards the medium and long term (3–15 years)

Solutions & Applications evolution: The direction in applications development is from reactive ICT-solutions to proactive ones which are based on physical human activity. Such applications are developed in the medium term and implemented and used increasingly in the long term. These applications enable safer operation in harsh conditions as decreased human performance can be detected automatically. Services are developed into a more dynamic direction. This includes the fact that service applications can be tailored based on situational information, and for this purpose also data processing methodologies are developed. Another element of dynamic services is their seamless online or offline operation based on situational information and the availability of data communication capacity in the given time. After the solution of basic technical requirements in relation to data security and identification, other drivers start to direct application development. These drivers are communal and social needs in remote areas, in the medium term, and utilization of personal situational information in the longer term.

Enabling technologies: In the long run, data speed and availability in the Arctic area can be improved via satellite connection. This increases the possibilities of service development. To implement well-being-related ICT applications, and especially proactive solutions, measurement technologies need to be developed. The first step is to develop non-invasive measurements and wireless body networks. In the later stage, ease of use and invisibility of technologies are the main drivers for technology development. This means development of wearable technologies, such as smart clothing. The development of measurement technologies also requires non-technological development. For example, completely new measurands, such as stress level or psycho-physical load need to be developed. This requires cross-disciplinary cooperation and semantic combination of various sensor systems. The long-term direction is to develop systems that are capable of learning and anticipating on the basis of big data analysis. A special branch of technologies in the health care field is the Lab-on-a-Chip devices (Foresight Horizon Scanning Centre 2010), which integrate and scale-down biomedical and other analytical laboratory functions and processes to a miniaturised chip format. This technology offers possibilities for moving many diagnostic and analytical activities out of fixed, centralised, facilities and providing real-time information to health care in remote locations.

Capabilities, resources and actors: Over time, there are increasing public-private partnerships in service development. Data integration enables advanced applications that provide an overall view on a person's well-being, but with separate accesses for different user groups, such as the person him/herself, his/her employer or health care professionals. The national service bus will be implemented and available for public service providers and public data starting from 2015. Later, also private service providers can start to use the service bus, and its full potential will be utilized. This way the national service bus provides a real boost for service innovation and businesses. Businesses develop from the start-up movement to more institutionalized infrastructures, such as data centres and data mining operators. Arctic conditions may provide a unique set for data centres, as snow can be utilized in cooling. Finally, public sensor networks need to be developed in order to enable a combined use of various data sources and situational information for application development.

6.2.3 Roadmap for Arctic machines and vehicles

Targets

The goal in the Arctic machinery roadmap is that there will be machines that are designed for the special purpose of being used in Arctic conditions and these designs are based on verified information and research findings, not on experience and practical know-how. The technology trajectory is from locally and manually operated solutions towards remote operation, and finally to autonomous machines. This development requires Arctic specification in R&D and improved knowledge transfer in networks (Figure 23).

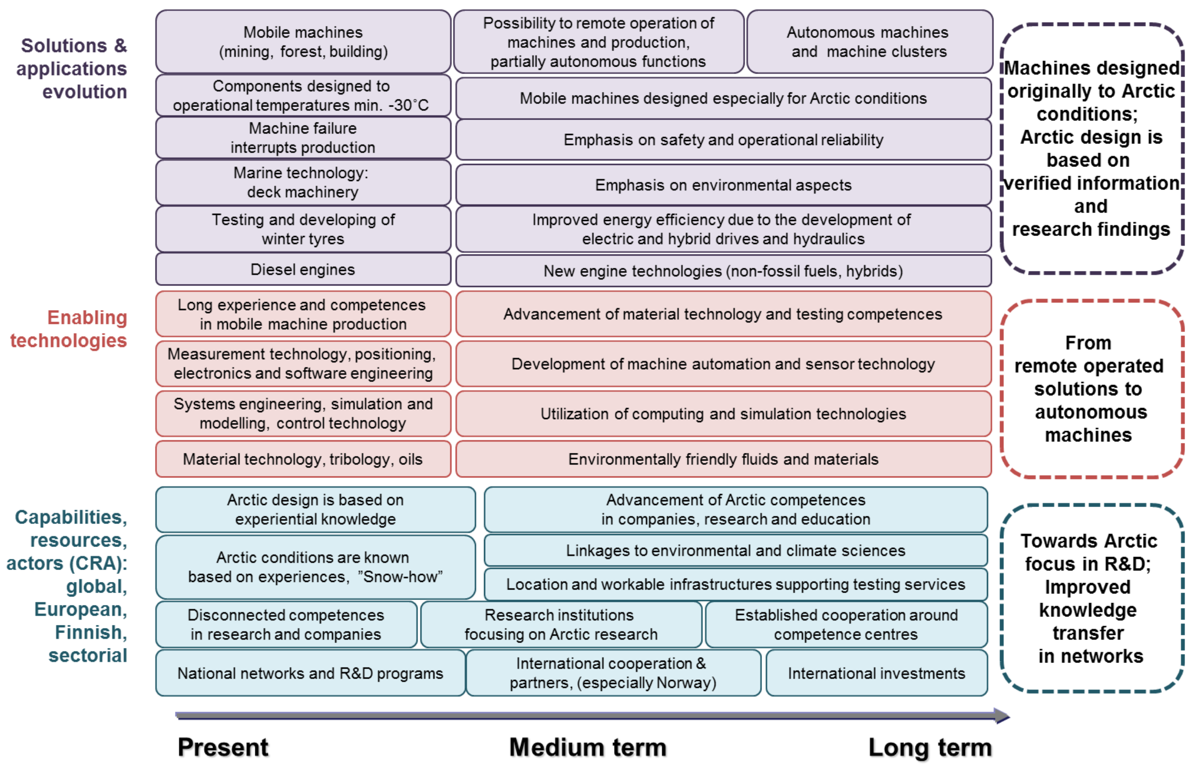


Figure 23. Roadmap for theme "Arctic machines and vehicles".

Present state of the technology (1–3 years)

Solutions & Applications evolution: Finland has creditable traditions in the production of mobile machines for mining, forestry and the building industry. These machines can be used in a cold climate, as components are typically designed for temperatures at a minimum of -30˚C. The demand for machines to be used at even lower temperatures is so far so low that there has not been a need to design machines especially for the Arctic context. Operational reliability has not been a primary requirement in machine design. If any machine failure occurs, the production typically stops instantly in, for example, a mine or logging location. In addition to mobile machines, other applications relating to this theme are deck machinery for the shipbuilding industry and engine technology, especially diesel engines. There is also know-how in relation to winter tyre testing and development in Finland.

Enabling technologies: The development of mobile machines requires a wide range of technologies. In addition to mechanical engineering, there is a need for automation and control engineering, systems engineering, simulation and modelling, as well as for material technology, tribology and chemical engineering (the development of oils). Today, autonomous functions in machines are rare, and limited to closed environments, e.g. underground mines. To develop these features, one needs a combination of advanced measurement technologies, positioning technologies, electronics and software engineering to machine building.

Capabilities, resources and actors: The Northern location has created experiential knowledge of operations in a cold climate. It seems that, in the field of mechanical engineering, present Arctic designs are more based on these experiences than on scientifically verified knowledge. Experience, “Snow-how”, appears also in the maintenance of road infrastructure, and e.g. airports. There are also competences on the Arctic testing of vehicles and machine components available in Finland in several companies and research organisations (Oulun yliopisto 2014). Geographical location and functioning infrastructures (e.g. air connections to Lapland) support the opportunities in this field. However, the competences in this field are scattered across different organisations, such as universities, universities of applied sciences, and VTT and other research and technology organisations. National networking and R&D programs have limited opportunities in the field, as all the big component producers in the field are multinational companies, and they are important players in machine development. Finnish companies have the capabilities to produce Arctic machines and components, such as hydraulic systems, but the demand so far is low.

Developments towards the medium and long term (3–15 years)

Solutions & Applications evolution: Remote operation of machines and production processes is the future direction of solutions development. In the medium term, it will be possible to realize partially autonomous functions, and in the long run, the target is to produce completely autonomous machines and ships for the Arctic context. Environmental aspects and operational safety need to be taken into account in the application development, and these requirements will be more stringent in the long run. For example, mobile machines need to have backup systems that enable moving the machines from working location, if any failures occur, because it may be impossible to organise maintenance operations in the remote locations of the Arctic. In relation to environmental aspects, the development of bio-based liquids for hydraulics and improvement of the energy efficiency of machines become necessary.

Enabling technologies: When machines are planned and built for Arctic operations, it is necessary to pay careful attention to material development and testing. Remote operation and autonomous functions require the development of automation systems and sensoring technology. Also, better utilization of calculation and simulation techniques is needed. The development of environmentally friendly hydraulic oils and liquids, and improvement of energy efficiency are important aspects form the environmental point of view. In the long run, alternative energy sources will replace fossil fuels, and therefore engine technology will shift more towards hybrid solutions.

Capabilities, resources and actors: Competences in relation to Arctic machine engineering need to be strengthened in companies so as to improve the possibilities of producing Arctic machines and vehicles. The first step is to build these competences in research and education institutions. A central aim is to increase Arctic knowledge that is based on research, especially mechanical engineering and automation competences need to be combined with environmental and climate sciences and research findings. There are remarkable gaps in Arctic knowhow, e.g. in relation to hydraulics, because these topics were researched extensively in the 1980s. Since then, materials and technologies have developed remarkably. Therefore, there is a need for updating the planning guidelines in the field. Outdated instructions and standards may slow down development in the field. There is a need for improved cooperation in R&D. In the medium turn, there should be research organisations that focus on Arctic machinery, and later these should develop into knowledge centres that involve other actors in cooperation. It is important to improve the sharing of knowhow, information flows among different actors, possibilities for cooperation. There should be also more international cooperation and active search for partners, especially Norway is an important partner in the field of Arctic machinery. In the long run, the goal should be to increase international investments in Finland.

6.2.4 Roadmap for the Arctic bioeconomy

There are different ways to define a ‘bioeconomy’. For example, the Finnish bioeconomy strategy defines the notion of bioeconomy as follows:

> *Bioeconomy refers to an economy that relies on renewable natural resources to produce food, energy, products and services. The bioeconomy will reduce our dependence on fossil natural resources, prevent biodiversity loss and create new economic growth and jobs in line with the principles of sustainable development.* (TBFS 2014: 3)

Also, the report makes a following definition from the perspective of Finland:

> *The most important renewable resources in Finland are the biomass, or organic matter, in the forests, soil, fields, water bodies and the sea, and fresh water. Ecosystem services are the services offered by the environment, including binding carbon dioxide and opportunities for recreation. Another key aspect of the bioeconomy is not wasting natural resources but using and recycling them efficiently. (TFBS 2014: 6)*

In a recent paper, McCormick and Kautto (2013) defined bioeconomy as:

> *The concept of a bioeconomy—also called the —bio-based economy or—knowledge-based bio-economy (or KBBE)—can be understood as an economy where the basic building blocks for materials, chemicals and energy are derived from renewable biological resources, such as plant and animal sources [1–3]. This type of economy can meet many of the requirements for sustainability from environmental, social and economic perspectives if it is designed and implemented intelligently.*

The OECD (2009: 15) definition of a future bioeconomy integrates the following three aspects: knowledge of genes and cell processes, different dimensions of renewable biomass, and the integration of biotechnology applications across sectors. Figure 24 shows a roadmap for bioeconomy developments in the Arctic context. In this roadmap, we will generally adhere to above-mentioned definitions, but it should be noted that the specific Arctic context could bring some new emphases to these definitions. For example, bioeconomy in the northernmost Arctic region is obviously not concerned with forestry, but it could be more about specific sustainability regulations that touch upon the maritime traffic in the region, or issues of fishing or mining natural resources.

Currently, the bioeconomy is high on the political agenda. For example, the EU, UN and OECD have produced several strategies and papers on bioeconomy. For example, the European Commission has described the bioeconomy as one of the core elements of smart and green growth. This aspect has been mobilised in different policy initiatives in the EU, such as the 7th Framework Programme and Lead Market Initiative (McCormick & Kautto 2013: 2591). Several nation-states, such as Finland, Sweden, Norway, Germany, and the Netherlands have set the bioeconomy high on their political agenda. Thus the key issue in the current stage of the bioeconomy is that it is much driven by policy actions and regulations; it is thus an active outcome societal action, an entity that does not exist in a vacuum on its own. In 2014 Finnish governmental organisations have realised a national strategy for the bioeconomy (TFBS 2014) which forms a sound basis for further development of the bioeconomy agenda. While the strategy is not explicitly set in the Arctic context, it obviously has critical Arctic repercussions. The basic components of the Finnish bioeconomy strategy are:

- diversification of bio-based products based on a more versatile use of biomass
- pioneering bioenergy production and use
- increased use of bio-based raw materials in the chemical industry
- timber construction to account for a significant share of urban construction
- bioeconomy in the field of cleantech
- new innovations in the food industry
- biotechnology and the health sector
- water resources
- decentralised, resource-efficient bioeconomy solutions

Most of the components in the list above have Arctic dimensions. However, especially the final bullet point – decentralised, resource-efficient bioeconomy solutions – has explicit Arctic consequences. This component focuses, firstly, on improving regional self-sufficiency in energy and nutrients, and the promotion of energy and material efficiency. The second emphasis is on a more efficient use of nutrients through closed cycles that lessens the dependence on the region of import. The third emphasis is on the versatile energy use of local raw materials.

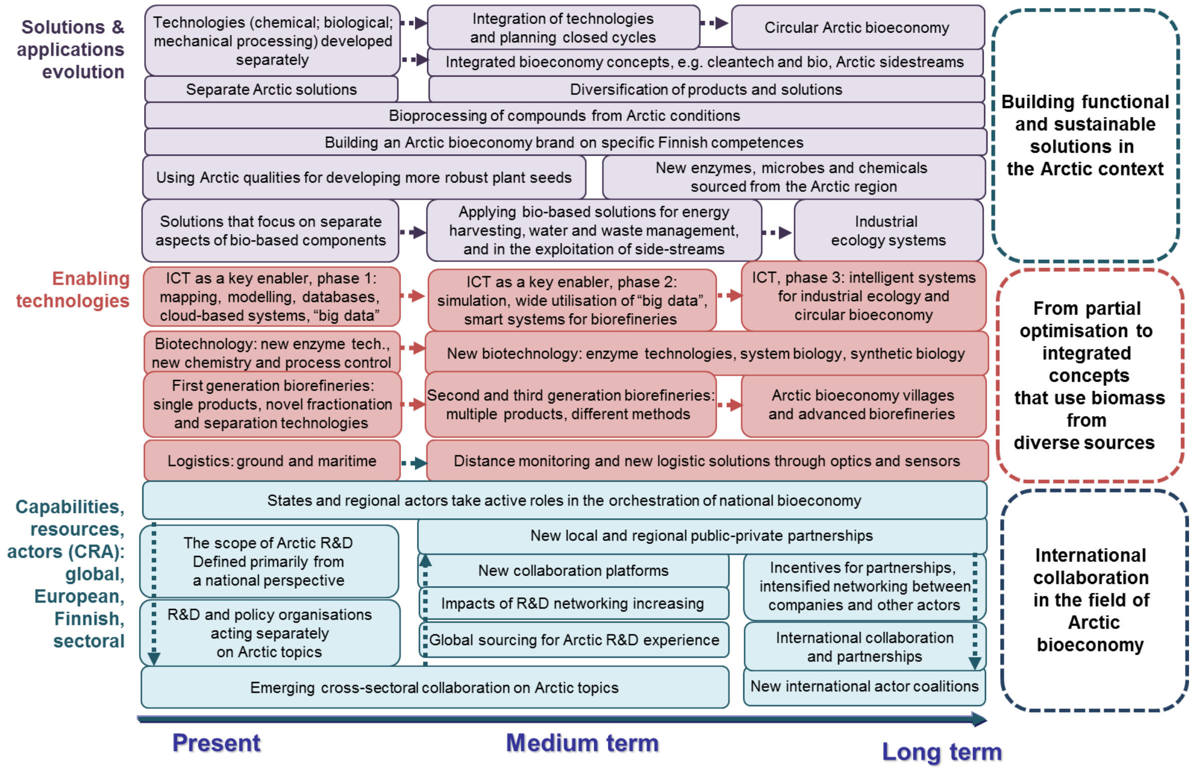


Figure 24. A roadmap of Arctic bioeconomy.

Targets

A future target in the solutions and applications of the Arctic bioeconomy roadmap is to build functional and sustainable solutions that would fit the Arctic context. To achieve this target, the development of enabling technologies should move from partial optimisation to integrated concepts that use biomass from diverse sources. A general guideline in the capabilities development is to increase international collaboration in the field of Arctic bioeconomy in multiple ways. It should be noted that, in the Arctic context, the notion of bioeconomy is particularly linked with the primary sector, such as agriculture, forestry, and fisheries, and with resource-efficiency and circular economy, that is, concentrating on sustainable and non-waste producing processes.

Present state of the technology (1–3 years)

Solutions & Applications evolution: A general characteristic of the present solutions development is that chemical, biological, microbiological and mechanical technologies are developed separately. This leads to sub-optimal partial optimisation and limits the possibilities of finding innovative and functional solutions. The same fragmentation also characterises the development of Arctic applications. Today, the focus is more on individual uses of bio-based components and their transformation, instead of parallel development of related applications. An example of the possibilities that the Northern location and cold climate may provide in relation to the bioeconomy is to use Arctic characteristics for developing more robust plant seeds. For example, it is possible to grow seed potatoes that are resistant to plant diseases due to the climatic circumstances. However, there are fields in the evolution of solutions and applications that are currently developing somewhat rapidly. One of these is bioprocessing of compounds from Arctic conditions, and thus scouting, for example, for compounds that would have pharmaceutical or nutritive functionalities.

However, as is noted in the roadmap visualisation, currently the focus is primarily on solutions that focus on separate aspects of bio-based components. Already, building a brand that builds on the Finnish strengths in Arctic bioeconomy, such as competence in technologies, sustainability and stable environment (e.g. “Finnish pure Arctic”) could be utilised to integrate the development of the Arctic bioeconomy. This brand could also carry development towards the medium and long term.

Enabling technologies: The key enabler in the Arctic bioeconomy is ICT. In the first phase, ICT will enable mapping solutions and different kinds of modelling solutions, such as system dynamic models for charting anticipated changes and transitions in systemic domains. Currently, ICTs offer several possibilities for adopting cloud-based systems and “big data” solutions in the Arctic bioeconomy. Another key enabler is biotechnology and, in the short time span of 1 to 3 years, the applications will be in the domain of new enzyme technologies, new methods for chemistry and process control. The third enabling technology is more a combination of technologies, namely the first generation biorefineries. The first generation biorefineries are already emerging in different parts of the globe, and currently they mostly focus on single products, such as biofuel. However, these biorefineries could already utilise novel fractionation and separation technologies and thus open new technological pathways that could lead towards more advanced biorefinery concepts with multiple product lines (see Ahlqvist et al 2013a & 2013b).

Capabilities, resources and actors: Currently, states and regional actors are taking active roles in the orchestration of the national bioeconomy. In the short run, this will lead to a position in which the scope of Arctic R&D will be defined primarily from a national perspective. Also, R&D and policy organisations are acting separately on Arctic topics, and searching for impacts mainly through separate pathways. However, there is already emerging cross-sectorial collaboration on Arctic topics that aims at new kinds of openings. This collaboration is supported by more long-term transnational co-operation in the Arctic, such as the Arctic Council that was set up in 1996 to drive interaction between the Arctic States.

Developments towards the medium and long term (3–15 years)

Solutions & Applications evolution: There will, obviously, be more solutions and applications in the field of Arctic bioeconomy, as the general bioeconomy trajectory develops and matures. One key direction in the solutions will be systemic applications. Thus, the integration of technologies and planning closed cycles, leading in the long term towards circular Arctic bioeconomy, will be a core development trait. This development will lead to a more long-term planning of Arctic closed loops, in which solutions, enabling technologies, and side-streams are approached as wider systems in which all the materials are used efficiently and practically no waste is produced. This development will also breed novel integrated bioeconomic concepts, such as combining cleantech and bio, and also solutions for the utilisation of Arctic side-streams. A potential integrated solution – that would have a good fit for the Arctic region – was presented in the Finnish bioeconomy strategy (TFBS 2014). The strategy outlines decentralised, resource-efficient bioeconomy solutions that would enhance the viability of regions. This solution could cover issues such as closed systems and the circular economy, in which the solutions are not thought of as single applications, but as bigger loops that take into account the entire chain of production across the life cycle. The Finnish strategy envisioned regional self-sufficient systems that would utilise energy and materials efficiently.

More generally, the medium to long term will witness a diversification of products and solutions in the field of Arctic bioeconomy. The solutions will increasingly build on knowledge combinations from chemical, biological, microbiological and mechanical domains. The basic research has then advanced, and there will be new knowledge, for example, about how climate change affects material flows in the Arctic conditions. These novel scientific perspectives open possibilities for the development of a future Arctic bioeconomy. Also, wood-based materials will be used more widely for high added value products (see TFBS 2014; Ahlqvist 2013a & 2013b). This will also bring new possibilities for the Arctic region. The sectorial boundaries will increasingly blur, and this will lead to the formation of new value network structures. New technologies, such as nanotechnology, will merge with existing value networks, thus also creating new niches in the Arctic bioeconomy.

The biomass that is going to be used will also be diversified. The use of biomass, and the ways of thinking about biomass, will be significantly widened, as wastes and side-streams will increasingly be perceived as raw materials and not as “mere garbage”. Additional possibilities can be found in the utilization of side streams (e.g. fisheries) and bioprocessing of compounds originating form Arctic conditions (e.g. light). The general line in the application development is to find synergies between bio-mass-based materials production and energy harvesting, water management, waste management, etc., and to strive for the development of entire industrial ecology systems in the long run. Waste and side-streams are utilised in a more sustainable way in the production processes. In general, the diversification development would benefit from building an Arctic bioeconomy brand on specific Finnish competences.

Bioprocessing of compounds, as well as sourcing of new enzymes, microbes and chemicals, will be become increasingly common. The sourced substances will probably have a great deal of applicability, for example, in the development of pharmaceuticals and industrial biotechnology. Bio-based solutions will also be more widely applied for energy harvesting, water and waste management, and in the exploitation of side-streams.

In the short to medium term, bioenergy production and utilisation will become increasingly viable. There are already several projects currently going on in this field in Finland. The production of bioenergy will emphasise transport fuels made out of wood-based biomass (bio-oil) and the refinement of pine oil to produce second generation biodiesel (TFBS 2014). In the medium to long term, liquid fuels based on wood-based biomass are on the horizon, and the side-streams e.g. from agriculture and food production will be widely utilised in biofuel production. The core of forest industry will be renewed, and innovative high value added products will be developed. This development is made possible by the formation of new value networks and the reorganisation of sectorial boundaries. The trend will be towards the development of novel products and methods, especially those based on biochemistry and biotechnology. Examples will be enzymatic processes for the refinement of biomass and new biomaterials. Another key trend is the utilisation of different side-streams, such as waste side-streams and industrial side-streams, as raw materials for new products. This development opens a trajectory towards a circular bioeconomy, based on the design of closed cycles for materials use. In these cycles, nothing is defined as “waste” anymore, but every material is perceived as a raw material for producing something.

Enabling technologies: In the second phase of development from the medium to long term, ICTs will enable different kinds of simulation solutions, wide utilisation of “big data”, and the building of smart systems for biorefineries. In the third phase – on the horizon in the third phase – the ICTs will enable intelligent systems for controlling industrial ecology and the circular bioeconomy. There will also be significant advances in biotechnology, especially in the field of enzymatic technologies, system biology and synthetic biology. These advances will open whole new avenues for the Arctic bioeconomy. The medium- to long-term horizon will also witness the emergence of second and third generation biorefineries that can have multiple products, produced through different methods. Thus, in the long run, the development will lead to Arctic bioeconomy villages and advanced biorefineries. Also, logistics will advance and novel distance monitoring and new logistic solutions, through optics and sensors, will be available.

Capabilities, resources and actors: At the level of resources and actors, there is already currently emerging cross-sectorial collaboration on Arctic topics. In the medium to long term, the cross-sectorial collaboration will lead to global sourcing for Arctic R&D experience. Also, it will push forward the impacts of R&D networking and lead towards new collaboration platforms. The increasing state activity in the Arctic region, catalysed by increasing commercial activities and increasing incentives for networking, will stimulate the networking between companies and other actors and the formation of new local and regional public-private partnerships. Thus, in the long term there will be several forms of Arctic collaboration and even multiple forms. Also, new international actor coalitions are likely to emerge.

6.3 Path 3 – Culture of Arctic experimentation

Targets

Path 3 (see Figure 25) is based on creating small and quick openings alongside the grand technological openings and spearheads described in paths 1 and 2. The third path leads to Arctic futures via agile experiments such as living labs, pilot environments, and fast prototyping, cross-breeding of sectors and ideas, and test beds. Living labs are considered to be user-centred open innovation environments, while test beds are seen as platforms for experimentation in large development projects. Path 3 does not focus on any specific Arctic technology, but on creating an infrastructure, tools and innovation policy that support experimentation leading to faster commercialization of new technologies and services of Arctic applications in traditional and emerging sectors. The impact of experimentation or innovation altogether is difficult to predict, but favourable conditions can be created in order to encourage them to emerge. Leaders at national, regional, and organizational levels are often challenged by this reality because establishing these conditions typically requires long-term, widespread systemic changes.

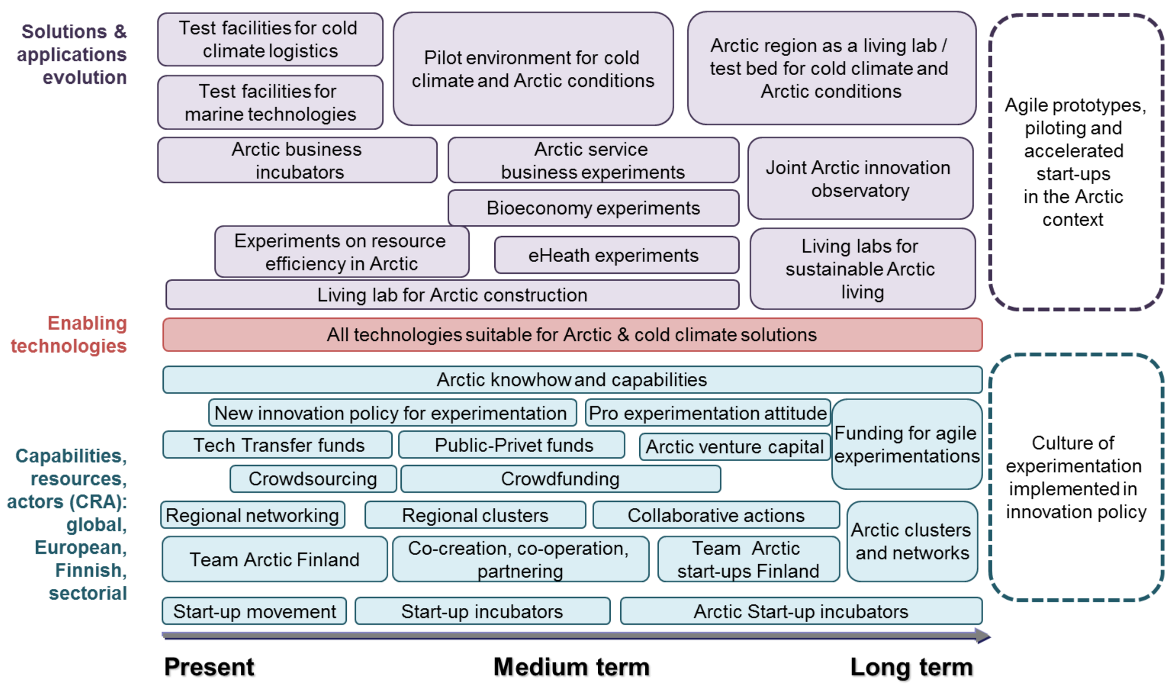


Figure 25. Roadmap for Path 3 Culture of Arctic experimentation.

Present state (1–3 years)

Solutions & Applications evolution: Currently in the Arctic region, the innovation cycle for most services and products is long. Cold and sparsely populated environments limit the possibilities for innovation and business. The experimentation path provides tools and action models for e.g. co-creation and co-operation between technology and service developers and customers. Small-scale actions such as piloting or prototyping of new technology or services can easily be done together with customers. In the innovation process, piloting activities help to overcome the so-called valley of death, which occurs in between research and commercialisation. Arctic examples of experimentation include e.g. the testing and further development of technical prototypes such as electric and hydrogen snowmobiles, with lead users such as Arctic adventure tourism entrepreneurs. The advantage for a technology developer would be the ease of getting the crucially important feed-back for the next development stage or potential fund raising phase.

An example of a larger scale and more systemic experiment is the on-going living lab of Hiukkavaara Arctic Smart City in Oulu. Hiukkavaara is a pilot region for a smart residential environment and a testing environment for business and technology. It is planned to be ready by 2030. One of the first on-going pilot projects focuses on renewable energy experiments in city areas. The key sectors for experiments are Arctic construction, ICT, and Cleantech. (Hiukkavaara 2014)

Capabilities, resources and actors: 'The trial and error' attitude is not easily accepted in Finnish culture, and positive examples are needed help initiate the change. Whether talking about experimentation in a wider sense or focusing on entrepreneurial activities, accepting the risk of failure is crucial. Acceptance of uncertainty and risk is the first step in the transition towards the culture of experimentation.

Finland is currently recognized as one of the hottest start-up hubs in the world. There are several active incubators aiming to stimulate innovation in Finland, such as Aalto Ventures garage, Startup Sauna, VTT Ventures, Butterfly Ventures in Oulu, Lureco in Lappeenranta, to give examples of some of the start-up investment companies. None of the funds or incubation companies solely targets Arctic business, though Butterfly Ventures in Oulu has a Northern Start-up fund, which invests in early stage start-ups located in or planned to Northern Ostrobothnia region in Finland. Besides traditional innovation and technology transfer funds, crowdfunding is a promising way to fund small scale experiments.

Thus, further incubation and acceleration of especially Arctic business is still needed. Having a strong regional Arctic business and innovation hub is beneficial for creating and supporting business opportunities. At the moment, the Oulu region can be identified as the main innovation and business hub for Arctic business in Northern Finland. Cross-border interaction and co-operation between other Arctic business hubs, for example in the Barents region, would enhance cross-border investments and boost innovation and commercialization activities. Since the decline of the ICT sector, the region has actively promoted new entrepreneurship and started to act as an incubator for new business. The focus is mainly in ICT, Cleantech, life science, creative industries, tourism, logistics and heavy industries. The region has an active regional innovation alliance between local players. BusinessOulu, a development company owned by the City of Oulu, helps internalization of regional companies and has close ties to Northern Sweden and Norway. For example, in January 2014 BusinessOulu opened Finland House in Tromsø to help Oulu-based companies adapt their products and services to the Norwegian market and Arctic conditions and boost exports in northern Norway. (BusinessOulu 2014) The experiment of Hiukkavaara living lab and the activities of BusinessOulu lower the barrier for companies to perform experiments which leads to better and faster Arctic market penetration and give a positive indication of change towards the culture of experimentation.

Another example of cooperation between Arctic players is the Helsinki-based Team Arctic Finland, founded in May 2014 by the Federation of Finnish Technology Industries. The newly established Team Arctic aims to promote Arctic business opportunities and help Finnish companies by promoting co-operation and creating common concepts with government support. The founding members of Team Arctic are the Federation of Finnish Technology Industries, Gaia Consulting, Aker Arctic Technology, Arctia Shipping, Boskalis-Terramare, ESL Shipping, Fortum, Finnish Meteorological Institute, Konecranes, Lamor, Pemamek, Rolls-Royce Marine, Rautaruukki, STX Cabins Finland, STX Finland and Technip Offshore Finland. The focus is mainly on marine technologies, logistics, energy and construction, including traditional transport and ice-breaking services, new transport solutions and off-shore concepts, new port concepts, construction and venue services, steel constructions and their manufacturing processes, automation, telecommunications, IT services, weather services, security, oil combating and new energy solutions. (Teknologiateollisuus 2014)

Finnish companies do not necessarily identify themselves as being *Arctic* companies, even though prerequisites for being an Arctic player are fulfilled. It might be more consistent for companies to identify themselves as a technology or service provider in a more established and broader sector (such as in maritime, construction, transportation, cleantech or the energy sector) and Arctic defines the operational environment or a geographical segment of the market. This case shows the complexity of Arctic business.

Start-ups operating in the Arctic context would need a clear push and acceleration via more focused innovation funding, business experimentation funds, tech transfer funds or other type venture capital together with increased branding and focused co-operation. Many high-tech start-ups have a high competence in technology but fail in branding, marketing and providing solutions instead of technology. More competences are needed in creating high-tech start-ups based on new business models, such as services and solutions. Team Arctic Finland, with a subgroup focusing on high-tech start-ups, might be a solution for entrepreneurs to promote their business ideas to venture capitalists and potential customers.

Developments towards the medium and long term (3–15 years)

Solutions & Applications evolution: The experiments from Hiukkavaara living lab initiate a positive snowball effect leading to the wider adaptation of experiments. In the future, the Northern part of the Finland could act as a living lab for a wider range of Arctic business and technical experiments (e.g. e-learning, e-heath and other applications) creating services and technologies to be exported to other Arctic regions. New applications are created in close interaction with users, business partners and the public sector. Doing, using and interacting are the key themes describing the Arctic business development. The agile experimentation enhances learning and enables faster innovation cycles.

Capabilities, resources and actors: In the medium and long term, regional Artic business ecosystems will be strengthened in Northern Finland, and Arctic cooperation within Finland improved further. The innovation Observatory in Oulu would be the hub for innovation and business activities collecting feed-back and information of the experiments carried out. Interactions between different actors (universities, companies, investors, public sector, NGOs) will increase and the user-centric culture of experiments expands. In addition, cross-border interaction and co-operation between other Arctic business hubs, for example in the Barents region, would enhance cross-border investments and boost innovation and commercialization activities.

In the future, the focus is on creating and supporting new Arctic business in test-bed environments and living labs for technologies, service and business innovation. There will be a need for renewal of the national innovation policy so as to support the experimentation leading to the creation of new business opportunities. Entrepreneurial uncertainty could be further reduced by means of incubation, innovation clusters, public-private funds, collaborative actions, clustering and networking in the Arctic region.

6.4 Path 4 – Snowdrift strategy: fading Arctic business

The fourth path is based on the hypothesis that Arctic business potential remains unrealized. In these circumstances, it is reasonable to forget the Arctic context as a focus area. In this path, Arctic conditions are not the starting point of competence development, but rather an additional element or approach to the competence development on other fields. From this perspective, the integration of Arctic aspect in the other technology-related strategies, such as bioeconomy strategy is crucial. The needs for competence development may also arise from local or regional needs. In the end, Finland is still situated in the Northern hemi-sphere, and there is a need for solutions for cold climate in construction, energy efficiency or human well-being. On the other hand, our location provides possibilities for local businesses, e.g. in relation to tourism. Another alternative in this path is to broaden the concept of Arctic competence so as also to cover other areas with some element of “extreme conditions”. In this case, Finnish actors in R&D or companies could provide solutions for extreme conditions for the global market. Such a market could be found e.g. in the tropics, in mountainous areas or sparsely populated areas.

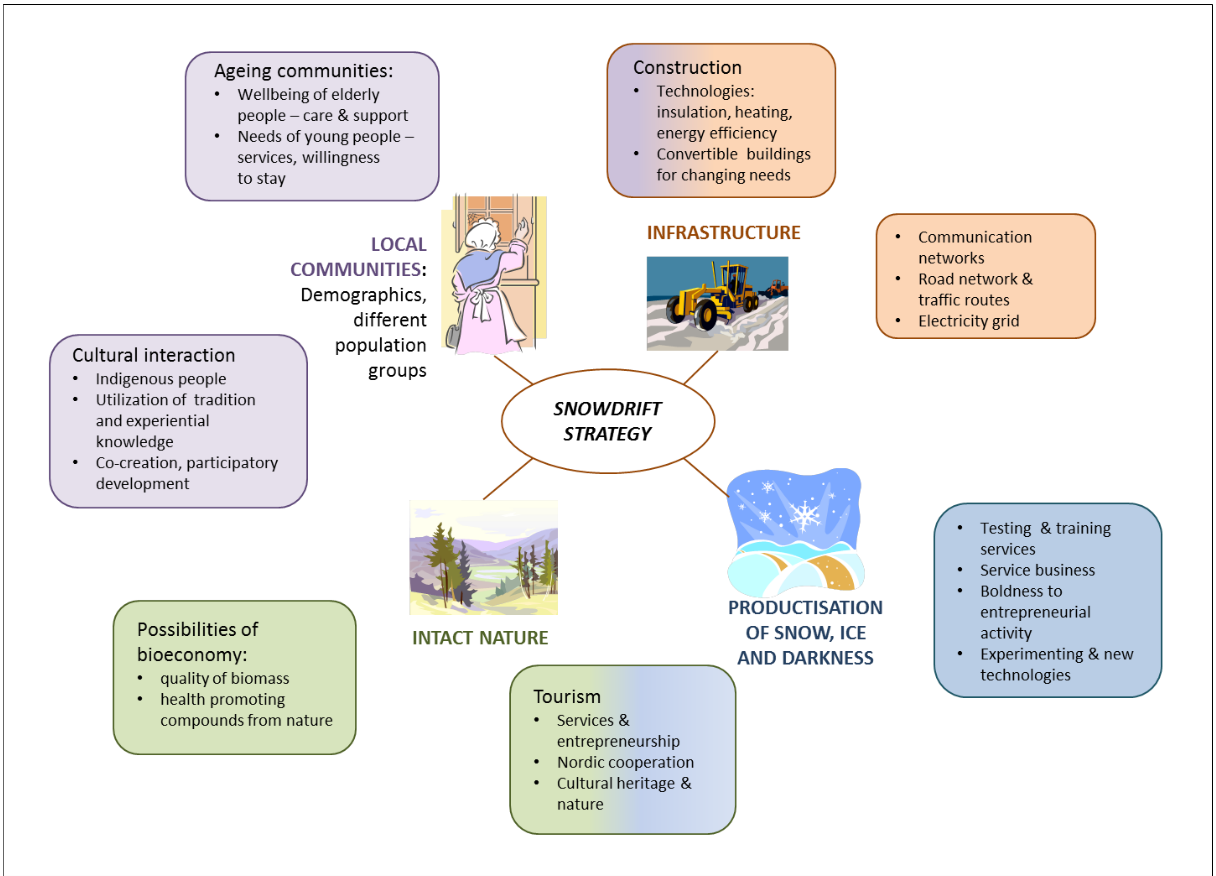


Figure 26. Local themes in Path 4 Snowdrift strategy.

Figure 26 shows the themes that appeared in a workshop in relation to the Snowdrift strategy. The lower part of the figure describes the possibilities of utilising the resources we have in Northern Finland. From this perspective, nature and natural conditions (snow, ice and darkness) should be seen as resources to develop such livelihoods as biomass utilisation, tourism and testing or education services. The upper part of the figure depicts the competence needs that arise from the needs of local communities and the maintenance of infrastructures. An ageing population and the moving of younger generations from the area are challenges that the Northern communities will confront to a growing extent in the future. There are increasing needs for new solutions supporting elderly people to be able to stay at home for a longer time. Another important aspect of the northern communities is the cultural interaction between different population groups. This refers to potential conflicts between indigenous people and industries operating in the area. An important aspect in this sense is participatory development methods and co-creation as guiding principles. Also, public-private partnerships and cooperation are needed in order to make sustainable changes. Infrastructures need to be developed to guarantee the possibilities for livelihood in the Northern areas. This development serves tourism and local people, and covers communication, traffic and energy networks. In construction, new concepts are needed for convertible buildings that can be adapted to the changing needs of the communities in the course of time.

6.5 Concluding remarks

The roadmaps presented in previous sub-sections are not intended to depict the future in a deterministic way, i.e. we do not assume that any of the visions or roadmap explorations presented in this report will in fact become a reality, as such. Future development is likely to include some elements that are presented in these roadmaps, but there will also be new and surprising elements that obviously could not be taken into account when creating the roadmaps. Also, these roadmaps have been created in participatory processes with representatives mainly from a research context. The voices of business actors might have changed the view somewhat. However, these roadmaps describe some of the key transformations and elements in the transition within each theme. They should be approached as strategic tools for creating a deeper understanding of the blurry concept of “Arctic expertise” and setting agendas for strategic pathways. Table 9 concludes the findings of the technology roadmaps.

Table 9. Conclusions of the technology roadmaps for Paths 1–4.

		Strategic conclusions	Enabling technologies
Path 1	***Arctic marine technology and maritime transport***	From traditional competences in shipbuilding to a combination of different competences (e.g. material technology and environmental scanning)	From machine-building to learning systems
Path 2	***Arctic communities and construction***	Towards low-carbon Arctic communities and energy supply security	Towards decentralized technology concepts through advanced sensory technologies, monitoring and control systems and energy storage systems
	ICT-solutions for well-being	From reactive solutions to the development of proactive solutions and contextualisation of services	From non-invasive measurements and wireless body networks to invisible technologies
	Arctic machines and vehicles	From Arctic use to designs originally targeted to Arctic conditions, based on verified information and research findings	From remote operated solutions to autonomous machines
	Arctic bioeconomy	From partial optimisation to integrated concepts that use biomass from diverse sources	From single biorefineries to integrated bioeconomy villages: ICT as a key enabler (utilisation of big data and the development of integrated data systems)
Path 3	***Culture of Arctic experimentation***	Towards a culture of experimentation in innovation policy and technology development	Application in the relevant fields of technology
Path 4	***Fading Arctic business***	Change from the Arctic focus to a concentration on local needs and resources	Technologies serving local needs (infrastructures, social needs, utilisation of biomass and mineral and ore resources)

7. Discussion and conclusions

The roadmapping approach adopted in this project produces roadmaps on at least two levels (strategic and technology level) in order to discover relevant future perspectives both at the level of single technologies and at the level of strategy and innovation policies. The roadmaps represent themes and issues that appeared in the roadmapping process. Therefore, the experts who participated in the process have had a crucial role in the formation of the outcome. The roadmapping process consisted of three phases: (1) scoping (brainstorming workshops, construction of thematic mindmaps), (2) generation (technology surveys, interviews, patent analysis, roadmapping workshops), and (3) outputs (reporting and presentation of results). The process produced a great deal of minute data, for example, visionary application examples and demonstration projects that bring useful practical elements to support the strategy paths.

Originally, the scoping phase resulted in three roadmap themes covering various technologies. Information gathering in the generation phase was started based on these guidelines, for example, the technology survey was designed based on this setting. Later, when Finland's strategy for the Arctic region 2013 was published, in August 2013, and the policy analysis was completed, we decided to formulate the roadmaps based on four strategy paths. This made it necessary to transform the material collected following different frames to different kinds of outcome than those originally intended. This caused some discontinuity in the information gathering of the roadmapping process. On the other hand, this may be inevitable in open ended processes such as roadmapping, where the final result is shaped based on the insights generated throughout the process. In general, this project contributed to the methodological development in the field of technology foresight by developing a methodological approach, which combines quantitative and qualitative methods for seizing wide and equivocal technology domains, such as "Arctic technology".

The first key result of the roadmapping process was the characterisation of a novel way to scope the "Arctic aspect" in the context of emerging technologies. The competence and technology scoping was formed to identify the specific Arctic competences, and related technological competences, and to set these in an explicit Arctic context. The rationale was to ascertain the specific "Arctic element" in different emerging technology pathways. We ended up in a three-layered structure of Arctic competence consisting of (1) competences relating to Arctic conditions, (2) Applied technology competences needed in operations in the Arctic area, and (3) Cross-sectional technology competences covering critical enabling technologies that can be applied in different application areas. These three levels together formulate a comprehensive picture of Arctic technology.

Furthermore, the key results of the roadmapping process are crystallised in four strategy paths for the Arctic regions. These are:

(1) Spearhead strategy: Arctic marine technology and maritime transport – a focused strategy that emphasises traditional Finnish competences in shipbuilding and the maritime industry set in the Arctic context;

(2) Flying geese approach: emerging Arctic pathways – a wider strategy that emphasises a selection of strong Arctic competences;

(3) Culture of Arctic experimentation – a strategy based on experimental policies and technology approaches; and

(4) Snowdrift strategy: fading Arctic business – the Arctic does not form a credible focus of activities and is forgotten or set as a subordinate perspective inside some other topic.

These paths should be seen as potential or possible ways to develop Arctic competences in the future. They can be seen as alternatives to each other, but especially the three first paths complement rather than exclude each other. The fourth path is more clearly an alternative way to proceed, because it is based on a presupposition that Arctic business potential does not become materialized.

7.1 Recommendations

The generic outcomes of the entire roadmapping process can be wrapped up in three groups. The first group is called *the outcomes channelled by Arctic conditions*. This group consists of results that are explicit consequences of Arctic conditions, such as harsh climate conditions, sparse population and long distances. The key outcomes in this group are related to emerging Arctic logistics (such as maritime transportation, pipelines, transport infrastructure), natural resources (such as onshore oil and gas, emerging offshore projects, minerals), and use of renewable energies (such as wind energy and bio-based energy). The second group is called *the questions of policy, regulation and infrastructure*. These include the possibilities and challenges of R&D funding and resource allocation, development of infrastructure, co-operation in Arctic policy issues, and, in the end, realising all of this systematically by taking into account the demands of sustainability in the widest possible sense. The third group is called *novel technological possibilities*. Our new way to scope Arctic competencies, and identify related technologies, has shown that there are plenty of novel possibilities for technology development, and even rethinking technological development, when set in the Arctic context. The key possibilities emerge from specific Arctic competences, such as Arctic communities, energy production, and structural performance. These specific Arctic competences are supported by more generic cross-sectional technology competences, based on e.g. material technology, environmental technology, ICT, machinery and equipment, and related research infrastructures.

We conclude this report by summarising the recommendations that can be made based on the roadmaps presented above. The recommendations are divided into three groups by the intended direction of change: (1) the direction of national (innovation) policies, (2) the direction of technology R&D development and investments, and (3) the theoretical-methodological direction.

(1) On the national level, a clear definition of Arctic expertise is necessary in order to scope the strategy and make it possible to direct R&D funding to selected key competence areas. This may be essential so as to be able to improve the efficiency of funding and grow the critical mass in R&D. In the longer term, R&D activities can be organized into knowledge centres concentrating on certain fields of Arctic technology development. In this development, it is important to enable the correct balance between concentration and networking so as to avoid the fragmentation characteristic of today's organisation of R&D activities in the field, and to guarantee the necessary combination of different disciplines and approaches. Also, close cooperation between research and industries is necessary.

    There are major uncertainties affecting development in the Arctic area. Therefore, there are also considerable risks involved in any decisions concerning operations or R&D activities in this field. Single firms, especially SMEs, may be too small as actors to bear such a risk, or they may not have enough resources to be aware of the developments taking place in the Arctic. The solution for this can be a combined environmental scanning and technology foresight process organized on a national level. This process would incorporate a continuous collection of market and other relevant information in order to formulate an evidence-based view of the future technology needs.

(2) Development and operations in the Arctic area are slow and long-term processes. Therefore, it is necessary to have long-lasting funding for R&D. Alternative forms of funding should also be developed to promote experimental development models (as was described in Path 3). This direction also requires the adoption of a new culture in R&D&I activities in general. There is, for example, a need for new ways to measure success, failure and the expectations of development processes, as important lessons may be learned in projects that are not necessarily successful in economic terms.

This project showed that it is not possible to define an exhaustive list of Arctic technologies, but Arctic element can be understood as an additional component of technology development. Therefore, it is important to coordinate the R&D funding between different strategies and research programmes to be able to identify areas where shared objectives can be found. In relation to the technology themes covered in this project bioeconomy, health technologies or sustainable mining are, for example, domains where a link to the Arctic theme can be recognized.

(3) This project contributed to a theoretical-methodological development, especially in the field of future-oriented analysis of emerging technologies. In this field, the combination of qualitative and quantitative methods in the analysis can create significant advantages. The methodological development begun in this project should be continued in relation to some technology domain other than the Arctic in order to test and further develop the approach.

Another direction in the methodological development that requires further attention is the combination of roadmapping to other, more short-term and more business-oriented analyses. There seems to be a gap between the long-term approach of Innovation Policy Roadmapping, the method that was applied in this project, and other methods aimed at business model development.

References

Acia (2004). ”Arktisen alueen lämpenemisen vaikutukset”. Ympäristöministeriö, Ulkoasiainminis-teriö, Helsinki. Available at: http://www.ym.fi/download/noname/%7B687A54EC-BCC0-4AA5-AC21-424A3B3AC5F7%7D/32837 [ref. 18 Sept 2014]

Ahlqvist,Toni, Kettle, John, Hytönen,Eemeli, Niemelä, Klaus, Kivimaa, Antti Vanderhoek, Nafty, Dufva, Mikko, Mäkinen, Tuula, Kurkela, Esa & Valovirta, Ville (2013a). *South Australian Cellulosic Value Chain Technology Roadmap. Stage 2. Future options for the cellulosic fibre value chain in the Green Triangle, South Australia: strategic technology roadmaps, business cases and policy recommendations*. Report and executive summary. 99 p. VTT Customer Report. Public. VTT-CR-04761-13.

Ahlqvist,Toni, Kettle, John, Hytönen,Eemeli, Niemelä, Klaus, Kivimaa, Antti Vanderhoek, Nafty, Dufva, Mikko, Suominen, Arho, Sundqvist, Henna Mäkinen, Tuula & Kurkela, Esa (2013b). *South Australian Cellulosic Value Chain Technology Roadmap. Stage 2. Future options for the cellulosic fibre value chain in the Green Triangle, South Australia: strategic technology roadmaps, business cases and policy recommendations.* Appendices. 192 p. VTT Customer Report. Public. VTT-CR-04761-13.

Ahlqvist, T., Valovirta, V., Lokkanen, T. (2012) Innovation policy roadmapping as a systemic instrument for forward-looking policy design, *Science and Public Policy* 39, 178–190.

Alkærsig, Lars, Piirainen, Kalle (2013) "Technological competence mapping in the North Sea region." *ECOWindS Newsletter* 2:4-7.

AMSA (2009). Arctic Council Arctic Marine Shipping Assessment 2009 Report pp. 160, 24–25.

Antikainen, J., Tolonen, S., Yli-Koski, M. (2014). ”Arktinen osaaminen ja politiikka. Suomen arktisen osaamisen strategiset avaukset”. MDI, Helsinki. Unpublished report of SMARCTIC project.

Arbo, P., Iversen, A., Knol, M., Ringholm, T. and Sander, G. (2013) Arctic futures: conceptualizations and images of a changing Arctic. *Polar Geography* 36:3, 163-182.

Arctic info (2013) “Building port Sabetta on Yamal”. Available at: http://www.Arctic-info.com/ArcticPath/Photobank/Page/building-port-sabetta-on-yamal- . [ref. 5 May 2014]

Arctic info (2013b) “Arctic Mining, Resources and Activity”. Available at: http://www.arctis-search.com/Arctic+Mining,+Resources+and+Activity [ref. 6 May 2014]

Arctis (2013) “NSR Transits 2012”. Available at: http://www.arctis-search.com/NSR+Transits+2012&structure=Arctic+Sea+Routes [ref. 2 May 2014]

Barents Observer (2013) Roadmap for Shtokman development, 3 Apr 2013 Available at: http://barentsobserver.com/en/energy/2013/04/roadmap-shtokman-development-03-04 [ref. 6 May 2014]

Berkman, P.A. and Young O.A. (2010). Governance and environmental change in the Arctic Ocean. *Science* 324, 339–240.

BusinessOulu (2014) BusinessOulu aims to boost exports to Norway by 50 million euros. Available at http://www.businessoulu.com/en/news-events/news/businessoulu-aims-to-boost-exports-to-norway-by-50-million-euros.html. [ref. 31 Jul 2014]

Brigham, Lawson W. (2011) The Challenges and Security Issues of Arctic Marine Transport, in Kraska, James (ed.) Arctic Security in an Age of Climate Change. Cambridge: Cambridge University Press, p. 27.

Dodds, K. (2010a). Flag planting and finger pointing: The Law of the Sea, the Arctic and the political geographies of the outer continental shelf. *Political Geography* 29, 63–73.

Dodds, K. (2010b). A Polar Mediterranean? Accessibility, Resources and Sovereignty in the Arctic Ocean. *Global Policy* 1:3, 303-311.

Ernst & Young (2013) Arctic oil and gas. Available at http://www.ey.com/Publication/vwLUAssets/Arctic_oil_and_gas/$FILE/Arctic_oil_and_gas.pdf. [ref. 9 Jan 2015]

Finpro (2012). Arctic Sea Exploration, Finnode phenomena study. Finpro St. Petersburg-team, 11/30/2012

Foresight Horizon Scanning Centre (2010)Technology and Innovation Futures, Technology Annex. Government office for Science, 194 p. Available at: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/288571/10-1252an-technology-and-innovation-futures-annex.pdf [ref. 18 Dec 2014]

Gazprom (2014a) Yamal megaproject. Available at http://www.gazprom.com/about/production/projects/mega-yamal/ [ref.12 Sept 2014]

Gazprom (2014b) Shtokman. Available at: http://www.gazprom.com/about/production/projects/deposits/shp/ [ref. 5 May 2014]

Gazprom (2014c) “First oil First oil from Russian Arctic shelf loaded” Available at: http://www.gazprom.com/press/news/2014/april/article189209/ [ref. 5 May 2014]

Hasmi M. (2011) Survey of smart grids concepts worldwide. VTT working papers 166.

Helsingin Sanomat (2014) Kaasu tuo liikennettä Jäämerelle. *Helsingin Sanomat,* 20 Mar 2014

Hiukkavaara (2014) Hiukkavaara, kestävä pohjoinen talvikaupunki. Available at http://www.ouka.fi/oulu/hiukkavaara [ref. 30 Jul 2014]

Horton, A. (1999) Foreforont. A simple guide to successful foresight. *Foresight vol.1, no. 1*, p. 5–9.

Joy J., Jasmin E.A:, John V.J. (2013) Challenges of Smart Grid. *International Journal of Advanced Research In Electrical, Electronics and Instrumental Engineering*, Vol 2, Issue 3.

Jørgensen-Dahl, A. (2010) “Future of Resources and Shipping in the Arctic”, The Arctis database. Centre for High North Logistics (CHNL). Available at http://www.arctis-search.com/Future+of+Resources+and+Shipping+in+the+Arctic&structure=Marine+Transport+and+Logistic [ref. 2 May 2014]

Kauppalehti (2013) Statoil: Arktiset öljyvarat vuosikymmenten päässä. *Kauppalehti,* 1 Dec 2013. Available at: http://www.kauppalehti.fi/etusivu/statoil+arktiset+oljyvarat+vuosikymmenten+paassa/201312577615 [ref. 4 May 2014]

Koranoy, B. (2013) ”Ice levels, rule changes to boost Arctic northern sea route” Reuters. 29.5.2013. Available at: http://www.reuters.com/article/2013/05/29/us-shipping-arctic-idUSBRE94S0DG20130529 [ref. 5 May 2014]

Knell, N.F. (2008) The Reemergence of the Arctic as a Strategic Location. School of Advanced Military Studies, United States Army Command and General Staff College

Kuisma, Juha (2011). Kohti biotaloutta. Biotalous konseptina ja Suomen mahdollisuutena, Työ- ja elinkeinoministeriö julkaisuja, Kilpailykyky 6/2011, available at: https://www.tem.fi/files/-29342/TEM_6_2011_netti.pdf [ref. 17 Sept 2014]

Lapin Kansa (2014) Jäämeren radan kannatus kasvaa. *Lapin kansa,* 26 Feb 2014.

Lindberg, H., Isaksson, H. & Martisso, O. (2014) Minerals in Barents. The transportation needs in the Western Barents region. GeoVista AB.

McCormick, K. & Kautto, N. (2013). The Bioeconomy in Europe: An Overview. *Sustainability* 2013, 5, 2589–2608.

Megatrends (2011). TemaNord 2011:527, Nordic Council of Ministers, Copenhagen, available at: http://www.nordregio.se/en/Publications/Publications-2011/Megatrends/ [ref. 18 Sept 2014]

Mikkola, H. & Käpylä J. (2013) Arctic economic potential. The need for a comprehensive and risk-aware understanding of Arctic dynamics, FIIA Briefing paper 127.

Myllylä, Y. & Kaivo-oja, J. (2013) Arktisen toimintaympäristön tulevaisuusverstas 5.4.2013 – yhteenvetoraportti. 60 p. Unpublished raport of SMARCTIC project.

Navigant Research (2013) BTM World Market Update 2012.

OECD (2009) The Bioeconomy to 2030. Designing a policy agenda, Organisation for Economic Co-operation and Development, OECD Publications, 2009.

Oulun yliopisto (2014) ARC –Arktinen anoneuvo- ja työkonetestaus. Oulun yliopisto, Konetikniikan osasto, Raportti n:o 133, Oulu. Available at: http://herkules.oulu.fi/isbn9789526203508/isbn9789526203508.pdf [ref. 18 Dec 2014]

Pokela, P. (2014) “Building and Piloting Strategic Sustainable Business Concepts in the Arctic”. Teknologiateollisuus. Team Arctic Finland. 22.1.2014

Popper, R. (2008) Foresight Methodology, in The handbook of technology foresight, Concepts and Practice. Georghiou, L., J. C. Harper, M. Keenan, I. Miles, R. Popper (eds.) Edward Elgar Publishing Limited, Cheltenham, UK. p. 44–88.

Prime minister’s office (2013) Finland’s Strategy for the Arctic Region 2013. Government resolution on 23 August 2013, Prime Minister’s Office Publications 16/2013, 71 p.

Raunio, H. (2012) Pohjoinen silkkitie *Metallitekniikka*, 26 Jan 2012.

Rautajoki, T. (2014) Arctic Business forum yearbook 2014. Lapland Chamber of Commerce, 2014. p. 166.

Rautio & Hahl (2013) "Economic cooperation in the Barents Region" – Draft 010613 Akvaplan-niva AS Report 6265 –p. 88

READY4 Smart Cities (2014) READY4 Smart Cities – ICT Roadmap and Data Interoperability for Energy Systems in Smart Cities. Deliverable 5.3: Innovation and Research Roadmap. EU Seventh Framework Programme. Available at: http://www.ready4smartcities.eu/documents/38385/120604/D5.3+Draft+Innovation+and+Research+Roadmap/1a926fe7-bab6-4911-b703-ef9d8fb37e30 [ref. 18 Dec 2014]

Sakhalin 1 (2014) Available at: http://www.sakhalin-1.com/Sakhalin/Russia-English/Upstream/default.aspx [ref. 5 May 2014]

Shukman, D. (2014) Agreement reached on deep sea mining. BBC, 25 Apr 2014 Available at: http://www.bbc.com/news/science-environment-27158883 [ref. 5 May 2014]

Strandsbjerg, J. (2012). Cartopolitics, geopolitics and boundaries in the Arctic. *Geopolitics* 17:4, 818-842.

Teknologiateollisuus (2014) Team Arctic creates Arctic business opportunities for Finnish companies, 16 May 2014. Available at: http://teknologiateollisuus.fi/en/news/announcements/2014-5/team-arctic-creates-arctic-business-opportunities-for-finnish-companies [ref. 31 Jul 2014]

TFBS (2014) *The Finnish bioeconomy strategy*. Sustainable growth from bioeconomy. available at: http://www.tem.fi/files/40366/The_Finnish_Bioeconomy_Strategy.pdf [ref. 18 Dec 2014]

The Siberian Times (2012) Russia's newest port has begun construction on the Yamal peninsula. *The Siberian Times,* 22 July 2012. Available at: http://siberiantimes.com/business/others/news/russias-newest-port-has-begun-construction-on-the-yamal-peninsula/ [ref. 5 May 2014]

UNIDO (2005) Unido Technology Foresight Manual,Organization and Methods, Volume 1. United Nations Industrial Development Organization, Vienna. 246 p. Available at: http://www.research.ro/img/files_up/1226911327TechFor_1_unido.pdf *[Ref. 20.11.2014]*

Valor (2013) The Finnish offshore industry 2013. Available at: http://www.valor.fi/media/Finnish%20Offshore%20Industry%202013%20-%20English%20Summary.pdf [ref. 9 Jan 2015]

Valtiovartainministeriö (2013) Kansallisen palveluväylän viitearkkitehtuuri. 14.10.2013, Versio 1.00. Valtiovarainministeriö, Helsinki. Available at: http://www.hare.vn.fi/upload/Julkaisut/19147/2862901686195312.PDF [ref. 18 Dec 2014]

Varjus, A. (2013) Arktiset yhdyskunnat ja rakentaminen. Saavutettavuus, kestävyys ja kasvukykyisyys.SMARCTIC-hankkeen raportti, Oulun yliopisto, 2013

Appendices

Appendix A: Osallistujat

Alla olevaan taulukkoon on listattu asiantuntijat, jotka osallistuivat tiekarttaprosessiin joko järjestetyissä työpajoissa tai heitä haastateltiin. Osa haastatteluista toteutettiin ryhmähaastatteluina, jotka sisälsivät työpajamaisia elementtejä.

Nimi	Organisaatio	Osallistui työpajaan	Haastattelu/ ryhmä-haastattelu
Kari Aaltonen	Oulun yliopisto	x	
Petri Ahokangas	Oulun yliopisto	x	
Petteri Alahuhta	VTT	x	x
Robin Berglund	VTT/ Environmental data mining	x	x
Timo Bräysy	Oulun yliopisto		x
Antonio Caló	Oulun yliopisto		x
Jeroen Dillingh	VTT/ Wind Power Technologies	x	
Antti Haapala	Oulun yliopisto		x
Jussi Haapola	Oulun yliopisto / CWC	x	
Jaakko Heinonen	VTT/ Arctic technology	x	x
Seppo Hellsten	Suomen ympäristökeskus	x	
Jukka-Pekka Hietala	Tampereen teknillinen yliopisto/ IHA		x
Saara Hänninen	VTT/ Ships and marine structures	x	
Jari Ihonen	VTT/ Fuel cells		x
Jouko Isokangas	Oamk	x	
Merja Itävaara	VTT / Biotechnology		
Jouni Kaartinen	VTT/ Digital health		x
Jari Kaivo-oja	Tulevaisuuden tutkimuskeskus/ TU	x	
Aki Koivukoski	VTT / Service architectures and computing		x
Kari Kolari	VTT/ Arctic technology	x	
Pekka Koskinen	VTT/ Mechanical engineering solutions	x	
Pentti Kujala	Aalto yliopisto	x	
Pasi Kuvaja	Oulun yliopisto/TOL	x	
Kari Laine	Oulun yliopisto Thule-instituutti	x	
Ari Laitinen	VTT/ Efficient buildings		x
Eila Lehmus	VTT/ Structural performance	x	
Kauko Leiviskä	Oulun yliopisto	x	
Mikko Lensu	Ilmatieteen laitos	x	
Lasse Makkonen	VTT/ Arctic technology	x	x
Ulla-Maija Mroueh	VTT / Material recycling and geotechnology	x	
Petteri Multanen	Tampereen teknillinen yliopisto/ IHA		x
Yrjö Myllylä	Tulevaisuuden tutkimuskeskus	x	
Esa Mäkelä	VTT / Material recycling and geotechnology	x	
Esa Mäkinen	Tampereen teknillinen yliopisto / IHA		x
Kaj Mäntylä	VTT/ Solution development	x	
Pekka Nevasmaa	VTT/ Dracture mechanics and NDE	x	
Juha Nikkola	VTT/ Chemical synthesis and polymerisation technologies		x
Ilpo Niskanen	Oulun yliopisto/Thule	x	

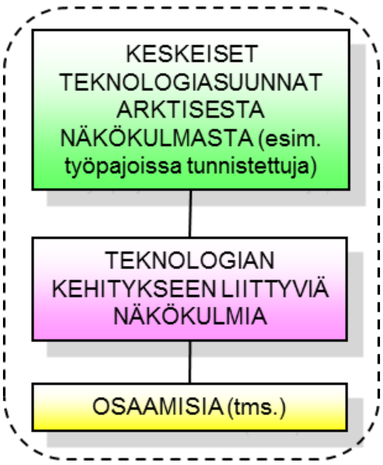
Vesa Pentikäinen	VTT/ Smart lighting and integration concepts		x
Sari Piippo	Oulun yliopisto/ NorTech	x	
Timo Pohjosenperä	Oulun yliopisto, Taloustieteiden tiedekunta	x	
Eva Pongracz	Oulun yliopisto, Thule-instituutti, NorTech Oulu	x	x
Anu Purhonen	VTT/ Service architectures and computing		x
Arja Rautio	Oulun yliopisto	x	
Jarmo Rusanen	Oulun yliopisto, maantieteen laitos	x	
Jorma Rytkönen	SYKE	x	
Kai Ryynänen	Rovaniemen ammattikorkeakoulu	x	
Jukka Sassi	VTT/ Ships and marine structures	x	
Veikko Seppänen	Oulun yliopisto, Martti Ahtisaari Instituutti	x	
Mika Sirén	VTT/ Producet processing and manufacturing	x	
Harri Soininen	VTT/ Business solutions management	x	
Pekka Tervonen	Oulun yliopisto/ CEE	x	
Anne Tolvanen	Metla, Oulun yliopisto	x	
Jouko Törnqvist	VTT/ Structural performance	x	
Minna Vikman	VTT/ Material microbiology	x	
Ilkka Väisänen	Oulun yliopisto	x	
Tomas Wallenius	VTT/ Wind power technologies		x
Kim Wallin	VTT/ Materials and built environment, general expenditure	x	
Jenni Ylä-Mella	Oulun yliopisto/ NorTech	x	

Appendix B: SMARCTIC-projektissa tuotetut mindmap-kuvaukset

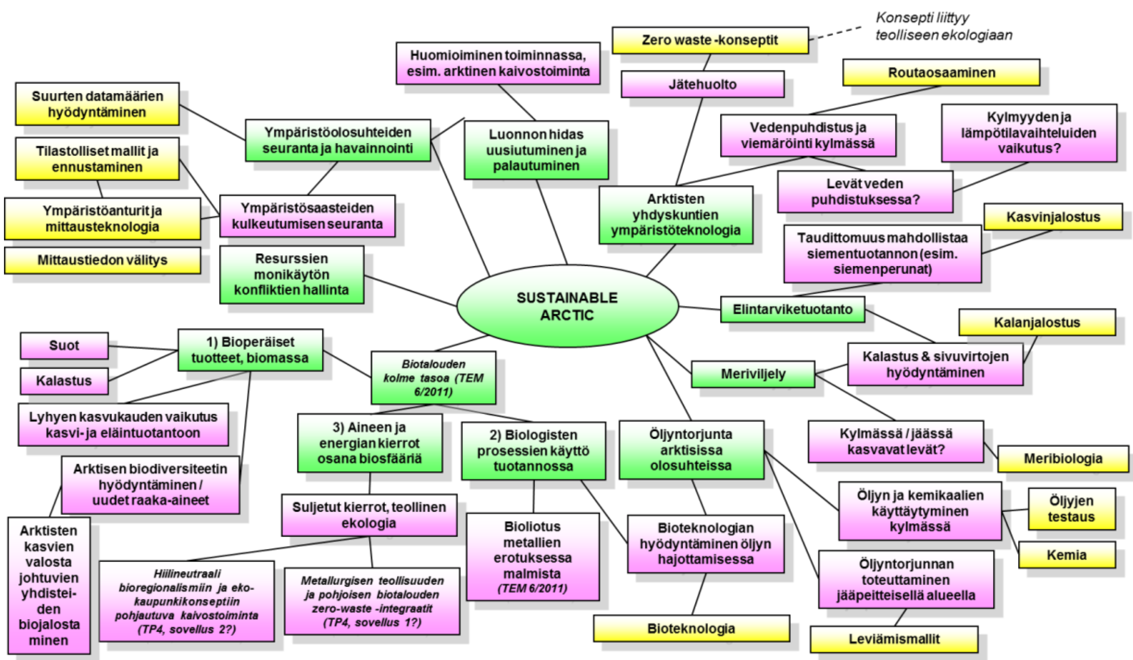
Arktisen teknologian osa-alueet

Kuvissa 2-4 esitetyt mindmapit perustuvat projektin alkuvaiheessa työpajoissa, haastatteluissa ja kirjallisuudesta kerättyyn näkemykseen arktisen teknologian sisällöistä. Mindmapien kehät on ilmaistu eri väreillä ja niiden muodostamisessa on hyödynnetty oheisia apukysymyksiä (ks. kuva 1):

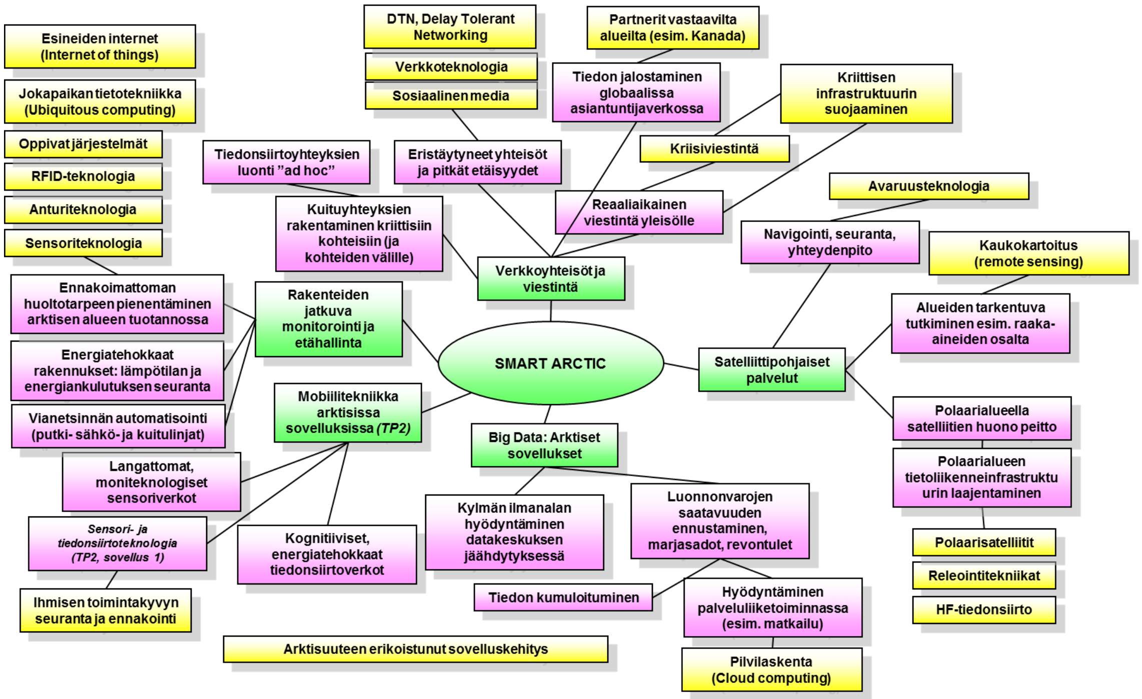
- Mitä näkökulmia aiheeseen liittyy? Miten aihe yhdistyy arktiseen? (vihreä kehä)
- Millä mahdollisuuksia teknologiat avaavat? Mitä avoimia kysymyksiä teknologian kehitykseen liittyy? Millä teknologioilla voidaan tuottaa ko. arktisia ratkaisuja? (violetti kehä)
- Mitä osaamisia tai osaamisen kehitystarpeita aiheeseen liittyy? (keltainen kehä)



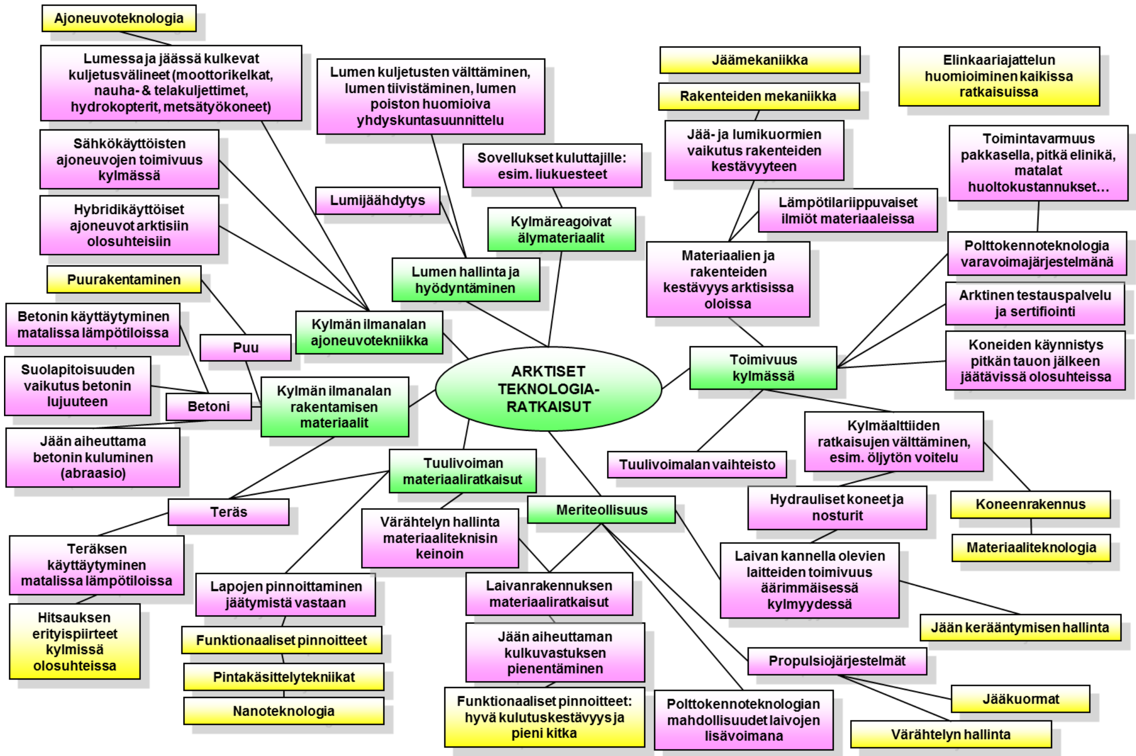
Kuva 1. Mindmapin rakenne.



Kuva 2. "Sustainable Arctic" –teema.



Kuva 3. "Smart Arctic"-teema.



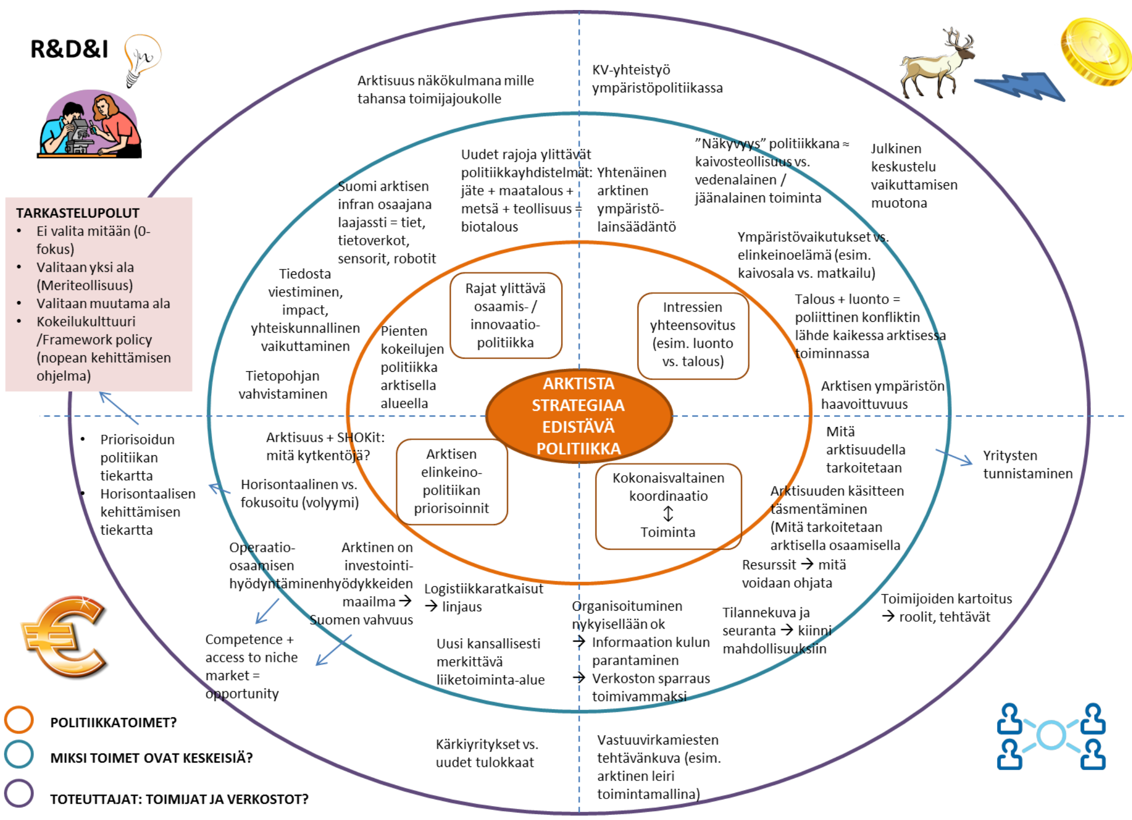
Kuva 4. "Arktiset teknologiaratkaisut" –teema.

Politiikkaselvityksen johtopäätökset

Toinen esimerkki mindmap-menetelmän hyödyntämisestä projektin tiedonhallinnassa liittyy MDI Public Oy:n toteuttaman selvityksen tulosten integroimiseen tiekarttatyöhön. Kuvassa 5. on esitetty tulokset ryhmätyöskentelystä, johon osallistuivat VTT:n ja MDI:n projektiryhmät. Työskentelyssä hahmottuneet strategiapolut toimivat lähtökohtana tiekarttatyön suuntaamisessa.

Työskentelyä ohjanneet apukysymykset:

1. **MITÄ** politiikkatoimia tarvitaan kansallisen arktisen strategian edistämiseksi?
2. **MIKSI** nämä politiikkatoimet ovat keskeisiä? Mitä niillä voidaan saada aikaan?
3. **KUKA** voi toteuttaa politiikkaa? Minkälaisia toimijoita/verkostoja tarvitaan?
4. Synteesi: **Miten** politiikkavaikutus maksimoidaan?
   - Mitkä politiikkatoimet tukevat toisiaan? (toimien yhdistelmät)
   - Miten näitä toimia edistetään samanaikaisesti?
   - Minkälaisella aikataululla toimia voidaan toteuttaa?
   - Mitkä toimet voivat heikentää toistensa vaikutusta?



Kuva 5. Arktista strategiaa edistävä politiikka. Tulokset ryhmätyöskentelystä VTT:n ja MDI:n työryhmien kesken.

Appendix C: Teknologiakyselyn teknologiakuvaukset

Alla olevissa taulukoissa on esitetty SMARCTIC-projektin teknologiakyselyssä käytetyt kuvaukset kaikille viidelletoista teknologiasovellukselle. Tunnukset vastaavat raportin luvussa 4.2 käytettyjä tunnuksia (vrt. Table 5).

Taulukko 1. Arktiset teknologiasovellukset, Ryhmä SUST.

Tunnus	Sovellus ja kuvaus
SUST1	**Ympäristöolosuhteiden seurannan ja havainnoinnin teknologiat** Arktinen luonto on haavoittuvaa ja taloudellisen aktiviteetin lisääntyminen alueella aiheuttaa yhä suurempia rasitteita ympäristölle. Ympäristöolosuhteiden ja ympäristön tilan seurantaan on mahdollista kehittää teknologisia sovelluksia. Tällaisten sovellusten toteuttaminen edellyttää anturiteknologista kehitystä, suurten datamäärien hallintaa ja toimivien tiedonsiirtoratkaisujen kehittämistä. Paristoteknologian kehittyminen tulee mahdollistamaan sensoreiden toimimisen itsenäisinä laitteina, jotka ovat yhteydessä langattoman verkon kautta esimerkiksi kaivosalueen valvomoon tai suoraan viranomaisjärjestelmään. Järjestelmän avulla voidaan saada reaaliaikaista tietoa ympäristön tilan kehittymisestä.
SUST2	**Arktisten yhdyskuntien ympäristö- ja energiateknologiat** Taloudellisen toiminnan lisääntyminen arktisella alueella lisää myös alueella asuvien ihmisten määrää. Tämä kehitys edellyttää uusien yhdyskuntien rakentamista ja kasvattaa yhdyskuntien ympäristöteknologisten ratkaisujen kysyntää. Arktiselle alueelle tarvitaan vallitsevissa olosuhteissa toimivia jätehuolto- ja vedenpuhdistusteknologioita. Infrastruktuurin toteuttamisessa tarvitaan routaosaamista. Yhdyskuntien energiaratkaisujen kehityksessä on kiinnitettävä huomiota hajautettuun ja paikalliseen energiantuotantoon. Energiajärjestelmien on sopeuduttava tuotannon ja kulutuksen voimakkaisiin muutoksiin.
SUST3	**Arktinen öljyntorjunta** Öljyvahingot ovat arktisen merenkulun ja öljynporauksen suurimpia riskejä. Öljyntorjunnan haasteita arktisella alueella ovat pitkät etäisyydet ja puutteellinen huolto- ja tukiverkosto sekä jääpeitteen ja kylmyyden aiheuttamat haasteet. Öljyntorjunnan toteuttaminen jääpeitteisellä alueella vaatii erityisiä ratkaisuja ja operaatiohallintaan liittyvää osaamista. Öljyntorjuntaratkaisut edellyttävät tietoa siitä, miten öljy käyttäytyy kylmässä ja miten se liikkuu jäissä. Näiden tietojen avulla voidaan kehittää öljyn liikkumisen mallinnusta.
SUST4	**Biomassan hyödyntäminen** Arktisella alueella kasvavat kasvit ovat sopeutuneet erityisiin olosuhteisiin, esimerkiksi lyhyeen mutta intensiiviseen kasvukauteen. Kasvukaudella lähes ympärivuorokautinen valo synnyttää kasveissa erityisiä yhdisteitä, joiden hyödyntäminen ja biojalostaminen voi tarjota uusia mahdollisuuksia. Arktisia olosuhteita voidaan hyödyntää myös esimerkiksi siemenkasvituotannossa, koska olosuhteet rajoittavat kasvitautien esiintymistä ja siten voidaan päästä taudittomaan siemenkasvituotantoon. Myös kalastuksen sivuvirrat voivat tarjota merkittävän hyödyntämispotentiaalin, kun elintarvikekelpoiset proteiini- ja öljypitoiset sivuvirrat hyödynnetään esimerkiksi ravintolisien, elintarvikkeiden ja ihonhoitotuotteiden valmistuksessa. Tämä edellyttää tarkoitukseen sopivien ekotehokkaiden biomekaanisten teknologioiden ja lopputuotesovellusten kehittämistä.

SUST5	**Aineen ja energian kierto** Kaivostoiminta lisääntyy arktisella alueella. Arktisen kaivostoiminnan ja metallurgisen teollisuuden keskeiseksi toimintaperiaatteeksi tulee nousemaan ekologinen kestävyys. Tämä edellyttää biotalouden ja teollisen ekologian periaatteiden integroimista alan kehittämisessä. Biotaloudessa materiaalien kierrot ovat tehokkaita ja kestäviä. Tavoitteena on prosessien jäte- ja sivuvirtojen täysimittainen hyödyntäminen eri prosessien synergioita hakemalla, toisin sanoen yhden prosessin jäte on raaka-ainetta toiselle prosessille. Tällainen ratkaisu merkitsisi sitä, että kaivokset käyttäisivät paikallista biomassaa energian lähteenä ja huolehtisivat vesistöjen suojelusta käyttämällä vedenkäsittelyyn menetelmiä, jotka perustuvat paikallisen teollisuuden sivutuotteisiin.

Taulukko 2. Arktiset teknologiasovellukset, Ryhmä SMART.

Tunnus	**Sovellus ja kuvaus**
SMART1	**Rakenteiden jatkuva monitorointi ja etähallinta** Arktisella alueella järjestelmien ennakoimattoman huollon toteuttaminen on hyvin kallista. Siksi rakenteiden jatkuva monitorointi ja etävalvonta voi tuoda merkittäviä etuja. Ihmiselle ankarien olosuhteiden vuoksi myös järjestelmien etäoperointi voi olla kiinnostava mahdollisuus. Anturiteknologian ja robotiikan kehitys mahdollistaa jatkuvaan monitorointiin sekä etähallintaan ja –operointiin liittyviä sovelluksia. Teknologisen kehityksen ansiosta voidaan toteuttaa yhä pienempiä antureita, jotka pystyvät kommunikoimaan keskenään tai ohjausjärjestelmänsä kanssa. Tämä kehitys mahdollistaa sulautettujen kunnonvalvontajärjestelmien toteuttamisen. Robotiikan alalla kiinnostava suuntaus on parvirobottien kehittäminen. Parvirobotit ovat ryhmässä toimivia robotteja, jotka kykenevät keskinäiseen päätöksentekoon. Niitä voidaan hyödyntää sovelluksissa, joissa fyysisesti hajallaan olevat kohteet edellyttävät monitorointia tai toimenpiteitä.
SMART2	**Sensori- ja tiedonsiirtoteknologian kehitys ihmisen toimintakyvyn seuraamiseen** Arktinen ympäristö asettaa alueella työskentelevät koetukselle syrjäisen sijainnin sekä vaihtelevien lämpötila- ja valaistusolojen vuoksi. Ihmisten toimintakyvyn seurantaan ja ennakointiin voidaan kehittää erityisiä järjestelmiä. Tällaiset järjestelmät voidaan toteuttaa yhdistämällä langatonta tietoliikennettä ja sensoriverkkoja. Terveydentilan ja suorituskyvyn etäseuranta olisi mahdollista esimerkiksi älyvaatteiden, langattoman kehoverkon ja tunkeutumattomien (non-invasiivisen) mittausmenetelmien kehittämisen avulla. Lisäksi sovellukset edellyttävät luotettavan ja energiatehokkaan tiedonsiirtoverkon toteuttamista. Sovellusten edellytyksenä on erilaisille sensori- ja radiotekniikoille avoin hierarkkinen verkkoarkkitehtuuri, joka mukautuu erilaisiin käyttötarpeisiin. Tällaisen verkkoratkaisun avulla sensorit voivat siirtää dataa joko saumattomana virtana prosessoimatonta dataa tai ohjelmistoteknisesti esikäsiteltynä siten, että kulloinkin tarvittava tieto siirretään.

SMART3	**Sovellusten kehittäminen pilvipalveluiden, isojen datamäärien ja palvelinliiketoiminnan ympärille** Pilvipalveluiden tehokas hyödyntäminen on olennainen osa arktisten alueiden toimintamahdollisuuksien kehittämistä. Arktiselle alueelle toteutettavat verkkoratkaisut mahdollistavat eri sovellusten kehittämisen tiedon keräämiseen ja siirtoon, mutta laskentaa, analysointia ja tiedon varastointia voidaan hajauttaa laajemmalle alueelle tehtäväksi ns. pilvessä. Toisaalta kylmä ilmanala ja toimivat tietoliikenneyhteydet tarjoavat mahdollisuuksia pilvilaskennan (cloud computing) ja suurten datamäärien hyödyntämiseen perustuvien palveluiden kehittämisessä. Pohjoisen luonnonolot ovat suotuisat runsaasti jäähdytystä tarvitsevien datakeskusten sijoittumiseen. Suuren datamäärän analysointiin perustuvia palveluita voidaan hyödyntää esimerkiksi arktisen ympäristön seurannassa tai arktisen matkailun edistämisessä.
SMART4	**Satelliittipohjaiset palvelut** Arktisille merialueille tarvitaan satelliittipohjaisia tietoliikennejärjestelmiä, jotta esimerkiksi sää- ja meriturvallisuuteen liittyviä palveluja voidaan välittää aluksille. Ympäristöön, säähän, jään liikkeisiin ja ilmastoon liittyvät ennustemallit luovat pohjaa kaupallisille palveluille, jotka omalta osaltaan vähentävät arktisen merialueiden sää- ja jääolosuhteista johtuvaa epävarmuutta ja riskiä. Näiden palveluiden kehittämisessä voidaan hyödyntää satelliittihavaintoihin perustuvia monitorointi- ja informaatiojärjestelmiä. Satelliittipohjaiset palvelut ja kaukokartoitustekniikat edistävät myös meriympäristön suojelua arktisilla laivareiteillä.
SMART5	**eHealth-palvelut ja etälääketiede** Arktisilla alueilla on harva asutus ja välimatkat lähimpiin palvelukeskuksiin voivat olla hyvin pitkiä. Siksi alueille tulisi kehittää sähköisiä palveluita ja järjestelmiä esimerkiksi terveydenhuoltoon. Tämä edellyttää tietotekniikan hyödyntäminen potilastyössä (eHealth-sovellukset) ja etäterveydenhuollon kehittämistä. eHealth-sovelluksia ovat esimerkiksi sähköiset terveysarkistot, henkilökohtaiset kannettavat laitteet tai terveysportaalit, jotka tukevat oman terveyden seurantaa. Etäterveydenhoito tarkoittaa järjestelmää, jossa potilas ja lääkäri ovat fyysisesti eri paikoissa. Tulevaisuudessa etäterveydenhoidon mahdollisuuksia lisää esimerkiksi ”Lab-on-a-chip”-teknologiat (LOC), jotka mahdollistavat diagnostiikan hyvin pienessä mittakaavassa. LOC-teknologian avulla diagnostiikka on nopeaa ja vaatii vähän energiaa, joten analyysit voidaan toteuttaa pysyvän infrastruktuurin ulkopuolella.

Taulukko 3. Arktiset teknologiasovellukset, Ryhmä ARCT.

Tunnus	**Sovellus ja kuvaus**
ARCT1	**Lumen hallinnan ratkaisut ja mallintaminen** Lumi tarjoaa arktisilla alueilla haasteita ja mahdollisuuksia, joita ei ole nykyisin vielä täysin huomioitu. Arktisten alueiden yhdyskuntasuunnittelussa lumi täytyy ottaa huomioon ja lumen hallintaan voidaan kehittää uusia ratkaisuja. Lunta voidaan myös hyödyntää esimerkiksi rakennusten jäähdytyksessä. Lumen käyttäytymisen paremmalla tuntemisella ja mallintamisella voidaan kehittää uudenlaisia hyödyntämismenetelmiä ja ratkaisuja lumen hallintaan. Mallinnuksessa fysikaalisia ilmiöitä ja prosesseja kuvataan matemaattisesti. Matemaattisten mallien avulla ilmiöitä voidaan simuloida ja tuottaa siten ennusteita siitä, miten ratkaisut tulevat toimimaan.

ARCT2	**Kylmän ilmanalan työkoneet** Kaikessa arktisilla alueilla tapahtuvassa toiminnassa, kuten kaivostoiminnassa, satamissa ja öljynporauksessa, työkoneiden kylmänkestävyys on tärkeässä asemassa. Työkoneiden suunnittelussa tulisi siksi suosia ratkaisuja, jotka eivät ole alttiita kylmälle. Esimerkki tällaisesta ratkaisusta on öljytön voitelu. Myös pitkään lepotilassa olleiden koneiden ja laitteiden käynnistäminen kylmissä olosuhteissa luo haasteita koneiden toimintavarmuudelle. Koneiden kehityksessä on huomioitava myös niiden huoltotarve ja elinkaarivaikutukset, kuten käytön aikaiset päästöt ja materiaalin kierrätettävyys.
ARCT3	**Materiaalien funktionaalisten ominaisuuksien kehittäminen** Materiaaliteknisellä kehityksellä voidaan lisätä tuotteiden käyttövarmuutta. Toiminnalliset älymateriaalit ovat vuorovaikutuksessa ympäristönsä kanssa ja reagoivat olosuhteissa tapahtuviin muutoksiin. Lisäksi ne voivat myös viestittää omasta tilastaan. Esimerkkejä toiminnallisista älymateriaaleista ovat esimerkiksi pinnoitteet, jotka voivat lisätä eristyskapasiteettiaan kylmässä tai kosteassa säässä. Arktisella alueella älymateriaaleja voidaan hyödyntää esimerkiksi jääkertymien estossa tai jääpeitteen aiheuttaman värähtelyn hallinnassa.
ARCT4	**Arktinen rakentaminen ja materiaalien kestävyyden parantaminen** Arktiset olosuhteet asettavat erityisvaatimuksia rakentamiselle ja käytettäville materiaaleille. Suunnittelussa ja materiaalivalinnoissa on huomioitava rakennusten koko elinkaari. Rakenteiden tulee kestää mahdolliset lumi- ja jääkuormat, ja rakennusmateriaalien, kuten teräksen ja betonin, käyttäytyminen ja kestävyys kylmässä pitää tuntea. Myös kosteuden ja lämpötilan vaihteluiden vaikutus materiaalien ja rakenteiden kestävyyteen on otettava huomioon. Arktisessa rakentamisessa on kiinnitettävä erityishuomiota energiatalouteen ja haastavien työskentelyolosuhteiden asettamiin reunaehtoihin. Arktiselle alueelle voidaan kehittää myös täysin omia rakennuskonsepteja, jotka mahdollistavat väliaikaisen rakentamisen ja rakennuskannan siirron paikasta toiseen.
ARCT5	**Polttokennoteknologian kehittäminen ja hyödyntäminen arktisissa oloissa** Polttokenno on sähkökemiallinen laite, joka muuntaa polttoaineen sisältämän energian suoraan sähköenergiaksi ja lämmöksi kennossa tapahtuvien hapetus-/pelkistysreaktioiden tuloksena. Polttokennon etu verrattuna perinteiseen polttomoottoriin on korkea hyötysuhde ja vähäiset päästöt, koska siinä ei tarvitse käyttää fossiilisia polttoaineita. Polttokennoteknologiaa voidaan soveltaa hyvin laajasti alkaen miniatyyrisovelluksista, kuten älypakkaukset, päätyen aina voimalaitoksiin asti. Arktisessa kontekstissa polttokennoteknologiaa voitaisiin hyödyntää esimerkiksi varavoimasovelluksissa tietoverkkojen tukiasemissa tai lisävoimana laivoissa, sillä teknologialla on hyvä toimintavarmuus pakkasella. Polttokennoilla odotetaan olevan merkittävä rooli myös hajautetussa sähkön ja lämmön yhteistuotannossa.

Appendix D: Osaamiskartoituksen tulokset

Soveltava arktinen teknologiaosaaminen

SMARCTIC-projektin työpajaprosessin ja täydentävän haastatteluaineiston perusteella muodostettu kokonaiskuva arktisesta soveltavasta teknologiaosaamisesta on esitetty taulukossa 1. Työpaja-aineiston perusteella oli mahdollista tunnistaa viisi ylemmän tason teemaa, jotka ovat: Yhdyskuntiin liittyvä osaaminen, Rakenteiden toimivuus kylmässä, Logistiikka ja kuljetukset, Resurssivarantoon liittyvä osaaminen sekä Energian tuotanto. Liitteessä esitellään kyseisiin osaamisalueisiin liittyviä tarkempia kuvauksia ja aiheiden piirissä toimivia suomalaisia organisaatioita. Organisaatioiden kartoitus tapahtui lähinnä verkkolähteisiin perustuen.

Taulukko 1 Yhteenveto soveltavasta arktisesta teknologiaosaamisesta.

Yhdyskunnat	**Rakenteiden toimivuus kylmässä**	**Logistiikka & Kuljetukset**	**Resurssi-varanto**	**Energian tuotanto**
Arktisuuden huomiointi yhdyskuntien suunnittelussa: Suunnittelu- ja projekti-osaaminen **Rakennukset ja rakentaminen kylmässä:** Materiaalien kylmänkesto ja rakenteiden toimivuus **Yhdyskuntien ylläpito**	**Meriteollisuus:** Laivakonseptit ja -järjestelmät **Offshore-rakenteet:** Rakenteiden toimivuus jäissä, jatkuva monitorointi, rakenteiden korjaus arktisissa olosuhteissa	**Merenkulku jääpeitteisillä alueilla:** Logistiikka-järjestelmät, meriliikenteen ohjaus-mekanismit **Tieliikenne:** Routimisen ja ikiroudan vaikutus tiestöön ja rautateihin	**Arktinen luonto:** Arktisen biodiversiteetin hyödyntäminen, Resurssien monikäytön konfliktien hallinta **Arktinen kaivostoiminta** **Öljyn & kaasunporaus**	**Arktinen tuulienergia:** Jäätävien olosuhteiden vaikutus teknologisiin ratkaisuihin ja toteutukseen **Uusien yhdyskuntien energiaratkaisut**: Combivoimalat, Energian varastointi ja vaihtelun hallinta Arktinen aurinkoenergia

Arktisiin yhdyskuntiin liittyvä osaaminen

Osaamisalueen sisältö

Suunnittelu	• Olosuhteet (pimeys, lumi, jää, kylmyys jne.) huomioon ottava suunnittelu • Pitkien etäisyyksien hallinta ja huomiointi suunnittelussa; palveluiden saatavuus • Resurssitehokkuus • Projektiosaaminen
Rakentaminen kylmässä	• Lumikuorman kesto • Betonin käyttäytyminen • Rakennustekninen toimivuus (ovet, ikkunat yms.) • lämmitys energiatalous ja –tehokkuus • Teräsrakentaminen (rungot yms.)
Ylläpito	• Talvikunnossapidon osaaminen; katujen ylläpito talvella; lumen poisto • Työ- ja elinympäristön turvallisuus • Biorytmi, Sopeutuminen kylmään ja pimeään

Osaamisalueella toimivat suomalaiset organisaatiot

Organisaatio	Osaaminen
Aalto-yliopisto, Rakennustekniikan laitos	Routa, veden jäätyminen huokoisessa aineessa, lumivyöryjen aiheuttamat dynaamiset kuormat
Lapin ELY-keskus	Alueiden käyttö, yhdyskuntarakenne ja rakentamisen ohjaus
RAMK	Lumi ja jää rakennetussa ympäristössä, lumi- ja jäärakentaminen
VTT	Routa
	Kylmän ilmanalan rakentaminen, rakennusfysiikka

Rakenteiden toimivuus kylmässä

Osaamisalueen sisältö

Meriteollisuus	• Arktisen alueen laivakonseptit • Laivojen osajärjestelmät, kuten propulsio-järjestelmät • Laivojen jäävahvistus
Offshore-rakenteet	Offshore-rakenteiden toimivuus jäissä: • Anturointi & jatkuva monitorointi • Huoltotarpeen ennakointi • Rakenteiden korjaus arktisissa olosuhteissa (esim. hitsaus)

Osaamisalueella toimivat suomalaiset organisaatiot:

Organisaatio	**Osaaminen**
Aalto-yliopisto, Sovelletun mekaniikan laitos	Laivojen jääkuormat ja suoriutuminen jäissä, mallikokeet, talvinavigoinnin järjestelmät
	Offshore-rakenteiden jääkuormat
Aker Arctic Technology Inc.	Laivojen ja merirakenteiden malli- ja täysmittakaavakokeet jääolosuhteissa, jäissä kulkevien alusten suunnittelu ja tutkimus
VTT	Laivojen jääkuormat ja suorituskyky jäissä
	Offshore-rakenteiden jääkuormat, jää-rakennevuorovaikutus
	Jään kertyminen merirakenteisiin, laivoihin, voimajohtoihin ja tuulivoimalan lapoihin

Logistiikka & kuljetukset

Osaamisalueen sisältö

Merenkulku jääpeitteisillä alueilla	• Jääpeitteen vaikutus laivojen kulkunopeuteen • Logistiikka-järjestelmien suunnittelu ja seuranta pohjoisilla latitudeilla • Meriliikenteen ohjausmekanismit
Tieliikenne	• Jäätiet • Jäädyttäminen / sulattamisen osaaminen • Teiden kunnossapito • Routimisen ja ikiroudan vaikutus tiestöön ja rautateihin

Osaamisalueella toimivat suomalaiset organisaatiot

Organisaatio	**Osaaminen**
Aalto-yliopisto, Koneenrakennustekniikan laitos	Renkaiden pito jäällä ja lumella
Ilmatieteen laitos	Jääpalvelu http://ilmatieteenlaitos.fi/jaatilanne
	Merien jääpeite, kaukokartoitusmenetelmät, jään rakenne, dynamiikka, paksuuntuminen ja liikemallit http://ilmatieteenlaitos.fi/jaatutkimus
Liikennevirasto	Talvimerenkulun turvallinen sujuminen ja jäänmurtopalveluiden saatavuus, teiden, rautateiden ja meriväylien kunnossapito
Tampereen teknillinen yliopisto, Materiaalioppi	Renkaan pito jäällä ja lumella
TraFi	Merenkulun turvallisuus ja jääluokkasäännöt
VTT	Jäänmurron yhteistyövälineet jäisillä merillä
	Liukkauden tunnistin autoihin
	Jään kitka

Resurssivaranto

Osaamisalueen sisältö

Arktinen luonto	• Lyhyen kasvukauden vaikutus kasvi- ja eläintuotantoon • Levinneisyysrajat (eteläinen, pohjoinen, korkeus) • Suot • Uudet raaka-aineet arktisesta ympäristöstä • Arktisen biodiversiteetin hyödyntäminen • Resurssien monikäytön konfliktien hallinta
Arktinen kaivostoiminta	• Maaperän koostumus • Infrastruktuurin rakentamisen haasteet: Maarakentaminen (routa, ikirouta), betonirakentaminen, vesien käsittely • Lumipeitteen vaikutukset, esim. kuljettimien kattaminen
Öljyn & kaasunporaus	*(Aineistossa ei tullut esiin tarkennettua sisältöä)*

Osaamisalueella toimivat suomalaiset organisaatiot

Organisaatio	**Osaaminen**
Arktinen keskus	Taloustoiminnan vaikutus arktisen alueen ekologiaan ja ympäristöön
GTK	Luonnonvarojen etsintä arktisessa
Helsingin yliopisto	Merijää, lumitutkimus, palsat
Ilmatieteen laitos, arktisen tutkimuksen yksikkö	Ilmakehä, biosfääri, maanpinta, ilmasto ja ympäristö http://ilmatieteenlaitos.fi/arktinen-tutkimus
Itä-Suomen yliopisto	Kasvihuonekaasuvirtojen muuttuminen arktisessa ilmaston muuttuessa
Lapin ELY-keskus	Ympäristönsuojelu
Metla	Metsien eri käyttömuotojen yhteensovittaminen ja kestävä luontomatkailu
MTT	Äärialueiden kasvintuotannon tutkimus ja tukeminen
Riista- ja kalatalouden tutkimuslaitos	Poro- ja lohitutkimus, kalojen tutkimus Inarinjärvessä
STUK	Arktisten alueiden ympäristöseuranta
SYKE	Ympäristömyrkyt, ilmastonmuutos ja otsonikato arktisessa
Thule-instituutti	Ympäristötutkimus ja –tekniikka
Turun yliopisto, Kevon tutkimuslaitos	Biologia, ympäristö

Energiantuotanto

Osaamisalueen sisältö

Arktinen tuulienergia	• Voimaloiden mitoitus • Jäänestojärjestelmät • Instrumentointi jäätävissä oloissa • Jäätämisen mallintaminen ja määrittäminen sijoituspaikoille • Jäätymisen vaikutus voimansiirtoon • Vaikutus lento- ja laivaliikenteen turvallisuuteen, tutkapeitto • Merituulivoiman perustusratkaisut
Uusien yhdyskuntien energiaratkaisut	• Combivoimalat • Energian vaihtelun hallinta • Energian varastointi
Arktinen aurinkoenergia	• Säteilyn kohtauskulman hallinta • Tehokkuus, pienen säteilymäärän hyödyntäminen

Osaamisalueella toimivat suomalaiset organisaatiot

Organisaatio	Osaaminen
VTT	Arktinen tuulivoima, lapojen jäätyminen, lapalämmityslaitteistot
	Arktisten offshore-tuulivoimaloiden jääkuormat