THE NSPS SHIPBUILDING VALUE CHAINS

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The Nova Scotia Department of Economic and Rural Development and Tourism (NSERDT) sponsored the research for this report. This report identifies, to the extent knowable at this early stage, companies in the shipbuilding value chain capable of providing the products and services necessary to construct and maintain the Arctic/Offshore Patrol Ships (AOPS), Joint Support Ships (JSS), Polar Icebreaker, and Offshore Fisheries/ Offshore Oceanographic Science Vessel (OFSV/OOSV) value chains.

Please note that the Canadian Surface Combatant (CSC) value chain is omitted from the report due to differences in its size, scope, and production schedule.

Errors of fact or interpretation remain the exclusive responsibility of the authors. The opinions expressed or conclusions made in this study are not endorsed by the project sponsor, companies mentioned, or individuals interviewed. We thank Rich Billard (MDA), Jim Hanlon (HMRI), John Huxtable (Hawboldt Industries), John Gillis (Kongsberg Maritime) and five anonymous reviewers in industry and government for reading the report and providing their perspective. We welcome comments and suggestions. The corresponding author can be contacted at lukas.brun@duke.edu.

Front picture: Microsoft Clip Art, used with permission

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List of Abbreviations

ABS	American Bureau of Shipping
ACOA	Atlantic Canada Opportunities Agency
ADCP	Acoustic Doppler Current Profilers
AHTS	Anchor-Handling Tug Supply
AOPS	Arctic/Offshore Patrol Ships
AUV	Autonomous Underwater Vehicle
BHP	Break Horsepower
BWM	Ballast Water Management
C4IS	Command, Control, Communication, Computer, Intelligence, and Surveillance
CAD	Canadian Dollar
CADm	Canadian Dollar In millions
CCG	Canadian Coast Guard
CCTV	Closed-Circuit Television System
CGGC	Duke Center On Globalization, Governance & Competitiveness
CGP	Controlled Goods Program
CHC	Canadian Hydraulics Centre Of The National Research Council
CIWS	Close-In Weapons Systems
CMMI	Capability Maturity Model Integration
CMS	Command Management System
COTS	Commercial Off the Shelf
CSC	Canadian Surface Combatant
CTD	Conductivity, Temperature And Depth
CWIS	Close-In Weapons System
DAB	Design and Build
DGPS	Differential Global Positioning System
DND	Department Of National Defence
DNV	Det Norske Veritas
DP	Dynamic Positioning
E3	Electromagnetic Environmental Effects
ECWS	Electronic Cooling Water Systems
EEZ	Exclusive Economic Zones
EO	Electro-Optical
EPA	US Environmental Protection Agency
EPTL	Enhanced Technology Priority List
ERRV	Emergency Rescue And Recovery Vessels
ERT	Environmental Response
EU	European Union
FELEX	Frigate Life Extension Program
FPSO	Floating Production Storage And Offloading
GMDSS	Global Maritime Distress Safety System
GVCs	Global Value Chains
HFIR	Helicopter In-Flight Refueling
HFO	Heavy Fuel Oil
HMRI	Halifax Marine Research Institute
HPU	Hydraulic Power Unit
HVAC	Heating, Ventilation, and Air Conditioning
IACS	International Association Of Classification Societies
IC	Industry Canada
ICES	International Council for Exploration of the Seas
IFF	Identification, Friend-or-Foe
ILS	Integrated Logistical Support
IMO	International Maritime Organization
IMR	Inspection, Maintenance And Repair
IOT	Institute of Offshore Technology
IPMS	Integrated Platform Management System
IRB	Industrial and Regional Benefits
ISI	Irving Shipbuilding Inc.
ISO	International Organization for Standardization
ISS	In-Service Support
ITAR	International Traffic In Arms Regulations
JSS	Joint Support Ships
LAN	Local Area Network.
LARS	Launch And Recovery System
LNG	Liquid Natural Gas
LO-LO	Lift-On Lift-Off
MCDV	Maritime Coastal Defence Vessels
MSPV	Mid-Shore Patrol Vessels
MOTS	Military Off the Shelf
MVP	Moving Vessel Profiler
MW	Megawatts
NOx	Nitrogen Oxides
NSERDT	Nova Scotia Economic and Rural Development and Tourism

NSPS	National Shipbuilding Procurement Strategy
OFSV	Offshore Fisheries Science Vessel
OOSV	Offshore Oceanographic Science Vessel
PERD	Program of Energy Research and Development
PM	Particulate Matter
PSV	Platform Service Vessels
PWGSC	Public Works and Government Services Canada
RAM	Rolling Airframe Missile
RAS	Replenishment-At-Sea
RCMP	Royal Canadian Mounted Police
RCN	Royal Canadian Navy
RDA	Regional Development Agencies
RFP	Request For Proposals
RHIB	Rigid Hull Inflatable Boat
RO-RO	Roll-On Roll-Off
ROV	Remotely Operated Vehicle
RPM	Revolutions per Minute
SAR	Search & Rescue
SEARAM	Phalanx and RAM
SME	Small-and-Medium-Sized Enterprise
SOF	Special Operations
SOLAS	International Convention for the Safety of Life at Sea
SOx	Sulfur Oxides
STC	Surface Treated Composite
TBS	Treasury Board Secretariat
TC	Transport Canada
UNCLOS III	Third United Nations Convention on the Law of the Sea
VCF	Venture Capital Funds
WECDIS	Warship Electronic Chart Display and Information System

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Executive Summary

This report identifies, to the extent knowable at this early stage, companies in the shipbuilding value chain capable of providing the products and services necessary to construct and maintain the vessels procured under the NSPS, and makes recommendations to government and industry about increasing the participation of Nova Scotia's companies in high value areas of the shipbuilding value chain.

In particular, the purpose of investigating the value chains of the NSPS vessels is to:

- Discover the value chain position and opportunities of Nova Scotia's companies;
- Identify innovation and technology trends in the Arctic/Offshore Patrol Ships (AOPS), Joint Support Ships (JSS), Polar Icebreaker, and Offshore Fisheries/ Offshore Oceanographic Science Vessel (OFSV/OOSV) value chains. *Please note that the Canadian Surface Combatant (CSC) value chain is omitted from the report due to differences in its size, scope, and production schedule.*
- Make recommendations for supporting the participation of Nova Scotia companies in the global value chains for these vessels, and make recommendations to industry and government about opportunities to move into higher value activities within the value chain.

Nova Scotia's position and opportunities in the NSPS shipbuilding value chains**:** We discovered that Nova Scotia's companies are well positioned across the NSPS shipbuilding value chains we evaluated, particularly for the Canadian icebreaker and the science vessels. While the details differ for each value chain, overall, we found that Nova Scotia's firms are particularly strong in the supply of advanced sub-systems, specifically navigation, electronic and communications equipment, and shipbuilding engineering and support services. Nova Scotia's weaknesses in the value chains include limited final product manufacturing by multinational firms and the increasing consolidation of production by non-Canadian multinational firms in the shipbuilding sector. The national offset policy, the Canadian Industrial and Regional Benefits (IRB), seeks to counter the impact of these trends in the NSPS shipbuilding value chains.

The report identifies a number of opportunities for Nova Scotia. Market opportunities exist within specific subsystems of the vessels procured in the NSPS, particularly in high technology instrumentation. Opportunities for developing the shipbuilding sector in Nova Scotia include creating value chain linkages with multinational corporations seeking to provide systems to the NSPS vessels. Opportunities exist for Nova Scotia to use investments required under the Canadian offset policy (IRB) and the Value Proposition to develop globally competitive capabilities within specific, niche areas in shipbuilding and allied ocean technology and marine energy sectors.

Innovation and technology trends**:** The report identifies five market and technology trends across the value chains we studied.

- Multifunctional and modular design
- Systems integration
- Signature reduction

- Fuel economy and ballast water management
- Unmanned vehicles

Multifunctional/modular design: ships are designed with the capability to carry out several missions or to add mission-specific packages over time. For example, the proposed AOPS design provides space for a larger naval gun, additional equipment space for Search & Rescue (SAR) and environmental response operations, enhanced cargo handling, and a larger helicopter and associated aircraft securing and haul-down systems to conduct surveillance, search and rescue, or environmental response. National governments can achieve multiple objectives with one vessel, and consolidate financial capital and human resources into one vessel instead of three or four.

Systems integration: The main development trends are toward more integration of command and control, communications, command support systems, wider bandwidths in fiber optic networks, and distributed processing. Multi-sensor data systems are becoming more sophisticated and comprehensive. The development of systems to integrate, manage, and present to the operators the ever-increasing amount of operational data is a major trend in software development for sophisticated vessels.

Signature reduction: A major design trend in shipbuilding, specifically in naval shipbuilding, is to reduce a variety of “signatures” produced by a ship. Ship signatures allow detection by sensors. Radar signature is being reduced through the design of external surfaces and the application of radar absorbent paints to the hull and superstructure. Infrared, or “heat”, signature is being reduced by masking high temperature areas, either by cooling or concealing exhaust plumes. Underwater noise signature is being reduced by better designing hulls and propellers to be more hydrodynamic and using air masking techniques. Internal noise signature caused by machinery is being reduced by applying self-noise monitoring techniques which identify the source of internal noise. Finally, magnetic signature is reduced through the use of non-metallic materials and demagnetizing metallic components.

Fuel economy and ballast water management: Naval architects are emphasizing improvement of speed, seakeeping, dynamic stability, and fuel economy in ships. New international regulations soon entering into force will require ballast water to be treated before discharging.

Unmanned vehicles: Unmanned vehicles in the air, surface, and underwater are becoming increasingly common on a variety of ships for reconnaissance, surveillance or targeting.

Recommendations: We were asked to make recommendations to the Province of Nova Scotia how to a) support Nova Scotia companies in the NSPS Shipbuilding value chains, b) how to move the Province and its companies into higher value-added activities in the value chains, and c) what value chain development activities should be conducted by the Province.

A. Supporting Nova Scotia companies

A.1. Connect with key players in the value chains – Since the overwhelming majority of the supply chain for the NSPS vessels is under the control of platform and mission systems integrators (and their suppliers), attention of the private sector and government should be focused on how companies enter the supply chains of these key value chain actors.

Our recommendations to companies about how to connect with key value chain players are to:

- Participate in industry forums and events as they take place. CanSec, WestDef, DefSec, and Industry Days hosted by tiered suppliers provide good opportunities for companies to exchange information about needs and capabilities.
- Communicate clearly what your enterprise has to offer and how it adds value to the large company's supply chain.
- Maintain up to date, accurate and detailed information about products and services on the company website and on the Canadian Company Capabilities registry on Industry Canada.
- Register on the online supplier portals of the major platform and mission systems integrators and subsystems manufacturers. Companies use this information to collect information about potential supply chain partners.
- Monitor MERX Canadian Public Tenders Service (www.merx.com) for upcoming projects and bidding opportunities in Canada.

Our recommendations to governments are to:

- Know the companies and their capabilities in the shipbuilding value chain in their geographic area of responsibility. Governments can create potential supplier lists by using the existing knowledge about the companies in their region, the Canadian Company Capabilities Registry hosted by Industry Canada, and information provided in this report.
- Facilitate site visits to companies in the higher tiers of the production hierarchy. As with industry forums, the ability of buyers to meet potential suppliers provides the opportunity for a quick exchange of information about needs and capabilities among companies.
- Attend industry forums and events to develop contacts for companies, particularly SMEs, not able to attend.
- Communicate to companies how large firms meet suppliers.

A.2. Help SMEs overcome barriers to entry in the shipbuilding value chain – We found that SMEs face four kinds of barriers to enter the shipbuilding value chain: information, network, certification, and coordination gaps. We recommend that government work to:

- Close information gaps: Since many of the companies in the ocean technology and shipbuilding sector are SMEs, governments should recognize and incorporate the resource and capacity constraints of SMEs in program design.
- Close network gaps: Foster linkages between local suppliers and systems integrators by, for example, developing and increasing the frequency of meetings between integrators and SMEs. Participation in industry-relevant trade associations can help close network gaps for SMEs.

- Close certification gaps: Evaluate small business assistance programs in the province to identify needs and gaps in program offerings. In particular, consider conducting a capability assessment of SMEs in Nova Scotia, especially in rural areas and First Nation communities, and developing or enhancing capacity development assistance programs.
- Close coordination gaps: Foster linkages among Nova Scotia and Canadian firms to offer systems or sub-system solutions to Tier 1 firms.

A.3. Inform value chain actors about the effect of public and private regulations on the value chain – We found that public and private regulations significantly affect the conduct of the value chain and what companies can participate in it. We recommend that Nova Scotia provide information about the IRB and the Controlled Goods Program on a publicly available website, advertise its existence, and compile a reference guide about common requirements of large companies placed on suppliers.

A.4. Improve communications about NSPS and relevant policies to companies and citizens – We found that confusion exists about the status of the NSPS process, particularly the time horizon and decision-making for different vessels; the difference between production and in-service support contracts, how access to the shipbuilding value chain is governed, and what opportunities exist for new business. We recommend that Nova Scotia use existing organizations and established networks to provide information to small business, rural areas, and citizens about the status of the NSPS, the relevant public and private policies regulating access to the supply chain, and the responsibility domain of different levels of government in regulating the shipbuilding value chain, assisting companies, and providing information.

B. *Moving into higher value-added activities* – We found emerging technology opportunities in specific systems, and that many of the best niches for high value activities occur at the junctures between different GVC stages. Specific examples include the interface between design and component production (dampening of anthropomorphic noise, engine vibrations, acoustic technology and vessel design), and the commercialization nexus between production and marketing of new end products. We recommend that Nova Scotia focus sector development strategies and programs on actors that participate, and are leaders in, these trends; use the province's innovation infrastructure to develop technology for sustaining and growing the shipbuilding industry; and grow and nurture a pool of technology-based entrepreneurs by encouraging entrepreneurial training.

C. Conducting regional value chain development activities

C.1. Connect with key players in the non-combat vessel value chain – We found that opportunities exist for Nova Scotia's firms in the non-combat vessel value chains due to complementarities between company capabilities in acoustics and digital imaging technologies and the primary purpose (research activities) of the vessels being built by Seaspan. While we recognize that accessing the supply chains for the non-combat vessels will require extra effort, we recommend that the Province increase engagement with the governments of British Columbia and Vancouver, work to establish links with Tier 1 and Tier 2 companies participating in the non-combat value chain, and to consider conducting a multi-provincial trade mission to Western Canada, perhaps in partnership with ACOA and regional development authorities.

C.2. Plan for the future

The NSPS presents a tremendous opportunity for Nova Scotia and Atlantic Canada to develop a globally competitive shipbuilding sector in niche, high value areas. We recommend that the Province develop a plan for how to develop the international competitiveness of the shipbuilding and related ocean technology sectors in Nova Scotia by evaluating how to increase the quantity of high-quality research with commercial relevance, growing and nurturing a pool of technology-based entrepreneurs, using the Province's innovation infrastructure to sustain and grow the shipbuilding industry, and expanding access and availability of investment capital to create and grow companies in the sector.

C.3. Broaden horizons

We found that further evaluation is warranted in three areas: workforce development, lessons learned from large government procurements, and how to improve coordination within Nova Scotia's regional innovation system. We recommend conducting a local labor market analysis and workforce planning study to identify occupational and education gaps; a comparative study of large, recent, and relevant government procurements to identify models, best practices, and lessons learned from other regions; and a study evaluating opportunities and gaps in existing programs to develop a coordinated, rational process by which actors in government, education, industry, and research work together to continue to build a regional innovation system leveraging the strengths already in Nova Scotia.

1. Introduction

1.1. Report Overview

The National Shipbuilding Procurement Strategy (NSPS), announced in October, 2011, offers a unique opportunity for the Province of Nova Scotia to develop and expand its shipbuilding and ocean technology sectors. The vessels procured under the NSPS will provide direct demand for the products and services of companies in Nova Scotia and can provide the basis for developing global expertise in niche areas of shipbuilding. The purpose of this report is to identify, to the extent knowable at this still early stage of the process, companies capable of providing the products and services necessary to construct and maintain the vessels procured under the NSPS (the "NSPS vessels") and to make recommendations to government and industry about increasing their participation in high value areas of the shipbuilding value chain.

1.1.1. Project purpose and scope

The primary purpose of the study is to identify and analyze the value chains for the NSPS vessels, with the exception of the Canadian Surface Combatants (CSC) and the smaller Canadian Coast Guard (CCG) vessels announced in April 2012. We limited our study because the CSC is both a much larger and much later program than others in the NSPS, and because the vessel descriptions for the smaller CCG vessels were not publically available during the research period. The analysis will provide insight into the local and global value chains involved in the design, construction and in-service support (ISS) of the vessels.

In particular, the purpose of the GVC analysis is to:

- Discover the value chain position of and opportunities for Nova Scotia's companies;
- Identify innovation and technology trends in the Arctic/Offshore Patrol Ships (AOPS), Joint Support Ships (JSS), Polar Icebreaker, and Offshore Fisheries/ Offshore Oceanographic vessel value chains;
- Make recommendations for supporting the participation of Nova Scotia companies in the global value chains for these vessels; and
- Make recommendations to industry and government about opportunities to move into higher value activities within the value chain.

The results of the study will inform the Province of Nova Scotia to support the efforts of Nova Scotia's companies to maximize and upgrade over time their participation in the global supply chain for the NSPS vessels. In addition, the results will be used to support industry consultation, mobilization, and capacity building.

The purpose of this chapter is to provide a general overview of the vessels being built by the NSPS and the shipbuilding value chain. After the overview, the report will investigate each NSPS vessel. These chapters will:

- Identify market and technology trends in the vessel's value chain, including detailed analysis of the high-technology systems proposed for the vessels;

- Provide a value chain schematic to:
    - Discover the value chain position of Nova Scotia's companies;
    - Identify the multinational corporations that operate in the value chains and where they are positioned;
    - Determine and identify, where possible, individual companies' local and direct linkages into GVCs; and
    - Analyze market opportunities in the GVCs for Nova Scotia's companies.

A concluding chapter will summarize the findings from our research and make recommendations to industry and government about regional value chain development activities to increase Nova Scotia's participation in the shipbuilding GVC for the vessels being built under the NSPS.

1.1.2. Research methods

We conducted the research for this report in four phases. In the first phase, we reviewed secondary source materials - press releases, industry publications, and online sources - for information on the NSPS, the vessels being built, a preliminary schedule for building the vessels, and general information about the shipbuilding industry. The purpose of this phase was to better understand the shipbuilding industry, the specific ships being built for the NSPS, and to begin identifying important actors in the production network of goods or services for these vessels.

In the second phase, we contacted naval architects, lead firms, classification societies, and regulatory bodies in the shipbuilding industry to develop a preliminary understanding of the shipbuilding value chain. Actors contacted during this phase were federal and provincial government agencies in Canada, industry organizations, and lead firms knowledgeable about the scope, conduct, and general dynamics of the shipbuilding industry and the NSPS. A research trip to Nova Scotia during the 2012 Atlantic Defence and Security Conference (DefSec Atlantic) provided an excellent opportunity for interviewing companies, government agencies, and other actors in the value chain. As a result of these interviews, we modified the shipbuilding value chain found in the *Nova Scotia Ocean Technology* report to better reflect the unique aspects of the vessels being built in the NSPS.[1] In particular, we highlighted the phases of design, the important role of systems integrators, and emphasized services throughout the pre-production, production, and post-production phases of the value chain.

In the third phase of research, additional interviews were conducted with lead and local firms, experts in technology and shipbuilding, and regulatory agencies. The objective of this phase was to better understand specific technical or regulatory aspects not fully apparent at the second stage, to identify additional companies in the value chain nodes, and to better understand their role in the production system. At this phase of the research, our questions became quite specific and covered the full range of issues discussed in this report. The topics and questions covered during the second round of interviews

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[1] The *Nova Scotia Ocean Technology* report is available at http://cggc.duke.edu/pdfs/2012-03-05_NovaScotia_OTReport.pdf

are summarized Figure 1. After completing the interview, we compiled a draft version of the report for external review in the fourth stage.

In the fourth phase of research, CGGC contacted individuals who are well-informed about the industry and asked them to review the value chain and accompanying report. We requested that they provide comments and corrections of either fact or interpretation. Revisions to the report as a result of the external review process were made, and the client was given the opportunity to give final approval of the report.

Figure 1: Research questions

Value Chain governance	Who are the main players?
	How can Nova Scotia's companies enter the main players' supply chains?
	What can government do to better support them?
Regulatory issues	How do public & private regulations affect the value chains?
Innovation	What are the promising technologies in the sector?
	How can government foster development of technology?
Regional issues	What opportunities exist for regional cooperation and trade?
Developing advantage for the future	How can NS best position itself for future advantage?
Priority research needs	What don't we know that we need to know?

Source: Duke Center on Globalization, Governance & Competiveness (Duke CGGC)

Conducting value chain studies in this manner is time intensive, but provides a level of detail and understanding of industries not replicable by a review of only secondary source materials or a quantitative analysis of buyer-supplier relationships common in other industry analyses. A bottom-up, ground level perspective offers insights into markets, technology trends, and the effective role for government action that would be difficult to achieve using other methods.

One limitation to our research should be noted. Since the contracts and designs for the vessels have not been finalized, a range of uncertainty exists about who will supply ship systems and subsystems for the vessels. Our approach throughout the value chain chapters was to identify the systems we think are important or unique to the ships, and to provide a list of suppliers for each component. When we had information about companies likely to provide a component or subsystem, we highlighted the company name. When we had a lower level of certainty about who would provide the component, we listed the leading manufacturers of the system, or companies with which we know the integrator or shipbuilder had worked in the past. As such, we reflected in our list of component suppliers the necessary uncertainty at this preliminary stage of the design-build process.

1.1.3. Report organization

The report is organized in three parts. The first part provides a general introduction of the NSPS vessels and the shipbuilding value chain. The second part analyses the value chains for each of the NSPS vessels, with the exception of the Canadian Surface Combatant, which is omitted from this report. The third part summarizes our findings and recommendations.

- Part 1: Overview
  - Ch.1: Introduction
  - Ch.2: Shipbuilding value chain
- Part 2: the NSPS Shipbuilding Value Chains
  - Ch.3: AOPS
  - Ch.4: Joint Support Ship
  - Ch.5: Polar Icebreaker
  - Ch.6: Science Vessels
- Part 3: Findings and recommendations
  - Ch. 7: Findings and recommendations

1.2. National Shipbuilding Procurement Strategy (NSPS)

The NSPS is the largest purchase of maritime vessels by the Canadian government since WWII. Announced in October 2011, the NSPS will purchase CAD 33 billion in combat and non-combat vessels over the next 20-30 years. The CAD 25 billion combat portion of the program was awarded to Irving Shipbuilding Inc. (ISI) to build 15 Canadian Surface Combatants (CSC) and six to eight Arctic/Offshore Patrol Ships (AOPS) for the Department of National Defence (DND). The $8 billion non-combat portion of the program was awarded to SeaSpan Shipyards (Vancouver) to build up to three Joint Support Ships (JSS), one Polar Icebreaker, three Offshore Fisheries Science Vessels (OFSV), and one Offshore Oceanographic Science Vessel (OOSV). Figure 2 summarizes the vessels procured under the NSPS.

Figure 2: The NSPS Combat and Non-Combat Vessels*

Combat Vessels ($25B)	Canadian Surface Combatant (15 vessels)	Irving Shipbuilding (Halifax)
	Arctic/Offshore Patrol Ship (up to 8 vessels)	
Non-Combat Vessels** ($8B)	**Joint Support Ship*** (up to 3 vessels)**	Seaspan Shipyards (Vancouver & Victoria)
	Polar Icebreaker (1 vessel)	
	Offshore Oceanographic Science (1 vessel)	
	Offshore Fisheries Science (3 vessels)	

* Does not include the $2B for small vessels construction (116 vessels) or the $500-$600m/yr for repair& refit (ISS)
** Does not include $5.2B Canadian Coast Guard vessels announced in April, 2012
*** Current JSS configuration contains armament

1.2.1. The NSPS Vessels

The preliminary NSPS vessel budget and construction periods for the vessels covered in this report are listed in Table 1.

The six to eight Arctic Offshore Patrol Ships (AOPS) are armed naval ice-classed offshore patrol vessels. The ships will be capable of conducting armed patrol and surveillance of Canada's Arctic, Atlantic and Pacific waters. The mission of the ships is to provide situational awareness and enforcement of Canada's Exclusive Economic Zones (EEZ). The estimated project cost is CAD 3.1 billion (TBS, 2012a).

The two or three Joint Support Ships (JSS) will supply fuel, ammunition, spare parts, food and water, and provide logistics support to forces deployed ashore. The JSS will also be home base for the maintenance and operation of helicopters during deployment and provide a limited sealift capability. The estimated project cost is CAD 2.6 billion (TBS, 2012a).

The Polar Icebreaker is scheduled to replace the CCGS *Louis S. St. Laurent* in 2017. It will be the largest, most powerful ship ever built in Canada, with planned 120-140m in length, accommodate 100 operating and 25 additional personnel, 2 helicopter pads and large cargo space. The construction is planned for 2015-2017 and will cost approximately CAD 800 million (CCG, 2012b).

Table 1: Preliminary NSPS Vessel Budget and Construction Period

Vessel Class	# of ships	Construction Funding (CADm)	Unit Cost (CADm)	In-Service Support (CADm)	Construction Period
Arctic/Offshore Patrol (AOPS)	6-8	3,074[1]	384-512	3,000[2]	2015-2024[5]
Joint Support (JSS)	2-3	2,613[1]	871-1,307	2,000[2]	2016-2018[1]
Polar Icebreaker	1	800[4]	800	n.a.	2015-2017[4]
Offshore Fisheries (OFSV)	3	244[4]	81	37.8[3]	2013-2015[6]
Offshore Oceanographic (OOSV)	1	144[4]	144	14.7[3]	2013-2014[6]

Sources: (1) TBS, 2012a; (2) DND, 2012a; (3) DFO, 2012; (4) CCG, 2012b; (5) DND, 2012b; (6) TBS, 2012b

Offshore Fisheries Science Vessels (OFSV) will replace 4 vessels commissioned in the 1970's and 1980's. The primary missions of the OFSV will be fisheries science, oceanography and hydrography. The ships will be 55m in length, capable of staying at sea for 31 days. The vessels will have modern propulsion systems, integrated bridge, modern acoustic sensors, and modern deck and trawl equipment. Two vessels are expected for delivery in 2014, the third is planned for 2015. The estimated construction cost is CAD 244 million (CCG, 2012b).

The Offshore Oceanographic Science Vessel (OOSV) when delivered will be a replacement for the CCGS *Hudson* built in 1963. The vessel mainly operates on Canada's Atlantic Coast and conducts oceanographic data collection for justifying Canada's claim under the United Nations Law of the Sea (UNCLOS III) for areas in excess of 200 miles from the coast. The data are also used by oceanographic researchers, oil & gas, and mining industries. The expected delivery of the vessel is 2015 at a total construction cost of CAD 144 million (CCG, 2012b).

The NSPS vessel budget and construction periods provided in this report are preliminary. The NSPS process is an ongoing effort and a number of factors influence the determination of the budget and construction periods, including the need to get design and production details finalized. The relevant Federal government actors for large procurements are the lead agency (DND-Navy or Department of Fisheries and Oceans – Coast Guard) responsible for definition of requirements and project supervision, Public Works and Government Services Canada (PWGSC) for the procurement process, Industry Canada (IC) for the Industrial and Regional Benefits policy and management of the Value Proposition, and the Treasury Board Secretariat (TBS) for contract approval.

1.2.2. The NSPS Shipyards: Irving Shipbuilding Incorporated and Seaspan

The ships will be built by Irving Shipbuilding Incorporated (ISI) (Halifax, Nova Scotia) and Seaspan (Vancouver and Victoria, British Columbia). Please see Figure 3. ISI's Halifax shipyard can build complex vessels such as cruise ships, anchor handling tugs, supply vessels, and Royal Canadian Navy (RCN) and Canadian Coast Guard (CCG) vessels. ISI currently is building nine Mid-Shore Patrol Vessels (MSPV) for the CCG, scheduled for delivery in Fall 2014, and RCN's Frigate Life Extension Program (FELEX). For the NSPS, ISI was awarded the opportunity to build the CSC and AOPS.

Seaspan, formerly Washington Marine Group, describes itself as an association of Canadian companies involved in coastal and deep sea transportation, bunkering, ship repair and shipbuilding services in Western North America. It includes a 35 acre custom built site in North Vancouver, and can design, construct, repair and maintain ocean vessels of all types. The work on Seaspan's portion of the NSPS ships will be split 80/20 between the North Vancouver yard conducting major vessel fabrication and its facility in Victoria tasked with final outfitting, tests and trials before delivery of the vessels (Canadian Sailings, 2011). Among Seaspan's current projects are the west coast portion of the FELEX, the Vessel In-Service Support Contract and the HMCS *Protecteur* at Victoria Shipyards, building nine new chip barges at Vancouver Shipyards, and commercial ship repair at Vancouver Dry-dock. (BC Shipping News, 2012)

Figure 3: Major Canadian Shipyards

Source: Western Economic Diversification Canada

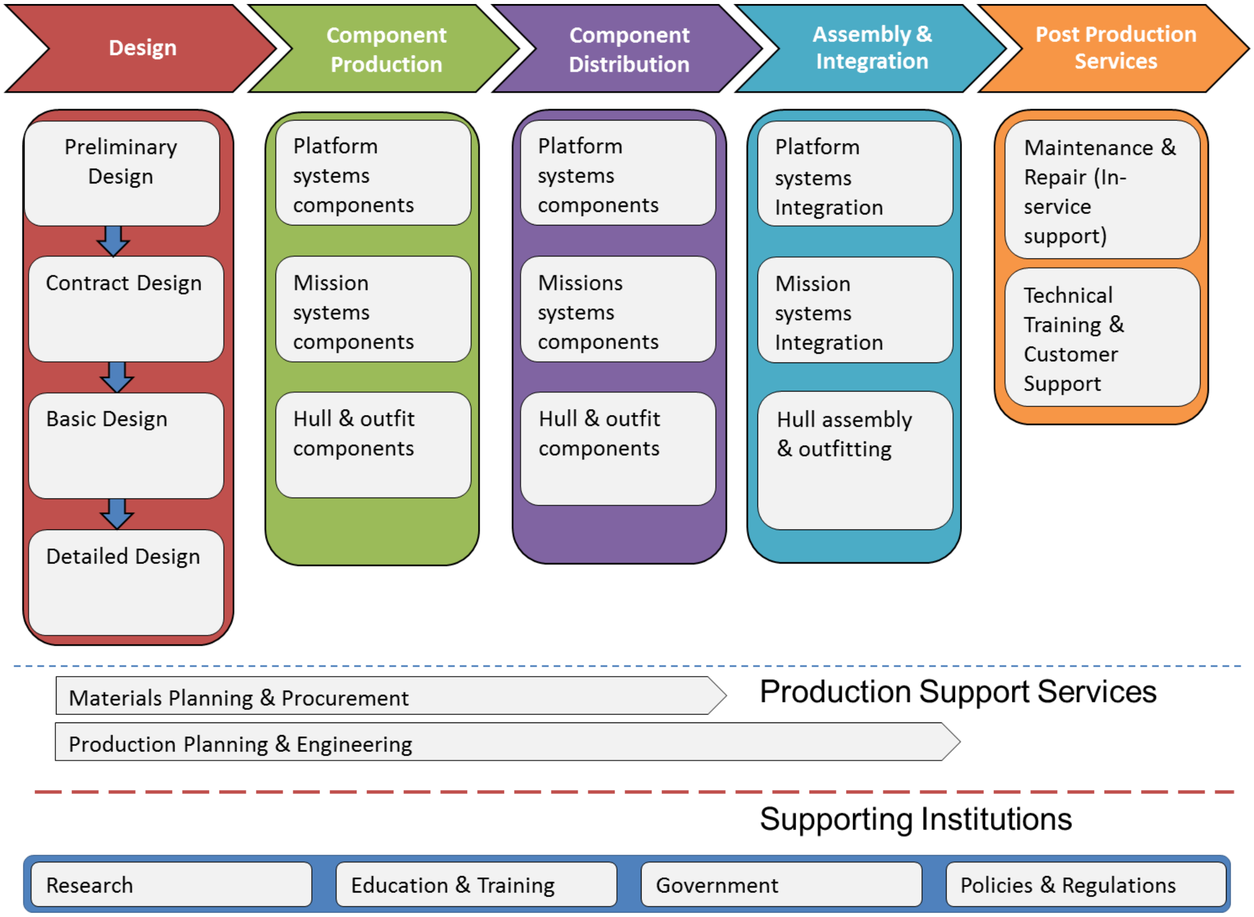
In April 2012, the Canadian Coast Guard announced the purchase of an additional CAD 5.2 billion from Seaspan under the NSPS program. Although details of the purchase are still emerging, an interview in *BC Shipping News* with Brian Carter, President of SeaSpan Shipyards, stated, “The government announced an additional 5.2 billion over 11 years for renewal and refits to the Canadian Coast Guard fleet, including helicopters. A large portion of this will be for new builds that will fall under our umbrella agreement to supply non-combat ships over 1,000 tonnes, but we’re in early days yet for this” (BC Shipping News, 2012, 12).

Both ISI and Seaspan have announced major facility upgrades to prepare for construction of the NSPS vessels. ISI will conduct a CAD 300 million expansion of its facilities, and has announced that Hatch Engineering will provide engineering support for facility expansion. In October 2012, SeaSpan announced a CAD 200 million expansion of its facilities. STX Korea was hired to help design a facility increasing the efficiency of the shipbuilding process through block assembly and extensive pre-outfitting capabilities. In addition, Seaspan will have a 300-tonne gantry crane to support block assembly and vessel erection at the facility, and will add a new blast and paint building needed for new construction and repair work (BC Shipping News, 2012; Shaw, 2012).

2. The Shipbuilding Value Chain

Modern shipbuilding involves multiple actors to design, construct and maintain a ship. Figure 4 illustrates the complex set of design, production, and post-production activities involving multiple actors across the shipbuilding value chain. The purpose of this section is to illustrate the shipbuilding process using the value chain as an orienting framework.

Figure 4: Shipbuilding Value Chain

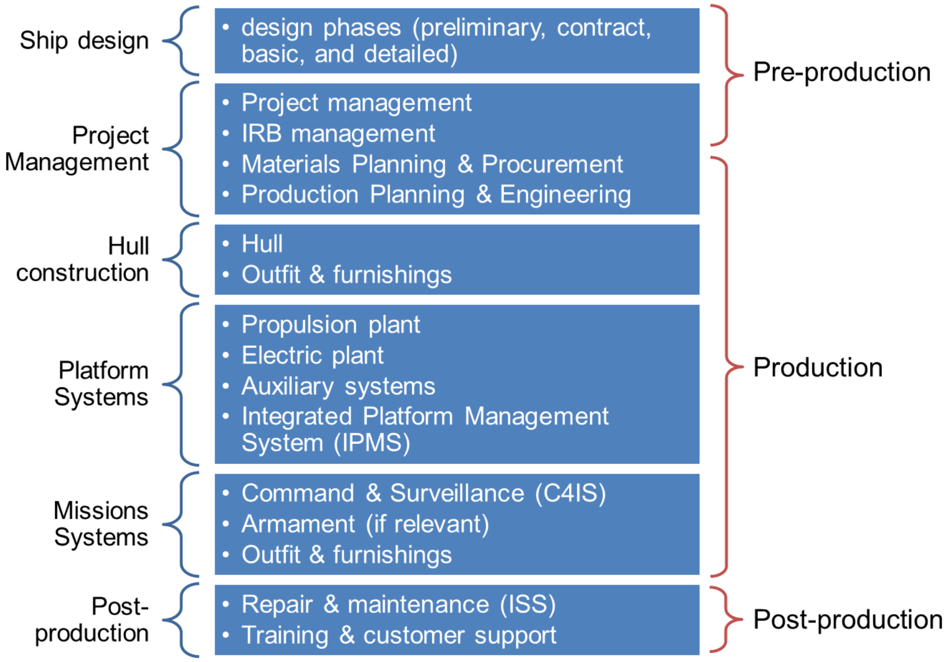


Source: Duke CGGC

The shipbuilding value chain is comprised of three major phases: pre-production, production, and post-production. The pre-production phase of shipbuilding includes the phases of design and project management. The production phase includes hull construction, platform and mission systems production and integration. Hull construction components and activities are those required to build the structure of the ship. Platform systems are components and subsystems needed to move and control the movement of the vessel. Mission systems are the components and subsystems needed to make the vessel perform the tasks for which it is designed. As one ship architect we interviewed stated, hull construction is “making the tub”, platform systems are related to “moving the tub”, and mission systems are “why you bought the tub.” Finally, post-production activities include repair, conversion &

maintenance (ISS) of the vessel after its final construction, and training & customer support. Figure 5 summarizes the phases and activities of modern shipbuilding.

Figure 5: Modern shipbuilding is comprised of multiple phases and activities



Source: Duke CGGC

The actors conducting each activity and phase differ across shipbuilders, regions of the world, and over time. Before the 1950's, shipbuilders were vertically integrated designers and producers of ships, and in-service support was conducted by the ship owner or the shipbuilder after delivery of the ship. For large government projects, the ship owner, shipbuilder, and in-service support provider was the government themselves, specifically the nations' navy or coast guard.

During the 1950's, and especially since the 1980's, dynamics within the shipbuilding industry led to a more fragmented shipbuilding model. In Asia, modular shipbuilding, in which pieces of the hull of up to 300 tons are separately built and assembled in blocks, dramatically increased efficiency and reduced costs. During the 1980's, the worldwide shipbuilding industry collapsed as demand for new ships sank. New shipyards in South Korea used the downturn to consolidate market share in shipbuilding by offering large commercial vessels at unprecedentedly low prices. The South Korean firms, like Hyundai Heavy Industries and Samsung Heavy Industries, rose to prominence by building huge shipyards capable of block construction and vertically integrating the steps of the shipbuilding process, including the integration of major systems.

Meanwhile, shipyards in North America and Europe mostly sustained themselves by building customized, specialty ships, like cruise ships, research vessels, and fulfilling government contracts, especially military orders. Platform and mission systems on these vessels became more complex as they were infused with high-technology. R&D costs for developing new systems skyrocketed, leading to consolidation among suppliers of high-tech components like propulsion systems and integrated electronic suites. These firms gained control over component production through vertical integration and licensing agreements, and they integrated forward into post-production services, leading to the emergence of today's big systems integrators. The model that has emerged in North America and Europe is for shipyards to contract the installation and integration of full ship systems to systems integrators to share risk and rationalize their supply chains.

North American/European shipbuilders are adopting modular design and construction methods developed in Asia. North American and European shipbuilders are investing in capability improvements to produce hulls in sections and install subsystems, for example HVAC, plumbing, and electrical wiring, before the hull is assembled. Seaspan has announced a CAD 300 million contract with STXKorea for upgrading their shipyards with this capability. ISI will begin similar upgrades to its facility as it prepares for construction of the AOPS. ISI used modular ship construction for the Halifax Class Frigates at its St. John, NB facilities in the 1980s.

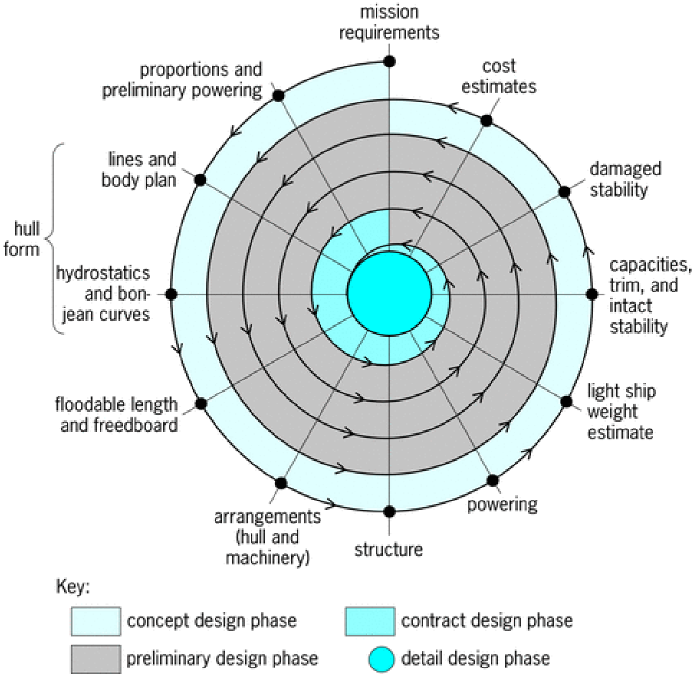
The competitive context of the shipbuilding value chain is important as it illustrates the ability of shipbuilders to organize the activities and phases of shipbuilding in ways that reflect past practices, core competencies and global trends. Shipbuilders, as the prime contractor for the NSPS vessels, are affected by global shipbuilding industry trends even as they sit at the top of a complex global supply chain for the vessels. Thus, shipbuilders both affect and are affected by the shipbuilding global value chain.

We now turn to the phases and specific components of the shipbuilding value chain, beginning with the phases of design. *Please note*: Firms identified in the discussion of value chain segments are supplemented in the data appendix with a listing of global, Canadian, and Nova Scotia companies in the shipbuilding value chain at the subsystems level. Their mention in this overview chapter is intended only for illustration purposes and does not imply either their inclusion or exclusion in the value chains for the NSPS vessels.

2.1. Design

The spiral ship design process typically begins with a decision, usually by the ship's owner, about the mission requirements of the vessel. A ship architect can then begin the process of defining the parameters and features of the ship. (See Figure 6). The major design phases have different objectives and may be conducted by different firms.

Figure 6: Ship design process ("Pugh's Wheel")



Source: MarineWiki

The major phases are:

- *Concept design phase* - The key objective is to arrive at the feasibility of the project. The design begins with an understanding of the ship's requirements and developing a range of solutions, from conservative to those incorporating the latest advances in technology, systems, and hull configurations and sizes. Concept designs showing the greatest promise are evaluated based on the tradeoffs in the weapons systems (if armed), optimization of the hull for powering, seakeeping, and stability, signature reduction, propulsion, and manning/automation.
- *Preliminary (or "basic") design phase* - The key objective is to plan the project. During the preliminary phase, major equipment is selected, and the general arrangement of the hull and equipment is made. General arrangement plans give architects, builders and owners a chance to see the basic, or "general", arrangement of passenger and crew spaces, machinery rooms, stores, holds, tanks and engineering before designs are finalized and yard work begins.
- *Contract design phase* - The key objective is to arrive at the costing of the project. The contract design phase selects a single, preferred design from a number of feasible designs in the concept phase. Specification of the hull form is conducted and initial selection of systems and major equipment is made. Prediction of drag on the hull of the ship is a challenging task for the naval architect. One of the major design tasks is to estimate the powering performance so that propulsion requirements can be determined. Estimates of resistance and power progress from the use of empirical data from similar ships to a more reliable approach to predict resistance, including scale-model testing. An initial design and build strategy for the project may also be conducted at this phase.

- *Detailed design phase* - The key objective is to construct the vessel. Detailed plans for the various parts of the ship are made. Specifically, this phase includes details of compartment arrangements, specifications of equipment integration, shock specification and maintainability. For combat or armed vessels, a full engineering analysis of weapons performance and characteristics is conducted, including analysis of the ship's structure, noise and vibration, weight and stability. This phase also covers construction standards, including how factory automation, cutting of parts in the factory, and data management will be conducted in a specific shipyard. This latter phase is called the construction (or "build") design.

2.1.1. Design trends in shipbuilding

Multifunctional/modular design: ships are designed with the capability to carry out several missions or to add mission-specific packages over time. For example, the proposed AOPS design provides space for a larger naval gun, additional equipment space for Search & Rescue (SAR) and environmental response operations, enhanced cargo handling, and a larger helicopter and associated aircraft securing and haul-down systems to conduct surveillance, search and rescue, or environmental response. National governments can achieve multiple objectives with one vessel, and consolidate financial capital and human resources into one vessel instead of three or four.

Systems integration: The main development trends are towards more integration of command and control, communications, command support systems, wider bandwidths with optical fiber data links, and distributed processing. Multi-sensor data systems are becoming more sophisticated and comprehensive. The development of systems to integrate, manage and present to the operators the ever-increasing amount of operational data is a major trend in software development for sophisticated vessels.

Signature reduction: A major design trend in naval shipbuilding is to reduce a variety of "signatures" produced by a ship. Ship signatures allow detection by sensors. Radar signature is being reduced through the design of external surfaces and the application of radar absorbent paints to the hull and superstructure. Infrared, or "heat", signature is being reduced by masking high temperature areas, either by cooling or concealing exhaust plumes. Underwater noise signature is being reduced by better designing hulls and propellers to be more hydrodynamic and using air masking techniques. Internal noise signature caused by machinery is being reduced by applying self-noise monitoring techniques which identify the source of internal noise. Finally, magnetic signature is reduced through the use of non-metallic materials and demagnetizing metallic components.

Fuel economy and ballast water management: Naval architects are emphasizing improvement of speed, seakeeping, dynamic stability, and fuel economy in ships. New international regulations which will enter into force requiring the bilge to be cleaned of fouling organisms, which will require ballast water management systems.

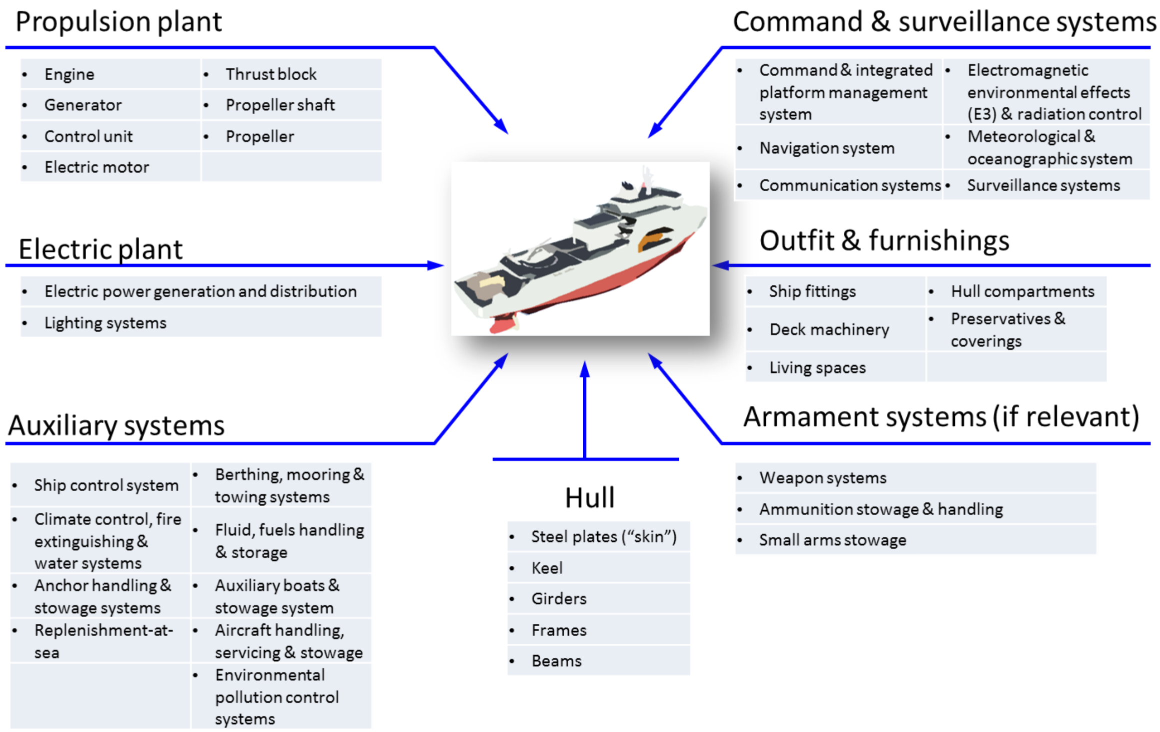
Unmanned vehicles: Unmanned vehicles in the air, surface, and underwater are becoming increasingly common on a variety of vessels for reconnaissance, surveillance or targeting.

2.2. Component Production

A ship is a system of systems. The main systems and subsystems for a ship are illustrated in Figure 7. The shipbuilding industry categorizes a ship's main systems into four main categories:

- **Hull**: fabricated using raw materials, such as steel, aluminum or composite materials. In modern shipbuilding hulls are built in sections. Steel plates are cleaned, straightened, shaped, and cut by specialized plate-burning machines to build the ship's outer surface, or "skin". The framework, to which the skin is attached, consists of the ship's structural components, specifically the keel, girders, frames and beams.
- **Platform Systems**: Platform systems are systems and sub-systems required to move and control the ship, and to make it inhabitable. Platform systems include propulsion engines and parts, propeller shaft and blades, and rudders. Major platform subsystems include HVAC and the Integrated Platform Management System (IPMS).
- **Mission Systems:** systems required to fulfill the purpose of the vessel. Subsystems include: navigational, electronic and communication systems, including a dynamic positioning (DP) system, differential global positioning system (DGPS), radar apparatus, radio navigational aid devices, radio remote control apparatus, as well as surveying and hydrographic devices.
- **Outfit & furnishings:** Deck and optional equipment installed depending on the intended use of the ship. Outfit and furnishings may include deck equipment such as winches, cranes, or pumps. Outfit and furnishing may be installed during or after construction.

Figure 7: Ship Systems and Subsystems



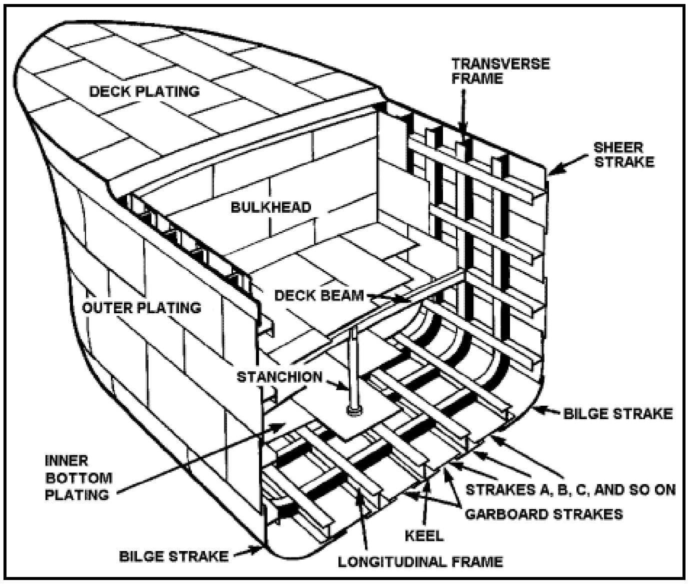
Source: Duke CGGC, based on the ABS Expanded Ship Work Breakdown Structure (ESWBS)

2.2.1. Hull

The hull is the main body of the ship consisting of an outside covering (“skin”) and an inside framework to which the skin is attached. Please see Figure 8. The skin, made of shell plating, provides water-tightness and strength. The plates have various thicknesses to reduce the total weight of the metal used and give the vessel additional strength at its broadest part. The plates, attached in rows from bow to stern, are called strakes. They are lettered consecutively, beginning at the keel and going upward. The bottom row of strakes on either side of the keel, are called garboard strakes. The strakes at the turn of the hull, running in the bilge, are bilge strakes. The strakes running between the garboard and bilge strakes are called bottom strakes and the topmost strakes of the hull are sheer strakes. The upper edge of the sheer strake is the gunwale.

The framework consists of the keel, frames, girders, beams, and bulkheads. The *keel* is the structural backbone of the ship, and runs the length of the ship. The keel provides longitudinal strength and distributes local stresses to other parts of the ship, particularly when it is dry-docked. To the keel are attached *frames* and *girders.* Frames are the vertical ribs of the ship and provide strength to the hull. Girders are the longitudinal beams making up the bottom of a ship. The center girder is always one continuous piece and is fastened to the keel with a continuous weld. Deck *beams* support the deck(s) and *bulkheads* strengthen the sides of the ship to resist water pressure.

Figure 8: Hull detail



Source: GlobalSecurity.org

The interior of the ship is divided by the bulkheads and decks into watertight compartments. The number of compartments is limited by the arrangement of mechanical equipment, particularly the engine room, and needed cargo space to hold large equipment and containers.

Hulls may be constructed with single or double bottoms. *Double bottoms* provide an extra level of protection against seawater and are favored when the operation of the ship may lead to the puncture of the outer hull. A double bottom creates a watertight space between the bottom plating and the tank top, the watertight series of plates attached to a ship bottom's framework used to increase longitudinal strength and carry the ship's cargo and machinery. The double bottom is at some height from the bottom, typically between .75 and 1.5 meters, and divided into watertight compartments. These compartments typically store fuel, oil, or ballast water, and can be used to adjust the ship's list and trim.[2]

The superstructure refers to the parts of a ship, other than masts and rigging, built above the hull and main deck.

The hull is protected against rust and fouling organisms with specialized coatings. The coatings act as a deterrent to the settlement of marine organisms on vessel surfaces below the water line. Modern hull coatings are sophisticated and require specialized skill to properly apply and cure the coatings. Coatings are integral to the performance of some ships, particularly icebreakers. Modern hull coatings are an area of significant global research and an area of activity for Nova Scotia's St. Francis Xavier University. Most existing anti-fouling paints use biocides to kill any marine growth on the hull, which affects the marine life of the waters where the ships operate. International regulations are changing quickly and forcing the development of new non-biocide bottom paints.

2.2.2. Platform Systems

Platform systems are the mostly mechanical and supporting electronic components and subsystems needed to move and control a ship, including propulsion engines and parts, propeller shaft and blades, and rudders. Major platform subsystems include HVAC and the Integrated Platform Management System (IPMS).

2.2.2.1. Propulsion system

The main components of a ship's propulsion system are the engine ("prime mover"), propeller shaft, and propeller. The *engine* is the principal source of power on a vessel. Please see Figure 9. Diesel-mechanical (or "direct-drive") and diesel-electric motors are used in most ships, although warships may also use gas or nuclear turbines to generate power for high speed sprints and to generate the large amounts of energy required for weapons systems. The *propeller shaft,* made of hardened steel, delivers power from an engine to the propeller. The *propeller* is attached to the end of the shaft and transforms rotation into forward or backward thrust. A brief discussion of each of these components of the ship's propulsion system is provided below.

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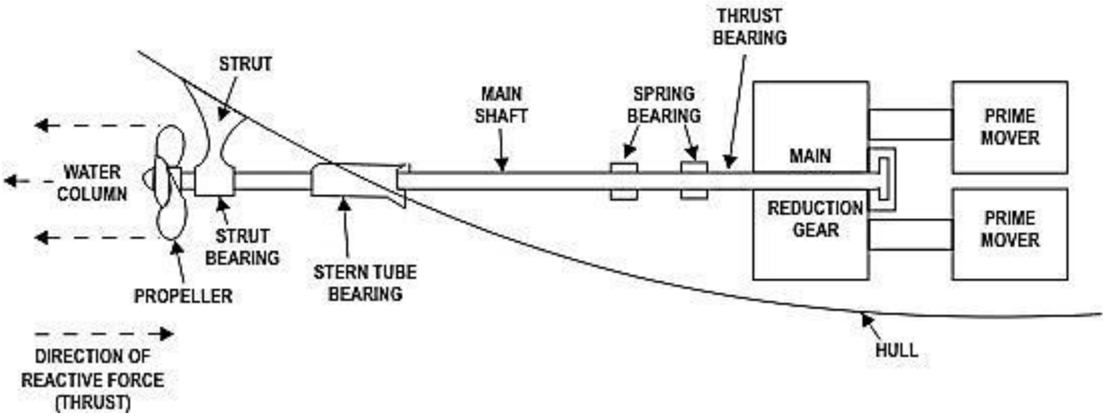
[2] Readers interested in additional information about hull construction may refer to Transport Canada's excellent coverage at http://www.tc.gc.ca/eng/marinesafety/tp-tp14609-4-construction-150.htm

Figure 9: Ship propulsion system



Source: http://www.propellerpages.com/?c=articles&f=2006-02-17_Ship_Propulsion

Engine ("prime mover")

There are three main ship propulsion types: direct-drive diesel, diesel-electric systems, and steam turbines. Of these, direct-drive diesel engines are the most commonly used, followed by diesel-electric systems. Steam turbines, with the exception of gas and nuclear steam turbines, are generally antiquated modes of ship propulsion and are not be used in the vessel categories covered in this report. Table 2 summarizes the configurations of diesel-mechanical and diesel-electric engines commonly found among different vessel categories.

Table 2: Common configurations of diesel-mechanical and diesel-electric engines

Category	Name	Propeller type	Benefits	Vessel categories
Diesel-mechanical	direct-drive diesel	Fixed propeller	simplicity, efficiency, ease of operation and maintenance	Large tankers, bulkers, container vessels, vehicle carriers
	double-engine, single-shaft	Controllable pitch	Flexibility, redundancy	Medium-sized ships and specialized vessels, including anchor-handling tug supply (AHTS) vessels, research vessels, and cable ships.
Diesel-electric	diesel-electric with fixed prop	Fixed propeller	Smaller engine rooms, reduced noise & vibration, flexibility in design and power use, redundancy, fuel efficiency	Cruise ships, ferries, ice-classed vessels, production support vessels, dredgers, submarines, warships (including the K/V *Svalbard*), and research vessels
	Diesel-electric with azimuthing thruster	azimuthing thruster	Energy efficiency, maneuverability	Cruise ships, ferries, ice-classed vessels, research vessels

Source: Duke CGGC, based on Leduc, 2001 and Shippipedia, 2012

Direct-drive diesel systems consist of a single diesel engine that directly turns the shaft and a fixed pitch propeller. The speed of the engine (90-105 rpm) is the speed of the propeller. Reverse thrust is possible, if a variable cam is installed, by running the engine in reverse. The direct drive system is commonly found in large tankers, bulkers, container and vehicle carriers. The overwhelming benefit of the direct drive system is its simplicity, efficiency, and ease of operation and maintenance.

A more sophisticated direct-drive diesel system (shown above) is the double-engine, single-shaft configuration. Two medium speed engines (or one medium and one small engine) are connected to a gear box that reduces the speed for optimum propeller efficiency. A clutch disconnects one engine if not needed, which provides redundancy, versatility, and efficient operation. The system is equipped with a controllable pitch propeller that allows for efficient operation at any speed and work load. The chief benefit of this configuration of the diesel-mechanical propulsion system is flexibility. It is commonly found in medium-sized ships and specialized vessels, including anchor-handling tug supply (AHTS) vessels, research vessels, and cable ships.

Diesel-electric systems change the way the diesel engine transmits power. For most of the 20th century diesel-electric systems could not compete with direct drive diesel systems. However, technological advances in diesel-electric systems improved, particularly in power electronics and motor drives, and reduced their costs. Modern diesel-electric systems have advantages for vessels that require dynamic positioning, or frequent changes in speed and direction. The benefits of diesel-electric systems over direct-drive diesel engines are:

- Smaller engine rooms: large diesel engines are replaced with multiple smaller generators;
- Reduced noise & vibration due to shorter shafts;
- Flexibility in design and power use: smaller engines can be located in any part of the vessel independent of where the power will be used. The power of one unit can be shared with multiple systems on the ship;
- Redundancy: generators can be reassigned to cover any machine downtime;
- Fuel efficiency: the system can provide better fuel efficiency during periods of low speed or load use (CAT Marine Insight, 2010).

Instead of directly powering the shaft and propeller, the diesel engine generates electricity via a generator, which in turn fuels electric propulsion motors used to provide power to the ship, including turning the shaft and propeller (Marine Insight, 2011; Patel, 2012). Specifically, the diesel engine turns generators at a high RPM to produce electricity. The electricity is carried via cables to switchboards which transmit it either to transformers or frequency converters isolating the current flow and achieving the proper voltage levels. The electricity then powers electric motors at the stern, which are connected to a shaft and fixed pitch propeller (MAN, 2012). These steps may be consolidated. For example, the electric generators may control the frequency and voltage necessary to turn the shafts and propellers (Patel, 2012). Diesel-electric engines are found on an increasing number of vessel categories because of their redundancy and versatility. Cruise ships, ferries, ice-classed vessels (including icebreakers), production support vessels, dredgers, submarines, war ships (including the K/V *Svalbard*), and research vessels have all been fitted with diesel-electric propulsion systems (Adnanes, 2003).

Shafting and thrust block

Propeller shafts deliver power from an engine to the propeller. Propeller shafts must be strong enough to bear the torque of the motor. Drive shafts are generally made of forged carbon steel, though at times low alloy steel forgings are used, yielding substantial reductions in weight.

The thrust block, an important component of the propulsion system, transmits the thrust produced by the rotating propeller into the ship's hull structure. Thrust blocks are essential for ensuring that the physical force generated by the ship's propulsion system (the thrust) is structurally accommodated to move the ship forward. The most common type of thrust block is called a Michell Bearing, named after its 1905 inventor. Michell Bearing is still in operation and owned by Rolls-Royce Power Engineering (UK).

Propellers

Propellers transform rotation of the shaft into forward or backward thrust. When a propeller rotates, the force created by the rotation acts against the mass of a column of water to propel the ship forward. Propellers may be fixed or controllable pitch. *Fixed pitch propellers* are more efficient in transmitting power at fixed rotational speeds. *Controllable pitch propellers* are used in vessels where rotational speeds vary because of needed maneuverability and control. For example, coastal and specialized vessels, such as dredgers, ferries, coastal freighters, medium-sized tugs, cruise ships, and research vessels, often have controllable pitch propellers because they provide an increased level of control in littoral waters, and can be used to navigate in ports with limited or no tug service availability. Propulsion systems also affect the choice over the type of propeller to use. Propellers are typically made of corrosion resistant metal alloys, such as aluminum-steel, nickel, aluminum and bronze. Propllers require careful analysis of expected load, strength, and efficiency requirements.

Azimuth thrusters are an important development in ship propulsion. An azimuth thruster is a configuration of ship propellers placed in pods that can be rotated in any horizontal direction, making a rudder unnecessary. Azimuth thrusters provide ships with better maneuverability and dramatically improved fuel efficiency. Azimuth thrusters are often used in cruise ships, ferries, ice-classed vessels, and research vessels.

2.2.2.2. Electric Plant

Electricity is needed to power auxiliary systems (climate control, combat systems, ship control, anchor handling – see auxiliary systems section for full list), lighting, and emergency systems on the ship. The type of propulsion plant determines how electric power is generated and distributed on the ship. Electric power generators are normally driven from their own dedicated diesel engine. However, ships with diesel-electric propulsion systems drive the electric generators from the main propulsion plant.

The SOLAS international maritime regulations require at least two electric generators for a ship's main electrical power system. One electrical generator must be independent of the main propellers and shaft. The consequence is that most ships have three electricity generators to ensure compliance with the regulation. One of the three generators is used for the normal load, while the other two are used to provide power in case of an unusually heavy electric load or the main generator is out of service (DC Marine, 2000).

The core elements of a marine electric distribution system are the main switchboard, motor control of auxiliary systems, and emergency services. Under normal operational conditions, the main switchboard distributes electric power to power panels. Power panels, located close to the system demanding the power, provide electricity to auxiliary, lighting and emergency systems on the ship. The main switchboard is generally located near the center of the distribution system, normally the main engine room or machinery control room.

Motor controls: Auxiliary systems, such as ventilation and lubrication systems, often have motors. The control of these motors can either be centralized or decentralized, depending on the design, size, and operational purpose of the ship. The benefit of centralized systems is that they place the machinery control and necessary protective systems in one location, typically via video display located on the bridge or machinery control room. Decentralized systems can be manually started and stopped near the location of the auxiliary system. Their overwhelming benefit is that they are inexpensive and easy to troubleshoot. The drawback of decentralized systems is the need for a higher degree of mechanical enclosure to ensure that cabling is protected from the corrosive effects of the marine environment.

Emergency services: In the event of a fire or flooding it is likely that the main generators and switchboard would be disabled. To ensure that electrical supplies are available to emergency and safety systems, an emergency generator and switchboard are typically located above the main deck in a space isolated from the main machinery. Emergency services are supplied from the emergency switchboard using distributed panels for navigation, safety and emergency lighting services.

For shipboard installations, specific protective systems are required to shut down all ventilation systems and all fuel oil systems in the event of fire. The arrangement of the motor control center for motorized auxiliaries (i.e., centralized or not) affects how the wiring for emergency services is designed. For lighting, the circuitry arrangement must be designed so that fire or flooding in one area will not cause loss of lighting in other areas or along escape routes.

2.2.2.3. Auxiliary systems

Auxiliary systems provide essential supporting capabilities needed for the operation and maintenance of the ship. These systems consist of:

- Integrated platform management system (IPMS)
- Ship steering system
- Berthing, mooring & towing systems
- Climate control (HVAC), fire extinguishing & water systems
- Fluid, fuels handling & storage
- Anchor handling & stowage systems
- Auxiliary boats & stowage system
- Replenishment-at-sea (RAS)
- Aircraft/helicopter handling, servicing & stowage

- Environmental pollution control systems

Integrated Platform Management System (IPMS)

The IPMS integrates machinery control, damage control, and on-board training functions on the ship. Specifically, the IPMS provides monitoring and control of ship propulsion, electric power generation, some machine controlled auxiliary systems (water, air systems, and stability control) and, if relevant, damage control systems on the vessel. On-board training systems can provide operational drills and emergency training without interfering with the monitoring and control of the ship's systems. L-3 MAPPS, Siemens, Sperry Marine, and Imtech are major IPMS manufacturers.

Ship steering system

The ship steering system includes the rudder and the system needed to control the rudder. Several marine rudder types exist. Raytheon Anschutz specializes in ship steering control systems

Berthing, mooring & towing systems

Berthing, mooring and towing systems are used to assist with port navigation and docking of the vessel. Berthing and mooring systems provide direction and range information to dock the vessel, while towing systems are used to interface with tugs at port. These systems often are integrated into one system in large vessels. Mampaey (Netherlands) is an example of a manufacturer of integrated berthing, mooring and towing systems.

Climate control, fire extinguishing & water systems

This group of subsystems includes climate control (HVAC), fire extinguishing and water systems.

Heating, ventilation, and air conditioning systems (HVAC): The purpose of the HVAC system is to maintain a standard of air quality in temperature and humidity for personnel and to remove equipment generated heat. Areas requiring critical temperature control are supported by heating and/or air conditioning, essential to the equipment's operation. The ventilation system removes internally-generated contaminants, fumes and humidity. Portable ventilation systems remove smoke and gas, and are designed for emergency applications where the installed ventilation system becomes inoperative. Warships have sophisticated HVAC and air handling systems to lock out outside air to prevent injuries in case of chemical, biological, radiological or nuclear (CBRN) attack. Bronswerk Marine specializes in marine HVAC systems.

Fire extinguishing: Systems needed to prevent and limit the spread of fires onboard the vessel. Fire extinguishing systems are linked to the command management system for continual monitoring.

Water & drainage systems: Three main water systems exist on large vessels: the jacket cooling water system, the firemain, and the Electronic Cooling Water Systems (ECWS). The jacket cooling water system is essential for maintaining the ship's engines within safe operational temperatures. A ship's firemain is used to a cool mechanical systems on the ship, including combat equipment and auxiliary systems, with seawater. The firemain is designed with loops and valves allowing small sections of the ship to be isolated in event of a fire. ECWS removes the heat generated by electronic equipment. Usually electronic equipment will not operate if the ECWS is interrupted or degraded. Drainage systems maintain the ship's buoyancy and stability by controlling and removing water during normal operation and firefighting. Drainage systems consist of the main and secondary drainage piping. The main drain line removes water from the main machinery and principal auxiliary spaces, while the secondary drainage system removes water from the ship's compartments and remote spaces.

Fluid, fuels handling & storage

Fluid, fuels handling and storage systems ensure proper functioning of diesel fuel and lubrication oil systems. Marine fuels used by the main engines and boilers are a viscous, tarry substance known as heavy fuel oil (HFO). Marine fuels will become "waxy" if not properly handled and stored in tanks with warming coils.

Anchor handling & stowage systems

Anchor handling and stowage systems are large winches used to launch, retrieve, and store the ship's anchors. Major manufacturers of these systems are Rolls-Royce and Macgregor (subsidiary of Cargotec).

Auxiliary boats & stowage system

Large vessels have auxiliary boats and stowage systems for the storage, launch and recovery of smaller boats used for operational and life-saving purposes. Auxiliary boats and davits may be manufactured by a number of small craft manufacturers and crane manufacturers.

Replenishment-at-sea

Replenishment-at-sea (RAS) systems are used to transfer fuel, ammunition, and ship stores from one ship to another while under way. Hepburn Engineering has manufactured several of the ship-to-ship supply systems and supply systems simulation and training modules used by the Canadian Navy. Rolls-Royce Marine is also a major supplier of RAS systems.

Aircraft/helicopter handling, servicing & stowage

Aircraft on the vessel require proper handling, servicing and storage. Jared Engineering (US), a subsidiary of PaR Systems (US) specializes in aircraft handling for the naval and marine industries. Indal (ON) part of Curtiss-Wright (US) has a long history of producing shipboard helicopter haul-down systems for the Canadian and US Navy.

Environmental pollution control systems

Environmental pollution control systems are becoming standard to control air, liquid and solid waste produced by ships. Specifically, these pollution control systems include:

- air emissions

- solid waste management systems
- black water and grey water
- fuel and oil pollution prevention
- ballast water/invasive species management systems

National and international regulations are increasing the number of environmental pollution control systems on ships. Air regulations are in effect, or soon will come into effect, limiting nitrogen dioxide, sulfur dioxide, and particulate matter released from vessels. Solid waste, sewage (black water), and runoff from baths and showers (grey water) are increasingly restricted by national and international environmental regulations. The International Maritime Organization (IMO) *Convention for the Control and Management of Ships' Ballast Water and Sediments* seeks to improve the quality of ballast water released by ships. The regulation requires ballast water to be treated and disinfected prior to release as a control against invasive species. Compliance with marine environmental regulations is voluntary for sovereign vessels (Tan 2005), which includes the NSPS vessels. However, it is our understanding that the RCN and CCG have decided to be compliant with the IMO convention.

2.2.3. Mission Systems

Mission systems are the components and subsystems required to fulfill the purpose of the vessel. Mission subsystems are generally electronic and include: navigational, electronic and communication systems, including a dynamic positioning (DP) system, differential global positioning system (DGPS), radar apparatus, radio navigational aid devices, radio remote control apparatus, and surveying and hydrographic devices.

2.2.3.1. Command and Surveillance systems

Command and surveillance systems provide essential communication, control, and operations management for the ship. In naval vessels, command and surveillance systems are referred to as command, control, communication, computer, intelligence, and surveillance (C4IS) systems. C4IS systems may include: command management system (CMS), navigation system, internal and external communication systems, meteorological and oceanographic systems, surveillance system, and electromagnetic (E3) and radiation control systems.

The command management system (CMS) is an integral piece of equipment that provides monitoring and control of the vessel and its auxiliary equipment. The CMS provides data display, processing, and system interface with the operational components of the vessel (navigation, radar, weather, and weapons systems).

Navigation capability provides ship positioning and targeting for weapons systems through the utilization of onboard electronics (receiving signals generated from satellites or shore-based transmitters) and depth-sounding equipment and systems.

Internal communications may include a public address system, a wireless communications system, a telephone system, and a closed circuit television system to communicate emergency and non-emergency information on board. A key internal communications system on modern ships is the

Ethernet (or equivalent) data communications network. In government ships, particularly in navy and coast guard ships, the internal communications system is often divided into unclassified and classified network. External communications are provided by radio transceivers, terminal equipment and antennas, and may include satellite communications and data transfer. Off-ship communication networks exist that support varying levels of ship-to-ship and ship-to-aircraft data exchange at varying classification levels (Link-16, for example).

Electronic warfare and intelligence-gathering capability consist of receivers for signal intercept, source analysis and active/passive deception devices.

2.2.3.2. Armament System

The armament system provides the means for fighting on the ship. The armament system may include anti-aircraft, anti-ship, and anti-submarine warfare systems. For vessels covered in this report, the armament system is only relevant for the AOPS and JSS. As currently configured, the AOPS will be lightly armed with 25mm and 12.7mm mounted naval guns and miscellaneous small arms. As currently conceived, the JSS will have at least one Close-in Weapons Systems (CIWS), two 12.7mm naval guns, and some decoy launching capabilities.

2.2.4. Outfit and furnishings

Outfit and furnishings include the ship fittings, deck machinery, optional equipment and the furnishings for storage compartments and living/working areas.

Ship fittings are the devices that are used to secure rigging and lines on the ship. These include cleats (used for securing lines), chocks (used for securing heavy machinery), and bitts (used for securing the ship’s mooring and towing lines).

Deck machinery will depend on the type of vessel and its planned operations. Typically, deck machinery includes launch and recovery systems (LARS) for optional equipment, and winches used to move cargo or equipment on the ship.

Optional equipment will vary greatly on the intended operational uses of the vessel. Optional equipment relevant for the vessels being built under the NSPS includes aircraft (helicopters and unmanned aerial vehicles), ROV/AUV, and lab space.

Furnishings for living, working, and storage compartments on the ship include furniture, lights, and lockers needed for the comfort and safety of onboard personnel.

2.3. Component Distribution

Distributors act as intermediaries between product manufacturers and the systems integrators or shipyards. Two main types of firms distribute components in the shipbuilding industry. The first type of firm specializes in procuring and delivering needed materials or components to the shipyards and systems integrators. Typically, these firms are regional, or, at most, national companies. These firms may combine mechanical or electronic components and offer these “bundled” systems to higher tiered firms.

The second type of company is the distribution arm of large multinational firms. Some of the best recognized branded manufacturers in the shipbuilding industry develop or own exclusive distribution networks. Product manufacturers with exclusive distribution networks typically own the network in the home market, and, at times, a few neighboring countries, but use distribution agreements with providers in other markets to extend their reach globally.

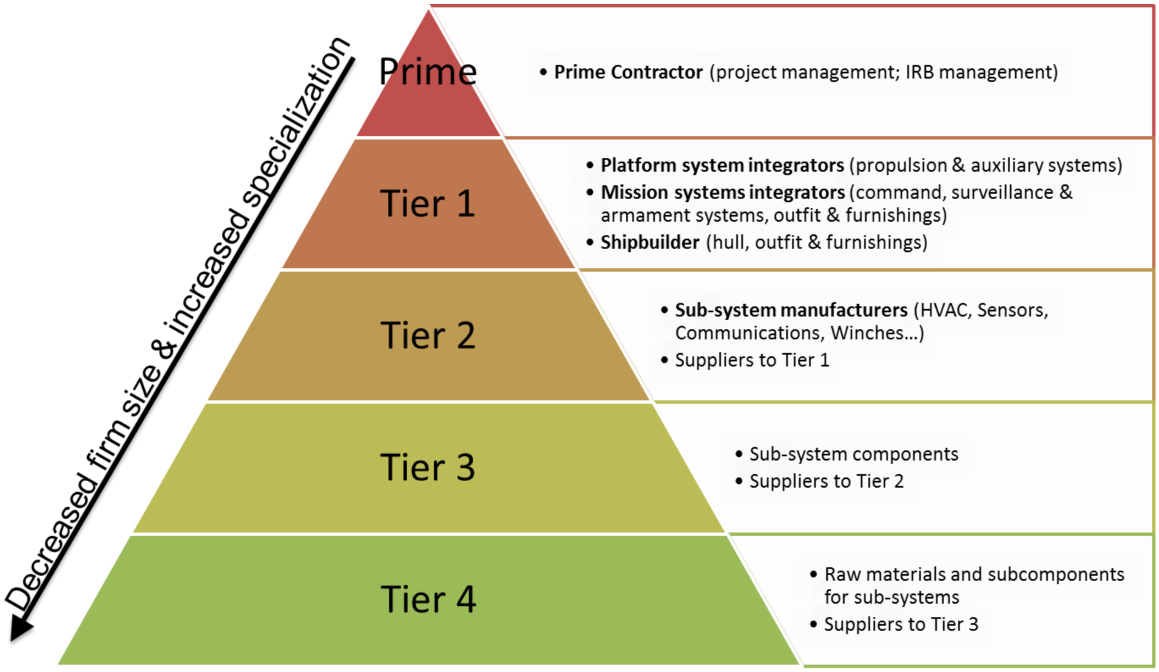
2.4. Assembly & Integration

The main activities in assembly and integration are:

- **Hull blocking & assembly**: Hull subassemblies are coated with protectant or specialized marine coatings, welded together to form large prefabricated units, and welded into position to form the ship. Once assembled, the ship is ready for launch and outfitting.
- **Outfitting:** After launch, the ship is berthed in a “fitting-out basin” for completion. The main machinery, piping systems, deck gear, lifeboats, accommodation equipment, plumbing systems, insulation, rigging and deck coverings are installed. The tendency in the shipbuilding industry is to schedule the outfitting of a vessel in sections, in order to synchronize fitting work in the different sections and compartments.
- **Systems integration:** Systems integrators install platforms and mission systems and ensure the cross-functionality of sub-systems. As sub-systems become increasingly complex, the role of a systems integrator has become increasingly important.

As illustrated in Figure 10 below, production assembly and integration activities are organized hierarchically, with the prime contractor holding the contractual relationship with the ship owner (in this case, the Canadian Federal Government, specifically the RCN and CCG). The prime contractor is responsible for a wide range of activities, including procurement, sub-contracting, risk management, scheduling, and IRB management. For the vessels contracted under NSPS, the prime contractors are ISI and Seaspan.

Figure 10: Shipbuilding Production System



Source: Duke CGGC

Just below the primes are the systems integrators. System integrators tend to specialize in either platform systems or mission systems. Platform systems are those needed for the ship to float and move on the water. Platform systems for the marine industry are similar to general industrial equipment used in other large, industrial sectors of the economy, including power plants, oil refineries and chemical plants. The companies providing platform systems are large, consolidated multinational firms. In terms of the systems described in Figure 7 [the ship systems figure], platform systems include propulsion, electric power, auxiliary systems, deck machinery, and the integrated platform management system controlling most of these systems. Mission systems are those needed for the ship to fulfill its design purpose. In contrast to platform systems, mission systems consist of highly-specialized companies making products for specific applications in the marine defence industry. Mission systems are sourced from a number of firms organized for the purpose by the mission systems integrator. In terms of the systems described in Figure 7, mission systems include the command and surveillance system (with the exception of integrated platform management system), and the armament system, if relevant.

Below the systems integrators are the suppliers to the platform systems integrators, the mission systems integrators, and to the shipbuilders responsible for hull construction and, typically, the outfit and furnishings. These company actors are typically referred to as the second tier suppliers. Additional tiers to this system increase in specialization and generally decrease in the size of the firm.

2.5. Production Support Services

Materials planning and procurement: As the design for a ship develops, the shipbuilder identifies suitable subcontractors to supply items the shipyard does not produce. Materials planning and procurement requires coordination between the design and procurement functions of the shipbuilding value chain. The design team provides the material definition and estimation for steel, pipes, and cables, the ship's subsystems, mechanical and electronic components, and deck and optional equipment, while the procurement team gathers technical product information to create a database of suppliers.

The procurement function for the hull and structural portions of the vessel typically is conducted by the shipbuilder, in coordination with the ship's designer and ship owner. The procurement function for the ship's subsystems, specifically the mechanical, electronic, and optional equipment components, typically is conducted by the platform and missions systems integrators for the vessel, in coordination with the ship design team and ship owner. Lower-tier companies may act as suppliers to the systems integrators and the shipbuilder.

Equipment selection is an iterative process as complete information about component products is received from suppliers. Oftentimes, the ship designer will use a generic component to act as a placeholder for further developing the ship's design while the procurement office gathers more information. Product specifications from different suppliers then can be gathered by the design team and examined as suitable alternatives until one product is finally selected in the final detailed design stage.

Selection of equipment in the design and build phase has implications for the post-production in-service support phase. For example, propulsion systems made by two manufacturers may have similar prices, meet design specifications, and yet have different maintenance costs and schedules. Evaluating systems for total cost of ownership has become one reason why coordination between the design and build team and the in-service support provider has become increasingly common for complex vessels, especially naval vessels. A second reason for increased coordination between the design and build team and in-service support is the creation and delivery of the technical data package, which provides the "owner's manual" equivalent for large vessels. The technical data package lists the technical specifications and maintenance schedules for the ship's systems and subsystems. The coordination between the DAB and ISS provider can be conducted by an integrated logistical support (ILS) provider.

Production planning and engineering: Production planning and engineering is a complex undertaking involving design, assembly, and installation. It ensures that, as the design for the ship develops; individual parts and equipment are allocated to the appropriate stage in the production hierarchy of assemblies and subassemblies. Production planning and engineering includes assembly and production planning, cut and weld planning, and approval and release of design data. Production planning and engineering requires coordination with the design phase. Specialized firms are often retained for production planning and engineering, though some shipbuilders maintain this capability in-house.

2.6. Post-Production Services

In-Service Support (ISS): In-service support provides the maintenance, conversion and repair of the vessels. In-service support generally is conducted at planned intervals to ensure the ships remain seaworthy and in good condition. While in-service support historically has been conducted by the ship owner, the increased sophistication of naval and coast guard vessels require that the shipbuilder or specialized service provider conducts maintenance and repair. The ISS for each NSPS vessel category is a separate contract.

Technical Training: Technical training includes simulation used to train personnel on the operation and maintenance of the vessels' systems. As defence budgets have reduced, the operational expense of onboard training makes companies specialized in virtual reality and training simulation attractive alternatives. On a warship, functional trainers are typically included as part of the initial combat systems delivery.

2.7. Supporting Organizations and Institutions

2.7.1. Education and research

Education and research institutions are important to the development of the shipbuilding value chain. Universities and research centers provide the conditions necessary to support the development of shipbuilding for two key reasons. First, educational institutions assist in workforce development, from joiner and journeyman to project managers and systems engineers, needed to build the NSPS vessels. Community colleges and universities are important in helping supply personnel capable of fulfilling these functions. Second, universities and research centers are important actors in developing new systems used on sophisticated marine vehicles, like the ships being constructed for the NSPS, and applying new solutions to problems faced in the marine environment. Dalhousie University's investment in a ballast water facility within the Aquatron Laboratory investigating how to reduce the presence of invasive species in bilge water is one example. St. Xavier's research into anti-fouling paints that do not harm the marine environment is a second example. DRDC-Atlantic conducts acoustics, marine materials and ship dynamics research. Third, developments in a number of high technology subsystems and instruments, including the instrumentation profiled in *Nova Scotia's Ocean Technologies* report (CGGC, 2012), are the result of university researchers collaborating with business and government. University researchers are in the unique position of being able to tap existing technical expertise, either at the home institution or through research networks, to solve problems. Participation in these formal and informal research networks is important to the development of the technology and eventual commercialization of products in the shipbuilding and supporting industries' value chains.

2.7.2. Government agencies

The relevant Federal government actors for large procurements are the lead agency (DND-Navy or Department of Fisheries and Oceans – Coast Guard) responsible for definition of requirements and project supervision, Public Works and Government Services Canada (PWGSC) for the procurement process, Industry Canada (IC) for the Industrial and Regional Benefits policy and management of the Value Proposition, and the Treasury Board Secretariat (TBS) for contract approval.

Regional Development Agencies (RDAs) in Canada are ACOA, Western Economic Diversification, Fed Dev-Ontario and Canada Economic Development-Quebec. RDAs assist Industry Canada with developing strategies specific to each procurement project, identify industry partners across Canada, and help evaluate IRB proposals. RDAs act as advocates to promote industry in their region. Some RDAs may also have programmatic funds available to help businesses become compliant with regulations.

2.7.3. Policies and Regulations

2.7.3.1. Canadian policies and regulations

The key government policy underpinning the NSPS is the Canadian Shipbuilding policy (PWGSC, 2012b). This policy states that the Government will continue to procure, repair and refit vessels in Canada subject to operational requirement and the continued existence of a competitive marketplace (PWGSC, 2012b).

Other key elements relevant to the NSPS are the requirements of respondents to the NSPS Request for Proposals (RFP) to adhere to the Industrial and Regional Benefits Policy (IRB) and to commit to undertake Value Proposition investments. While not explicitly stated within the RFP, the Controlled Goods Program, as administered by PWGSC, is applicable (PWGSC, 2012b). An overview of the policies is provided below.

Value Proposition: in their bids for the NSPS competition, all shipyards agreed to contribute an amount equal to 0.5% of the value of any contract price paid for all resultant NSPS contracts to the improvement of the health and viability of the greater Canadian marine industry over the long-term. This commitment was reiterated by the shipyards selected to build the combat and non-combat NSPS vessels within the Umbrella Agreements they signed with the Government of Canada.

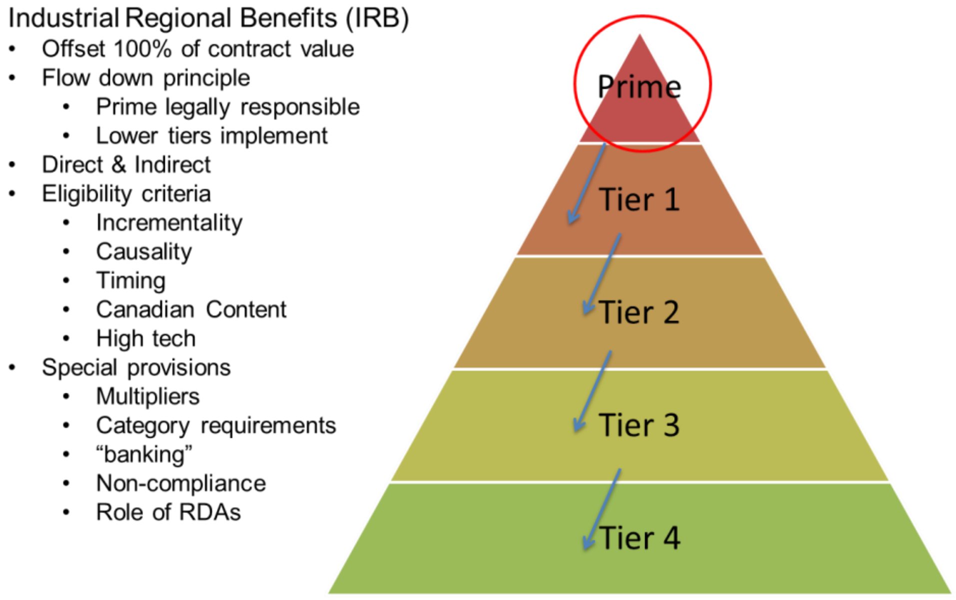
Investments under this provision are expected to address at least one of three Value Proposition priority areas within the greater Canadian marine industry: Human Resources Development, Technology Investment, and Industrial Development Activities (PWGSC, 2012b). Investments could include commitments to continuous improvement; investment in skills and human resources, capability and infrastructure reinvestment, partnerships with provinces and other enterprises; long-term supply chain development (outsourcing and sub-contracting to small and medium-sized enterprises); and increased commercial work (PWGSC, 2012). There is no multiple applied to Value Proposition activities, and the activities are not cost-recoverable under the NSPS contracts.

Industrial and Regional Benefit (IRB): The IRB Policy requires companies to undertake business activities in Canada valued at 100 percent of the value of the defence or security contract they have been awarded by the Government of Canada. Industry Canada is the Canadian agency in charge of managing and certifying compliance with the IRB. IRB transactions can be either *direct* (transactions that are directly related to the items being procured by the government) or *indirect* (transactions which are not directly related to the procured items and are, instead, related to investments, technology cooperation, and product mandates).

> A <u>direct IRB transaction</u> is between the IRB contractor ("prime contractor") and a Canadian recipient. It can be carried out by means of a contract, including any purchase order, sales agreement, license agreement, letter of agreement or other similar instrument in writing, that has an identified dollar value, meets the IRB eligibility criteria set forth in the specific procurement contract and has been approved by the IRB Authority.
>
> <u>Indirect IRB transactions</u> are business activities such as the purchase of goods and services related to the contractor's product or business lines but not directly related to the equipment or services being procured by Canada.

The IRB Policy is intended to provide Canadian companies with opportunities to develop and competitively sell innovative products and services to companies with IRB obligations, many of which are large multinational aerospace and defence corporations (Industry Canada, 2012). International companies participating in ship construction and in-service support must weigh the benefits of using existing international supply chain partners with the requirement to fulfill Canadian content.

Figure 11: Canadian Offset Policy



Source: Duke CGGC

The IRB is a contractual commitment by the prime contractor to place work in Canada as a result of successfully bidding a Canadian defence program. Bidders for defence contracts greater than CAD 100 million are required to identify plans to achieve benefits equal to 100% of the contract value. 30% of obligations are identified at the time of contract signing, 30% one year later, and remaining 40% over the remainder of the contract. If the contractor's bid is successful, it will have an annual review of achievements under the plan. Prime contractors generally "flow down" their IRB obligations by requiring lower tier companies to meet 100% of the contract value with IRB offsets. However, the legal responsibility for IRB fulfillment rests solely with the Prime. (See Figure 11).

Industry Canada lists five eligibility criteria for what "counts" as an IRB offset.

- Must be new work in Canada ("*Incrementality*").
- Benefits must be brought about due to IRB obligation to Canada (*Causality*). In other words, the work would not have been placed in Canada otherwise.
- Benefits must be completed within the contract period (*Timing*). The identification of benefits begins after the release of the request for proposal (RFP) and ends with final delivery.
- Only Canadian content of work is counted towards the IRB obligation (*Canadian Content Value*). Only Canadian labor and/or Canadian materials count as fulfillment of the IRB obligation. For example, an international company with a distribution or assembly facility in Canada may only count the value of the activity or labor occurring within Canada, not the total value of the product or service.
- Benefits must be high tech and sustainable in nature (*High Technology*). Indirect investments must be at the same level of technology as the platform being procured by the Government. In the past, fulfillment of the criterion has been approved by Industry Canada as long as the technology investment is generally equivalent to that purchased by the government.

Special provisions under the IRB policy are:

- "Multipliers" for special categories of activities. These categories are:
    - Investments into universities, public-private consortia, and Venture Capital Funds (VCF) are valued at up to five times the value of the investment. Industry Canada retains discretion whether the investment counts for IRB purposes and the multiplier of the investment.[3]
- IRB requirements - Common IRB requirements in the Canadian IRB program are for small-and-medium-sized enterprises (SMEs), Enhanced Technology Priority List (EPTL) and possibly a Direct IRB percentage. Although percentages for the categories have not yet been designated for the NSPS project, the policy is typically 15% for SMEs, and 5% for EPTL. Transactions with SMEs, less than CAD 100,000, are eligible to getting full credit for IRB purposes if Canadian content value is 70%. There is no regional or First Nations consideration through the IRB policy for the NSPS.
- Banking – excess funds under one IRB-required project may be used for five years in another IRB project.
- Non-compliance – liquidated damages are at 10% of the remaining obligation. For example, if a prime contractor has a CAD 10 million dollar obligation after the completion of the contract; it will have a CAD 1 million dollar remaining obligation to Canada. If the prime contractor has

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[3] Readers interested in the details of these and other IRB provisions may find the "model contract" on Industry Canada's website (http://www.ic.gc.ca/eic/site/042.nsf/eng/h_00066.html) helpful. In addition, Industry Canada and Regional Development Agencies can help answer questions about the IRB in greater detail than appropriate for this report.

multiple obligations under the category requirements (for example, an obligation for SMEs and for technology transfer), liquidated damages will not exceed 10%. In practice, non-compliance is avoided through close contact with prime contractors to identify the source of potential non-compliance and steps to remediate the issue before actual non-compliance occurs. Regional Development Authorities (RDAs) have a role in acting as points of contact between the prime contractor and Industry Canada to help ensure compliance.

- Role of RDAs – regional development agencies (ACOA, Western Economic Diversification, Fed Dev-Ontario and Canada Economic Development-Quebec) assist Industry Canada with developing strategies specific to each procurement project, identify industry partners across Canada, and help evaluate IRB proposals. Oftentimes, RDAs are the primary point of contact for companies.

Controlled Goods Certification: According to the Public Works and Government Services Canada (PWGSC) website, the

> Controlled Goods Program (CGP) is a domestic security program that regulates and controls the examination, possession or transfer of controlled goods and/or controlled technology. Anyone that deals with controlled goods and/or controlled technology in Canada is required to register with the CGP…The CGP was created in 2001 to strengthen the Canada - U.S. agreement on defence trade controls and is essential to maintaining the unique Canadian exemption with respect to the International Traffic in Arms Regulations (ITAR).

Controlled goods covered under the CGP are:

- munitions specifically designed or modified for military use (Group 2 of DFAIT export controls list)
- strategic goods (nuclear technology, satellite communications and ground control stations covered under Group 5 of the export control list)
- missile technology (Group 6 of export control list)

Companies covered under the program must be Canadian, which includes companies that are subsidiaries of multinationals doing business in Canada. Companies completing the certification process are visited by Department representatives to ensure compliance with the program. Certifications last 1 to 5 years, depending on the length of the contract for which the certification is required. Companies should discuss with potential customers and PWGSC whether CGP certification is required.

2.7.3.2. Private policies and regulations

The shipbuilding industry has a number of certifications and classifications relevant to the design, production, and post-production phases of shipbuilding.

The International Association of Classification Societies (IACS) is the umbrella organization for the world's major classification societies, including the American Bureau of Shipping (ABS), Det Norske Veritas (DNV), and Lloyd's Register. Classification societies set technical rules, confirm that designs and calculations meet these rules, survey ships and structures during construction and commissioning, and survey vessels to ensure that they continue to meet the rules. Designs typically are certified by the classification society, who must confirm that the design and calculations meet its technical rules. During production, each weld must be certified as being completed by a certified welder. As can be seen from these examples, certification and classifications societies are integral to the conduct of the shipbuilding value chain.

Purchasing is governed by the shipbuilder and the systems integrators. Company specific rules for purchasing can be extensive. Shipbuilders and systems integrators commonly require ISO 9001, a quality management system certification, but standards for specific companies may far exceed common requirements. Most large companies, particularly public ones, are governed also by standards of ethics and transparency that will flow down contractually to their suppliers, which may require suppliers to modify their own procurement and contracting processes to comply with customer provisions (Hanlon, 2013). Therefore, potential suppliers should actively contact potential buyers to understand the company's required standards and certifications for entry in the supply chain.

2.7.3.3. International regulations

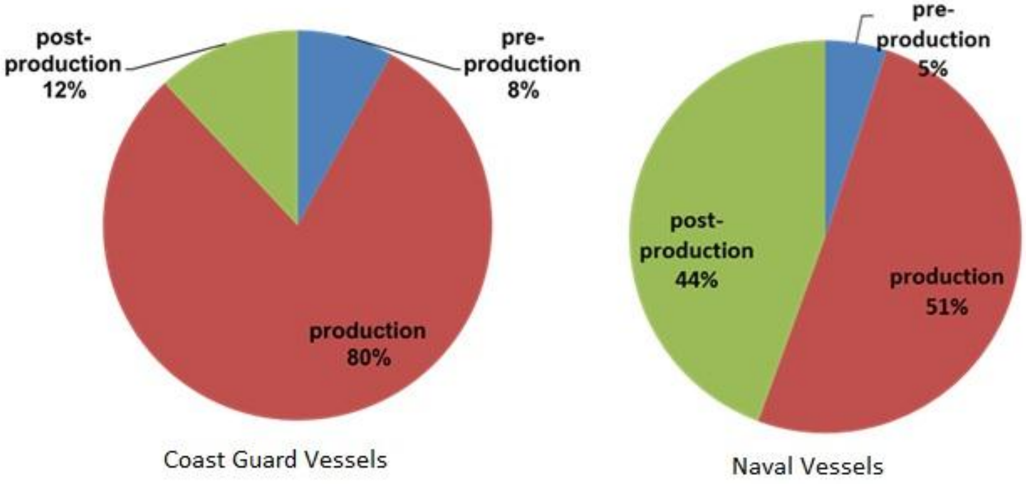
International Convention for the Safety of Life at Sea (SOLAS) governs many of the safety regulations for ships. Pollution controls are developed by the International Maritime Organization (IMO) and enforced at the national level. The IMO's mandatory audit scheme for national governments will enter into force in 2015, which will assess how effectively member states implement and enforce IMO Convention standards on maritime safety and environmental protection (IMO, 2012). The IACS has a special consultative role to help develop guidance for the IMO. It is the only non-governmental organization with observer status able to develop and apply rules in the shipbuilding industry (de Baere and Verstraelen, 2012).

2.8. Value-added activities

Duke CGGC conducted interviews with companies across the shipbuilding value chain to understand the distribution of value across the chain. We asked how the distribution of value existed across pre-production, production, and post production phases. As a result of these interviews, we conclude that for the science vessels (OOSV and OSFV) pre-production (design) captures approximately 8% of the value, production and production support activities constitutes 80% of the value, and post-production services 12% of the value.

For naval vessels, post-production services constitute a greater share of a vessel's total value. The proposed 25-year ISS contract for the AOPS is CAD 3 billion and CAD 2 billion for the 30 year JSS in-service support contract (cost: DND, 2012a; length of contract: TBS, 2012a). The implication is that the ISS costs for the AOPS and JSS are just less than the proposed vessel construction funding of CAD 3.1 billion and 2.6 billion, respectively (TBS, 2012a).For the naval vessels covered in this report, pre-production captures approximately 5% of the value, production makes up 51% of the value, and post-production 44% of the value. Please see Figure 12.

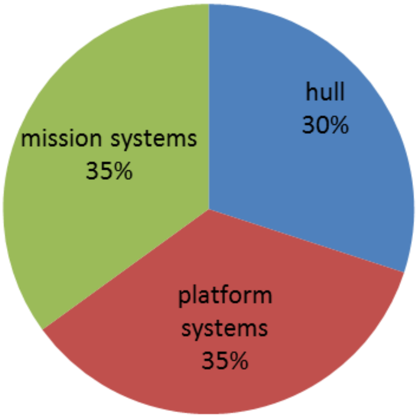
Figure 12: Distribution of value across phases of production



Source: Duke CGGC

Within the production portion of the shipbuilding value chain, the consensus among interviews was that hull construction historically was less than the platform and mission systems. Historically, the hull made up 30% of the production cost of a ship, while platform and mission systems each made up 35% of the production costs. Please see Figure 13. However, the high cost of steel suitable for shipbuilding has shifted these percentages to being roughly even among the three categories. The most expensive systems on non-combat ships (in descending order) are the propulsion and electric plant, the mission systems, the hull, and the outfit and furnishings. In combat vessels, the armament systems can be as much as the rest of the value of the ship combined.

Figure 13: Distribution of Value in Production Phase



Source: Duke CGGC

Some caveats are in order. The percentages assigned to the value-adding activities vary depending on the configuration and purpose of the ship. For naval combat ships, the value of the armament systems may double the cost of the ship. For the lightly armed AOPS and JSS, the cost of weapons systems is a more modest contribution to the total cost of the ships, but still constitutes a greater share of the mission systems costs than for the non-armed CCG vessels. For non-combat ships, the percentages will vary depending on the type of mission systems placed on the ship. For example, aircraft placed on ships can skew the percentages from a rough balance among hull, platform, and mission systems to mission systems. Conversely, leaving complicated or optional equipment largely off a vessel's design would skew the averages toward the hull or platform systems. The percentages assigned in Figure 12 and Figure 13 are based on averages seen across the range of the NSPS vessels evaluated for this report, which does not included the CSC.

2.9. Nova Scotia and the Shipbuilding Value Chain

2.9.1. Nova Scotia's Position in the Shipbuilding Value Chain

Companies located in Nova Scotia span across segments in the shipbuilding value chain. We identified 7 firms in the design segment, 74 firms in the component production segment, 18 companies in component distribution, 18 firms in assembly & integration, 32 companies in production support services, and 13 companies in post-production services. Due to space constraints, the full list of Nova Scotia companies in the shipbuilding value chain is provided in Appendix A. We mention below a few of the firms in value chain segments across the shipbuilding value chain.

Design firms in Nova Scotia include Fleetway, Martec, and EYE Consultants.

Platform system component manufacturers include Alscott Air Systems, DRS Pivotal Power, and Lunenberg Industrial Foundry & Engineering. Component manufacturers for mission systems include Jasco Research, MetOcean DataSystems and UltraElectronics, and Seimac. Outfit component manufacturers in Nova Scotia include Hawboldt Industries and Crimond Enterprises, Ltd.

Firms in the distribution segment of the shipbuilding value chain include a number of multinationals and local businesses connecting production with assembly & integration. Companies with sales or distribution facilities in Nova Scotia include multinationals like Kongsberg Maritime, Saab, and ABB, and Canada-focused firms like DBCan and Acklands Grainger.

In the assembly and integration segment of the value chain are shipbuilders, including ISI as the region's leading firm in ship construction. Nova Scotia hosts a number of other shipbuilders, including Rosborough Boats, AF Theriault, and Keltic Marine Group, capable of supplying auxiliary boats (lifeboats and rigid hull inflatables) for the NSPS vessels. The assembly and integration segment includes major multinational corporations in the province, including MAN Diesel & Turbo, Rolls Royce Marine, General Dynamics Canada, and Lockheed Martin providing platform and mission systems integration.

Post-production services include companies providing In-Service Support such as Babcock Canada, SNC-Lavalin and MacDonald, Dettwiler and Associates (MDA). The segment also hosts a number of companies providing training and simulation services, including Atlantis Systems International, BlueDrop Performance Learning, and CarteNav.

2.9.2. Strengths and Opportunities in the Nova Scotia's Shipbuilding Value Chain

The SWOT analysis of Nova Scotia in shipbuilding value chain is presented in Table 3.

Table 3: SWOT of Nova Scotia's Shipbuilding Value Chain

Strengths	*Weaknesses*
• Strong shipbuilding tradition and infrastructure • Strong institutions of higher education • Strong sensors & instrumentation sector • Long-term federal shipbuilding project	• The limited presence of manufacturing in the province by multinational firms • Heavy reliance on the federal budget • Limited presence in commercial shipbuilding • Reliance on US & UK markets for exports
Opportunities	***Threats***
• Access to the supply chains of major multinational firms to satisfy direct demand created by NSPS • Upgrading skills and technology to compete in the global supply chains of major multinationals • Develop niche areas in the shipbuilding value chain to satisfy emerging design and technology trends	• Potential delays in government budget and military spending • Consolidation of shipbuilding and defence sector by non-Canadian MNCs • Foreign competition to upgrading skills and technology

Strengths

Strong shipbuilding tradition and infrastructure – Nova Scotia has a long history in shipbuilding, dating back to the 1880s. Irving Shipbuilding, Inc. the centerpiece of the region's shipbuilding industry has built 80% of Canada's current surface combat fleet, including icebreakers. ISI's Halifax Shipyard is a full-service shipyard, offering a range of services from fabrication to machine shops. The shipyard also provides access to a large and extensive local subcontractor community In addition to ISI; several smaller shipbuilders are in operation in Nova Scotia, including A.F. Theriault and Rosborough Boats. These large and small shipbuilders have developed valuable infrastructure for shipbuilding and repair, which will only improve as a result of the NSPS.

Strong institutions of higher education– Higher education institutions, including the Nova Scotia Community College and Dalhousie University, are continuing to develop a workforce with the skills required in the marine construction and transportation industry. Demand for a range of shipbuilding skills, from welders to software engineers, is provided by the presence of large-scale shipyards like the Halifax Shipyard. Nova Scotia has maintained a good balance between the supply of and demand for a skilled shipbuilding workforce.

The knowledge assets in the region include the Bedford Institute of Oceanography, which conducts ocean related scientific research, St. Francis Xavier, and the Halifax Marine Research Institute, a new public-private research institute which now includes the Aquatron Laboratory at Dalhousie University. The benefit of this combination of education, research and innovation assets is not limited to the development of a trained workforce. Dalhousie and the Bedford Institute provide access to professional and research networks essential to product innovation, development, and commercialization in the shipbuilding and allied ocean technology sector.

Strong sensors & instrumentation sector – Nova Scotia's shipbuilding value chain is particularly strong in sensors and instrumentation. Ocean technology firms provide goods for shipbuilding-related industries, ranging from marine robotics to electronic navigation equipment. They also provide services such as enhanced engineering and environmental and computer knowledge for marine industries.

Long-term federal shipbuilding project – The presence of this large-scale, long-term federal project in Nova Scotia will provide several benefits to the Nova Scotia shipbuilding sector. First, it will ensure a steady demand for shipbuilding for an extended period. Second, the project will generate new investments in the region. The NSPS will help upgrade infrastructure and stimulate employment across the region. Finally, NSPS will help the region attract large and small firms, skilled workers, and engineers from other Canadian provinces and foreign countries, making the region's shipbuilding and OT cluster diverse and dynamic.

Weaknesses

Limited product manufacturing by multinationals in the province – many of the largest multinational firms in the shipbuilding value chain with a presence in Nova Scotia do not manufacture products in the Province. Although some of the major multinational firms in the shipbuilding sector maintain production facilities in Nova Scotia, most multinationals "reach-back" to their existing global supply chain to provide products needed in the shipbuilding value chain.

Reliance on federal budgets – the shipbuilding sector in Nova Scotia is largely dependent on domestic government spending. Although this reliance on government procurement and domestic customers is not unusual in many shipbuilding countries outside East Asia, Nova Scotia needs to diversify its end-markets to become globally competitive.

Limited presence in global commercial shipbuilding -- The province has a very limited presence in global commercial shipbuilding. Canada does not have a significant global presence in shipbuilding, unlike Finland and Russia who are market exporters of Arctic vessels, Italy in recreational vessels, and the East Asian giants of shipbuilding, such as Japan, Korea and China.

Reliance on US & UK markets for exports -- Nova Scotia's 2010 ship exports, CAD 3.2 million, went to just five countries: UK (88.6%), the United States (11%), Germany, St. Pierre-Miquelon and New Zealand (0.4% combined).[4] Diversification of end-markets should be strongly considered.

Opportunities

Access the multinational firms' supply chains– The immediate opportunity for firms in Nova Scotia is to participate in the supply chains of the major multinational firms seeking to sell products for the NSPS

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[4] see CGGC, 2012 pp.17-60 for details

vessels. From the standpoint of the multinationals, local partners help to satisfy the IRB requirements for Canadian content. From the standpoint of the local firm, access to the global firm's supply chain allows them the opportunity to prove capability and sell products or services for the NSPS vessels.

Upgrading skills and technology – Once access to the multinational's supply chain is provided and proven, local firms can use their experience developed during the NSPS to participate fully in the global supply chains of major multinationals. Access to the global firm's supply chain permits the local firm to upgrade skills, certifications, processes and technology to provide an array of products and services to global customers.

Develop niche areas in the shipbuilding value chain –Emerging design and technology trends are apparent throughout the shipbuilding value chain. These trends can be used to focus product and service offerings and develop long-term advantage in the shipbuilding value chain. Trends identified in the value chain chapters include:

- fuel/energy efficiency (both technology and design)
- ballast water management systems
- automation
- robotics
- sensors
- arctic capable equipment
- smaller weapons systems
- secure communications systems
- combat systems integration
- electro-optics
- synthetic/simulated training

Furthermore, as one of Canada's major offshore oil and gas industry bases, Nova Scotia can benefit from the need of the growing offshore oil and gas sector for specialized ships, such as platform service vessels and anchor handling tug supply vessels.

Threats

Potential cuts or delays in government budget and military spending – The opportunities in the shipbuilding sector in Nova Scotia are threatened by cuts or delays in military spending. The reduction in spending would affect both the immediate sales and the longer-term upgrading opportunity for companies.

Consolidation by non-Canadian MNCs in global value chains -- Over the last decade, many MNCs have grown through acquisitions of smaller firms to expand their offering across different end markets while simultaneously consolidating their R&D efforts. This has led to the increasing presence of a few large multinationals in a wide range of instrument markets, which was once largely populated by specialized smaller firms. This highlights, on the one hand, the growing role of global lead firms in providing smaller firms an access to global value chains, and, on the other hand, the importance of creating value chain linkages with MNCs for maintaining the competitiveness of Nova Scotia firms.

Strong foreign competition -- strong foreign competition exists in many of the systems and subsystems in the shipbuilding value chain. Although the precise nature of the competition depends on the product, strong foreign competition for systems and subsystems reduces the opportunity for firms in Nova Scotia.

3. Arctic/Offshore Patrol Ship (AOPS)

Prepared by Lukas Brun

This chapter examines the value chain of the Artic/Offshore Patrol vessels. The first section of the chapter provides an overview of the AOPS, including its stated mission, proposed characteristics, and recently built similar ships. The second section of the chapter examines the value chain for the AOPS, a description of the proposed systems and subsystems unique to the vessel, and firms likely to supply them. The third section of the chapter investigates Nova Scotia's position in the value chain for the AOPS, and describes the strengths, weaknesses, opportunities, and threats for Nova Scotia in the AOPS value chain.

3.1. Ship Purpose and Characteristics

3.1.1. Overview

The AOPS is an armed, 98m long Royal Canadian Navy vessel capable of speeds of 17 knots in open water and 3 knots icebreaking in 1m of level ice. The IACS Polar Class 5 ship is designed to have both good seakeeping and icebreaking performance to accomplish its "constabulary" mission of patrolling and enforcing Canada's sovereignty in the Arctic, Pacific, and Atlantic oceans. The AOPS project has its origins in 2007 when Canada announced it would build six to eight polar-classed patrol vessels for CAD 3.1 billion, with approximately $4.3 billion provided for operations and maintenance over the 25-year lifespan of the ship (DNF/CF, 2007). In 2010, Canada announced its intention to build up to eight AOPS as part of the CAD25 billion combat portion of the NSPS, which was awarded to ISI in October 2011.[5]

Figure 14: AOPS

Source: RCN/Soule, 2011

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[5] From *Defense Industry Daily* (http://www.defenseindustrydaily.com/canadas-national-shipbuilding-strategy-07164/): "May 9/12: AOPS delayed. The Ottawa Citizen reports that the NSPS' 1st project, the armed Arctic Offshore Patrol Ship, has been pushed back to 2018. In addition, the $3.1-billion project is now expected to cost $40 million more than anticipated. The information comes from documents tabled in Canada's house of Commons on May 8/12, presumably DND Sessional Paper No. 8520-411-134…The project was announced in 2007, with a contract award expected by 2009, and a 2013 delivery date. The NSPS wasn't even finalized until October 2011, which had pushed expected delivery to 2015. Now it's 2018."

The ship is designed to commercial ship standards (IMO/SOLAS) with the goal of maximizing commercial off-the-shelf (COTS) systems and system components. The intent behind this design principle is to reduce the design risk, and, consequentially, reduce construction costs for the prime contractor and federal government. The AOPS is designed to add mission packages over time or as threat conditions warrant. For example, the design provides space for a larger naval gun, additional equipment space for Search & Rescue (SAR) and environmental response operations, enhanced cargo handling, and a larger helicopter and associated aircraft securing and haul-down systems (RCN/Soule, 2011).

BMT Fleet Technology (Ontario) and STX Canada Marine (Vancouver and Ontario) were contracted by the Canadian government to develop technical specifications and design of the AOPS in early 2008. BMT Fleet Technology is lead contractor and has developed the technical specifications for the AOPS. STX Marine, a wholly-owned subsidiary of STX Offshore and Shipbuilding Korea, designed the ship. BMT and STX may provide engineering support to the Canadian government during construction of the vessels (STX Marine Canada, 2012).

The AOPS design has completed the classification design specification stage, its hull form has been tested and validated for power and ice capability, and the design has been reviewed by Lloyds Classification Society (RCN/Soule, 2011). It is expected to be the first NSPS vessel built at ISI. The scheduled date for “cutting steel” (beginning construction) is 2015. (Please see Figure 15).

Figure 15: AOPS Status

Major Milestone *AOPS	DND Published Date
NSPS Selection of Shipyards	October 2011 ✓
Signing of Umbrella Agreement	February 2012 ✓
Signing of AOPS Ancillary Contract (initial planning)	June 27, 2012 ✓
Signing of AOPS Design Contract	2013
Finalize Engineering & Planning	2015
Signing of AOPS Build Contract	2015
Cut Steel on First AOPS	2015
Delivery of First AOPS	2018
AOPS Program Complete	2024

** Dates published by DND as of May 9, 2012*

Source: DND, 2012b

3.1.2. Ship Purpose

The Canadian Navy has expressed the need to exercise better control of Canada’s Exclusive Economic Zones (EEZs, or 200 nautical mile [321 km] limit) in all three oceans, particularly the Arctic.[6] The Arctic is a complex navigational environment with multiple boundaries and contested maritime jurisdictions.

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[6] Effectively patrolling the Northwest Passage has been the topic of a number of articles in the *Canadian Naval Review* and *Broadsides*. See, for example, Thomas, Douglas (2007) “Warship Developments: Arctic/Offshore Patrol Ship” *Canadian Naval Review* Vol. 3.3, pp. 36-37..

While the Navy can effectively patrol close coastal waters in the Atlantic and Pacific with its Maritime Coastal Defence Vessels (MCDVs), these ships cannot be used at the limits of Canada's EEZs. The MCDVs have a limited ability to operate in the open ocean, limited speed [15 kts/28 km/h], and limited capacity to support boarding operations and lack the ability to support a helicopter. Currently, the Navy must use its large combatant vessels, destroyers and frigates, which are expensive to operate and already over-tasked, to patrol the open ocean at the limits of Canada's EEZs. The military considers the AOPS as replacement vessels for the existing Kingston-class MCDVs, which are not ice-strengthened.

AOPS will be used year-round in a variety of roles, including domestic surveillance, search and rescue, and to support other government departments. The AOPS will allow the Navy to expand its patrol operations, currently limited to the Hudson Bay, to the west and north encompassing the entire Canadian portion of the Northwest Passage, from Lancaster Sound in the east, the Canada/US boundary in the west, and north to Grise Fjord. The current concept of operations is to deploy the AOPS for four months and follow the ice as it retreats north in early summer and depart as the ice expands at the end of the Arctic's navigation season at the end of October/early November. Plans are in place to extend deployment for up to six months by 2030 (RCN/Soule, 2011).

3.1.3. Similar Ships

The Canadian AOPS will be one of a handful of ice-classed offshore patrol ships maintained by Arctic rim countries and New Zealand. (Please see Table 4). The AOPS are designed after Norway's *Svalbard*, a Norwegian Coast Guard icebreaker and offshore patrol vessel entering service in 2002. General features common to both the AOPS and *Svalbard* are the ability to serve as both icebreaker and offshore patrol vessel. Both vessels are armed and capable of carrying at least one helicopter. However, they differ in some major design elements. The *Svalbard* uses a conventional icebreaking bow for light icebreaking and cruising, but uses a specially designed stern – with azipod thrusters to turn the vessel – for heavy icebreaking. Due to cost constraints, the AOPS will use a conventional bow-first design for both light and heavy icebreaking, propelled by diesel-electric twin shaft motors with bolt-on propellers, similar to existing Canadian Coast Guard icebreakers. New Zealand's ice-classed offshore patrol vessels *Otago* and *Wellington*, part of the Royal New Zealand Navy's Project Protector, were designed by STX Marine Canada (McGreer, 2011). Currently, Canada is the only nation with plans to build a new class of ice-classed offshore patrol vessels, although Denmark plans to complete a third *Knud Rasmussen*–class vessel by 2020.

Table 4: Recent Ice-Classed Offshore Patrol Vessels

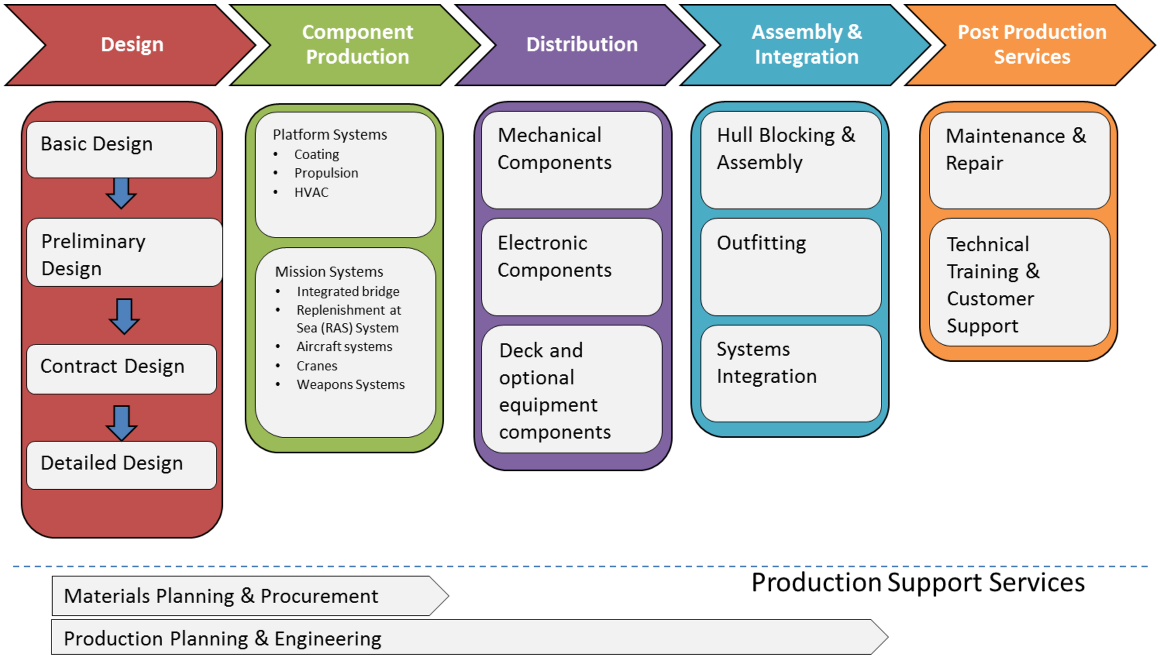
Country	Class	First Year in service	Ice class	Length	Size	Speed	Prop.	Main Gun	Helicopter
Norway	Svalbard	2002	n.a.	89m	6,375t	17.5kts	RR	Bofors 57mm	NH90 (2)
Denmark	Knud Rasmussen	2008	n.a.	61m	1,720t	17.5kts	MAN	76mm Otto Melara	Westland Lynx
New Zealand	Protector	2010	1C	85m	1,900t	12-15kts	MAN	Bushmaster (Alliant) M242 25mm	Kaman Super Seasprite
Canada	AOPS	2018	PC5 (PC4 bow)	98m	5,874t	17kts	(?) MAN, RR or Wartsila	(?) Bushmaster (Alliant) M242 or equivalent 25mm	CH-148 Cyclone CH-149 Cormorant

Source: Duke CGGC, from industry sources

3.2. AOPS Value Chain

The purpose of this section is to describe each phase of the AOPS value chain, to describe important aspects of the AOPS, and to identify firms participating at each phase of the value chain. Our evaluation about companies providing the product components or services is necessarily preliminary at this early stage of the AOPS project and is subject to change. The information provided is based on interviews and review of publicly available reports conducted by Duke CGGC as of November 15, 2012.

Figure 16: AOPS Value Chain



Source: Duke CGGC

3.2.1. Design

The Royal Canadian Navy specified that the AOPS must meet the following design requirements:

Seakeeping: The AOPS will be able to operate independently and effectively in Canada's EEZs, including such diverse environments as the Canadian Arctic, the Grand Banks of Newfoundland and the northwest coast of (Haida Gwaii) the Queen Charlotte Islands. The AOPS must also be capable of navigating the St. Lawrence River year-round and berthing at Quebec City.
Ice Capability: The AOPS hull will be ice strengthened to operate in medium first-year ice and denser old ice that may strike the hull of the ship. The vessel is rated to have an IACS ice classification of PC5, with a PC4 bow. This reflects that the patrol ship will encounter small chunks of multi-year ice as a part of conducting its mission, and as a safety measure for hitting undetected ice at night and bad weather. This ice capability is exclusively for the ships' own mobility, and will not provide icebreaking services to other ships.
Endurance/Range: The ship will have the ability to sustain operations for up to four months and have a range of at least 6,000 nautical miles (11,000 km). The current range of the vessels is 6,800 nautical miles at an average 14 knots, but can expand its range with a slower average speed of 10 knots.
Command and Control: The ship's electronic equipment have the ability to ensure safety of navigation and flight, as well as sufficient command, control and communications capability to provide and receive real-time information to and from the Canadian Forces Common Operating Picture.
Speed: The ship will be able to maintain an economical speed of 14 knots [26 km/h] and attain a maximum speed of at least 20 knots [37 km/h].
Armament: The ship will have gun armament for armed patrol capability.
Boat Operations: The ship's crew will be able to conduct boat operations up to moderate, 1.25 to 2.5m waves (Sea State 4), support operations ashore via landing craft, and support naval boarding parties. The ship will also be designed to embark and operate an on-board helicopter, as well as house one flying crew and one maintenance crew. The helicopter and hanger are essential for Arctic missions in the CCG and Navy's experience. A hanger is needed to overcome a major operational limitation of Denmark's *Knud Rasmussen*.
Class Life: The six to eight ships should remain operational for 25 years.[7]

BMT Fleet Technology (Ontario) and STX Canada Marine (Vancouver and Ontario) were contracted by the Canadian government to develop technical specifications and design of the AOPS in early 2008. BMT Fleet Technology is lead contractor and has developed the technical specifications for the AOPS (STX Canada Marine, 2012). STX Marine, a wholly-owned subsidiary of STX Offshore and Shipbuilding Korea, designed the ship.

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[7] Source: DND/CF Arctic/Offshore Patrol Ship Backgrounder (http://www.navy.forces.gc.ca/cms/3/3-a_eng.asp?id=617). Similar statements can be found at DND/CF http://www.materiel.forces.gc.ca/en/aops.page.

The AOPS hull is designed to balance between ice-breaking, seakeeping, maneuverability, and speed. To achieve this balance of capabilities, the bow is strengthened to PC4, which allows navigating in waters with multi-year ice, in addition to a PC5 hull permitting safe travel in 1m of first year ice. Multi-year ice is particularly hard and hulls must be designed to survive in waters potentially filled with multi-year ice. Seakeeping was potentially challenging to achieve since the ships are planned to operate in both open water and ice. The hulls for icebreakers are flat with a wider beam to permit icebreaking, yet in open water, flat-bottomed boats roll, which is uncomfortable for onboard personnel. The AOPS will have a long hull to "cut" into open water and retractable fin stabilizers to provide a good balance between icebreaking and seakeeping objectives (STX Canada Marine, 2012; RCN/Soule, 2011).

The AOPS design has completed the classification design specification stage, its hull form has been tested and validated for power and ice capability, and the design has been reviewed by Lloyds Classification Society (RCN/Soule, 2011). Seakeeping requirements for the design were evaluated at Sea State 6 for transit, fueling, and boat launch and recovery; Sea State 5 for boarding operations, and Sea State 3 for helicopter operations. The design was found to be feasible with no operational limitations in a test of the hull at the NRC Institute of Offshore Technology (IOT). Unlike many of the NSPS vessels, a draft of the system requirements for the AOPS, as of September, 2010, is publicly available. Unless otherwise stated, information in this chapter about system level requirements is based on AOPS-SRD (2010), STX Marine Canada (2012) and RCN/Soule (2011), found in the bibliography.

Table 5: AOPS design team

AOPS Design
STX Marine Canada (design)
BMT Fleet Technology (technical specifications)

Source: Duke CGGC

3.2.2. Component production

ISI, as prime contractor for the AOPS, will have project management responsibilities for constructing the vessel. Project management activities include IRB management, production management responsibilities, and material planning responsibilities for constructing the hull, and perhaps, for outfit and furnishings. Hatch Engineering has been contracted to provide upgrades to the Irving yard for construction of the NSPS combat vessels, including the AOPS.

Table 6: AOPS Project management and site engineering

AOPS Project Management
ISI (project mgmt., IRB mgmt., production planning, materials planning for hull, outfit& furnishings)
Hatch Engineering (contractor for site engineering)

Source: Duke CGGC

3.2.2.1. *Hull construction*

The AOPS hull will require steel appropriate for an ice-classed vessel. Lloyd's Register and the Atlantic Bureau of Shipbuilders (ABS) certify two Canadian steel mills capable of manufacturing steel grades suitable for polar class vessels: Essar Steel Algoma in Sault Ste. Marie, ON, and Gerdau Ameristeel in Whitby, ON (ABS, 2012a; Lloyd's Register, 2012) (see Table 7).

Hull coating: the AOPS will require hull coatings appropriate for operations in low temperature and ice infested environments. AkzoNobel/International Paint (UK) is a leading manufacturer of well-known coatings suitable for ice-infested environments. Jotun (UK) also offers hull coatings suitable for this environment.

Table 7: AOPS hull construction

Hull Construction
ISI (prime contractor)
Russel Metals (ON) (metals broker)
Samuel, Son & Co (ON, NS) (metals broker)
• Gerdau Amersteel (ON) • Essar Steel Algoma (ON) • or foreign purchase
AkzoNobel/International Paint (hull coating)
Jotun (hull coating)

Source: Duke CGGC

3.2.2.2. *Platform systems*

Propulsion system and electric plant: Propulsion will be provided by a diesel-electric twin screw propulsion system. The prime mover (engine) will be two 4,500 kW propulsion motors. The electric plant will consist of four 3,300 kW diesel generator sets, which will provide ship service power and power for very slow speed operations. The propeller diameter will be 3.8 meters with a 1 meter hub and bolt-on blades. The shafts will be compliant with PC5 requirements and capable of withstanding 150% (4,500kW per shaft) of designed torque ("overtorque") during ice-breaking maneuvers. The propulsion and electric plant are designed for broad availability of engines in the power range, and reflect the design principles enunciated by the RCN to use existing systems to lower costs.

A number of manufacturers of marine engines could provide the propulsion system and electric plant based on these specifications. Firms that manufacture propulsion system components tend to fall in one of three categories of manufacturing capability. They either manufacture primarily diesel engines, primarily electric motors, or they act as entire propulsion system integrators that design and manufacture the entire system from diesel engines through the propellers. Firms that manufacture entire propulsion systems include ABB, GE, MAN Diesel and Turbo, Rolls Royce, and Wartsila. One benefit of full propulsion system integrators is the reduced risk of potential inoperability of systems provided by different manufacturers.

As illustrated in Table 4 (p.53), MAN Diesel & Turbo provided propulsion systems for both New Zealand's *Protector*-class (also designed by STX Canada Marine) and Denmark's *Knud Rasmussen*. Rolls-Royce Marine provided the propulsion system for Norway's *Svalbard*.

DRS Pivotal Power (NS) specializes in static power conversion equipment for naval vessels.

Integrated Platform Management System (IPMS): The IPMS will be integrated with the ship's Combat Management System (CMS), have a system for on-board training of personnel, provide footage of fixed CCTV Cameras, control the propulsion system, electrical power generation and distribution, stability and load management, including a ship stability calculator, and monitor and/or control the following auxiliary systems:

- seawater systems (firemain, sprinkler system),
- bilge and ballast systems,
- fuel filling and transfer systems,
- aviation fuel filling and transfer systems,
- fresh and potable water systems,
- black and grey water systems,
- compressed air systems,
- tank level management system, and
- HVAC, including crash Stop Ventilation
- ground fault detection system (insulation resistance),
- cathodic protection system,
- uninterruptible power system,
- deck de-icing system, and
- helicopter power system.

L-3 MAPPS (Montreal) and Siemens (Germany) specialize in naval IPMS. AOPS may use a separate system – an integrated bridge system (IBS) – for navigation and rudder control. Raytheon Anchutz (Germany) and L-3 MAPPS produce IBS suitable for the AOPS.

Table 8: AOPS Platform systems companies

AOPS Propulsion, Electric Plant and IPMS
Propulsion plant
Rolls-Royce Marine (diesel-electric propulsion)
Wartsila Canada (diesel-electric propulsion)
MAN Diesel & Turbo (diesel-electric propulsion)
Electric plant
Rolls-Royce Marine
Wartsila
DRS Pivotal Power (static power conversion equipment)
IPMS & IBS (ship steering)
L-3 MAPPS (IPMS, IBS)
Siemens (IPMS)
Raytheon Anchutz (IBS)

Source: Duke CGGC

Auxiliary systems

Cold temperature protection: Although the current concept of operations for the AOPS is to remain out of the Arctic during winter, machinery and personnel support systems must be protected against cold temperatures. The AOPS will use recovered heat from engine cooling circuits and exhaust recovery for HVAC and fuel tank heating. Heat will also be recovered from machinery space ventilation. Decks will be de-iced with blast heaters. Bronswerk Marine (Quebec) and Alscott Air Systems (Nova Scotia) are two leading companies providing HVAC and cold temperature protection systems. In anticipation of the ships being built at ISI, Bronswerk has opened a facility in Nova Scotia.

Landing craft and boarding boat operations: AOPS will be capable of launching rigid hull inflatable boats (RHIB) or other types of lifeboats in the Arctic. The boats can be launched and recovered in Sea State 5 conditions with small, retractable cranes (“davits”). The current configuration of the AOPS includes an 8.5m work/rescue boat, a 12m boarding/assault boat, and an 11m landing craft. The boats will be used to support RCN and Royal Canadian Mounted Police (RCMP) environmental response (ERT), search & rescue (SAR) or special operations (SOF). The craft onboard the AOPS will have to meet RCMP standards, including an aluminum hull and high-strength Hypalon/Neoprene rubber. The system level requirements for the AOPS reviewed by Duke CGGC state the AOPS will have a *Zodiac* Hurricane Rigid SR2 Aluminum Sea Rigid Hull Inflatable Boat or its replacement. A number of other RHIB manufacturers exist, including Polaris (BC), Brig (Czech – assembled in Canada), Kanter Marine (ON), and Rosborough Boats (NS).

Aviation facilities: The AOPS has a flight deck, fixed hanger, flight deck firefighting capabilities, and night/limited-visibility control capabilities for flight operations up to Sea State 3. The AOPS is equipped with aviation facilities to support two types of helicopters: a smaller CH148 Cyclone or a larger CH149 Cormorant if required. The AOPS will be able to land, stow, refuel, and conduct minor repair to the smaller CH148. For the CH149, the AOPS will only have the capability to land and refuel the aircraft. At times, reference is given to the Bell 212 or 412 as placed on the AOPS; however, our understanding is that these helicopters will be retired from Canada’s forces by the time the AOPS becomes operational. Flight deck firefighting will be provided by the manufacturer of the ship’s general firefighting system. Don Brenton specializes in fire suppression systems for the RCN. Indal (ON) specializes in aircraft haul-down systems widely adopted by the RCN and the U.S. Navy.

Replenishment-at-sea (RAS): RAS systems are used to transfer fuel, ammunition, and ship stores from one ship to another while under way. The current AOPS specifications state that the vessels will carry a liquid receiving station and a light line transfer systems for ship-to-ship transfer of stores up to a maximum weight of 23 kilograms. Hepburn Engineering is manufacturer of several of the ship-to-ship supply systems and supply systems simulation and training modules used by RCN. Rolls-Royce Marine is also a major supplier of RAS systems. Hawboldt Industries makes a special capstan for the RCN used as part of the receiving RAS stations on the Canadian frigates.

Anchor handling & stowage systems: Anchor handling and stowage systems are large winches used to launch, retrieve, and store the ship’s anchors. Anchor handling winches are normally referred to as an anchor “windlass.” Major manufacturers of these systems are Rolls-Royce and Macgregor (subsidiary of Cargotec). Hawboldt Industries also designs and manufacturers anchor windlasses.

Environmental pollution (ballast water & diesel exhaust) control system: Current specifications of the AOPS state it will comply with the "*IMO International Convention for the Control and Management of Ships' Ballast Water and Sediments*.” In addition, the AOPS will have ballast water tanks and ballast water control and monitoring systems to facilitate the use of fresh water generated on-board as liquid ballast. Manufacturers of ballast water management systems include Trojan Technologies (ON).

Diesel exhaust contains nitrous oxide (NOx), which must be removed to achieve the goal of the AOPS to be compliant with MARPOL Annex VI Regulation 13 (*MARPOL 73/78 Annex VI Regulations for the Prevention of Air Pollution from Ships, Chapter III Requirements for Control of Emissions from Ships, Regulation 13 Nitrogen Oxides (NOx))*. Our understanding is that the AOPS does not seek to be compliant with MARPOL Annex VI regulations (Regulation 14) for sulfur oxide (SOx). Many marine engines sold by the major manufacturers comply with the regulation for NOx. In addition, Marine Exhaust Solutions (PE) offers diesel exhaust scrubbing solutions, if needed to comply with Regulation 13 or 14.

Table 9: AOPS Platform auxiliary system companies

AOPS Auxiliary Systems Manufacturers
Bronswerk Marine (cold temperature protection/HVAC)
Alscott Air Systems (cold temperature protection/HVAC)
Don Brenton (fire suppression)
Zodiac (RHIB)
Polaris (RHIB)
Brig (Czech – assembled in Canada) (RHIB)
Rosborough Boats (RHIB)
Kanter Marine (RHIB)
Rolls-Royce Marine (RAS, anchor handling/windlass)
Macgregor (anchor handling/windlass)
Hawboldt Industries (anchor handling/windlass)
Hepburn Engineering (RAS)
Indal/Curtiss-Wright (helicopter haul-down)
Marine Exhaust Solutions (diesel exhaust scrubbing)
Babcock (RAS, stores lift & handling, flight-deck handling, integrated waste mgmt.)

Source: Duke CGGC

3.2.2.3. Mission systems

Combat system: AOPS is a naval ship but serves a constabulary, rather than a combat, purpose. As a reflection of that purpose, the operations room will be manned when the ship is at sea only as threat conditions warrant. In addition, the general design principles of the AOPS are particularly relevant for the combat systems on the vessels; COTS equipment is to be maximized, software development minimized, and the combat communications system will be integrated with the LAN, rather than being a separate system (STX Marine Canada, 2012).

The AOPS combat system consists of 1) command, control, communication, computer, intelligence and surveillance system (C4IS), 2) armament system, and 3) the flight control & landing system (note: flight control discussed under auxiliary systems). ISI has announced that Lockheed Martin has been selected to be the combat systems integrator for the AOPS. Although the AOPS design allows space for additional combat system sensors, its current configuration is fairly modest in this regard. Our understanding is that the AOPS combat system will primarily consist of a 25mm naval gun, various radars (S-Band, X-Band), a Warship Electronic Chart Display and Information System (WECDIS), and friend-or-foe identification (IFF) system. We review the primary subsystems for the AOPS combat system and Lockheed's existing partners for supplying similar systems.

The C4IS system consists of the command, control, and information system, (secure) local area networks (LAN), navigation system, communication system (interior, exterior, optical, and the Global Maritime Distress Safety System (GMDSS)), surveillance system, meteorological and oceanographic system, and the closed-circuit television system (CCTV). Saab may provide the command and control system (CCS) in partnership with Lockheed Martin. Lockheed has long-standing relationships with Saab Canada (NS), Raytheon (US), and Thales Canada (ON/Quebec) to provide necessary radars. Saab has expertise in 2D and fire control radar, Raytheon has expertise with navigation radars, and Thales has expertise in 3D air and surveillance radars. Rutter Technologies (NL) is a leading manufacturer of ice-hazard radar. Lockheed's portfolio of products includes the WECDIS. Telephonics (US) has been a partner with Lockheed for IFF systems on the Halifax Class modernization program.

Gun armament: The AOPS is proposed to have a small caliber (25mm) naval gun, two naval machine guns, and weapons lockers for small arms stowage. Lockheed Martin has been selected as the weapons systems integrator for the AOPS; however, to our knowledge Lockheed does not have a proprietary 25mm naval gun. Instead, Lockheed may use the Rafael (Israel) Typhoon 25mm, BAE's MK38, BAE Bofors 25mm, or Alliant Techsystems (US) Bushmaster (M242) 25mm naval gun for use on the AOPS. New Zealand's *Protector-class,* an ice-classed patrol vessel similar to the AOPS, uses Bushmaster (M242), yet the Typhoon, BAE (MK38) and BAE Bofors offer very good 25mm naval gun systems. Babcock's portfolio of products includes magazine stowage and ammunition lift/storage/handling.

Table 10: AOPS Mission Systems companies

Mission Systems
Lockheed Martin (Mission systems integrator)
C4IS system
Saab (CCS, 2D radar)
Raytheon (navigation radar)
Thales (3D air & surveillance radar)
Rutter Technologies (ice-hazard radar)

Mission Systems
Lockheed (WECDIS)
Telephonics (IFF)
Gun armament
Lockheed Martin (weapons systems integrator)
BAE MK38 (25mm naval gun)
BAE Bofors (25mm naval gun)
Rafael Typhoon (25mm naval gun)
MD/Alliant Techsystems Bushmaster (25mm naval gun)

Source: Duke CGGC

3.2.2.4. *Outfit & furnishings*

Cargo handling: The AOPS is equipped with a flexible cargo deck that can be used to stow containers or additional landing craft or motorized vehicles (snow-mobile, utility ATV, or truck). A 20-tonne crane for cargo handling is currently planned for use on the ship to haul containers and vehicles onboard and onshore. Ship-to-shore cranes are manufactured by a number of producers, including Rolls-Royce Marine, Wartsila and Babcock.

Table 11: AOPS outfit & furnishings

AOPS Outfit & Furnishings
Rolls-Royce Marine (ship fittings, deck machinery/cargo handling crane)
Wartsila (deck machinery/cargo handling crane)
Babcock International Group (cargo handling)

Source: Duke CGGC

3.2.3. Component distribution

As shipbuilding has become increasingly modular, the major systems integrators have gained control over the distribution (as well as the maintenance and post-production services) of the major subsystems such as propulsion, electronic equipment and deck equipment. These “turnkey” equipment suppliers provide their product as a full package, which can then be “plugged in” or integrated into the final craft with minimal effort or liability to the shipyard. This distribution arrangement is beneficial to the systems integrators, as they are able to realize greater economies of scope and scale. Shipyards benefit, as they can reduce the amount of supervision required for producing the final ship. A challenge to this arrangement, from the perspective of the multinational, is the IRB requirement to “offset” the purchases with Canadian content, since oftentimes, the multinationals have global production facilities and may only have distribution or assembly facilities in Canada. The extent of this “reachback” to their existing supply chain is a major determinant whether the companies will be able to provide direct or indirect offsets under the Canadian IRB policy.

Shipbuilders use component distributors for hull production and some outfitting & furnishing work, if the shipyard is responsible for ship fittings, deck machinery, and furnishings for living spaces. For example, a shipbuilder may choose to use a metal distributor to conduct the brokering and delivery of steel to the yard, or source the steel on its own. Similarly, a shipbuilder may delegate sourcing of ship fittings, deck machinery and furnishings to one of the systems integrators (typically the platform system integrator) or source the components through its supply chain. Where Irving will end up on this spectrum of delegation versus self-sourcing has not yet been determined. However, Irving generally prefers a limited number of suppliers in its supply chain.

3.2.4. Assembly and integration

Hull Blocking and Assembly: Modern shipbuilding follows a modular production method. That is, hull blocks are constructed independently from one another before being assembled into the structure of the final craft. This allows the shipbuilder to construct hulls more quickly and to work on multiple projects at one time. Irving Shipyards will be responsible for hull assembly for the AOPS.

Outfitting: Once the hull is assembled, it must be outfitted with electrical equipment, deck equipment, other mission-specific equipment, supplemental craft and amenities for crew. Outfitting will be conducted in coordination with the prime contractor and the systems integrators.

Systems Integration: As with the construction of all large vessels, systems integration is an important and high-value-added activity for research vessels. The integration of a large number of different systems, subsystems, equipment, and user panels into a single system is a unique challenge, requiring engineering expertise and sophisticated software. As ships have become more sophisticated, integration has grown increasingly important. Not only must subsystems and components within each system function, but increasingly, subsystems and components across systems must be able to communicate and function as well.

The increased complexity of systems integration has created a trend to purchase entire platform and mission system packages from large, vertically-integrated companies, such as Rolls Royce Marine, Wartsila or MAN Diesel & Turbo for platform systems, and mission systems integrators such as Lockheed Martin and General Dynamics. Previously, a shipbuilder might try to reduce costs by purchasing individual pieces of equipment and subsystems separately from dozens of different manufacturers. But the owner's risk of incompatibility among those many systems is becoming prohibitively high. This risk grows with the life of the ship. After a year in service, a dynamic positioning system malfunction could be attributed to the system itself, the electrical system, or the propulsion system. There is much less risk that distinct complex systems will not communicate properly if a firm has already designed and proven effective an entire system package. It also ensures that the owner has only one company to call for in-service support should something malfunction later in the life of the vessel. Owners are willing to pay a premium of between five and ten percent to avert this risk. Systems integration for the AOPS will be conducted by Lockheed Martin (mission systems) and one of the major platform systems integrators.

Table 12: AOPS Assembly & integration

Assembly & Integration
Irving Shipyards (Prime Contractor)
Lockheed Martin (Mission Systems integrator)
Rolls-Royce Marine (Platform systems integrator)
Wartsila (Platform systems integrator)
MAN Diesel & Turbo (Platform systems integrator)

Source: Duke CGGC

3.2.5. Post-production services

Once the AOPS is delivered, there remain a number of post-production activities that enhance the value of the ship to the owner. Maintenance and repair operations on the hull and ship subsystems are required, as well as technical training and customer support (ILS). The 25-year post-production service arrangement for the AOPS will be a completed separately during the project implementation phase (TBS, 2012a). The work will be carried out by either ISI, the mission systems integrator (Lockheed), or a specialized service provider such as Babcock Canada or SNC-Lavalin, the latter of which has the ISS contract for all Minor Warships and Auxiliary vessels.

Training and customer support services are becoming increasingly important in the naval market. Simulated training systems are offered by a number of system and subsystem producers, notably the mission systems integrators like Lockheed Martin and General Dynamics, and developers of separate platform systems such as the RAS. Software development and virtual reality/serious gaming companies, like Nova Scotia's Atlantis and BlueDrop, may work with systems manufacturers and integrators to develop better simulated environments for the naval market.

Table 13: AOPS Post production services

Post-production services
In Service Support (ISS)
Irving Shipyards (Prime Contractor)
Lockheed Martin (Mission Systems integrator)
Babcock Canada, SNC-Lavalin or other dedicated ISS provider
Integrated Logistical Support (ILS)
Lockheed Martin
Babcock Canada
Raytheon Anschutz
BAE Naval Systems
Virtual training
Lockheed Martin (Mission Systems integrator)
Rolls-Royce Marine (RAS training)
Hepburn Engineering (RAS training)
Atlantis Systems International (simulated environment)
BlueDrop Performance Systems (simulated environment)

Source: Duke CGGC

4. Joint Support Ships (JSS)

Prepared by Shawn Stokes and Lukas Brun

This chapter examines the value chain of the Joint Support Ships. The first section of the chapter provides an overview of the JSS, including its stated mission, proposed characteristics, and recently built similar ships. The second section of the chapter examines the value chain for the JSS, a description of the proposed systems and subsystems unique to the vessel, and firms likely to supply them. The third section of the chapter investigates Nova Scotia's position in the value chain for the JSS, and describes the strengths, weaknesses, opportunities, and threats for Nova Scotia in the JSS value chain.

4.1. Ship Purpose and Characteristics

At their core, Joint Support Ships (JSS) are replenishment ships – manned surface vessels whose primary purpose is to replenish combat ships with fuel, ammunition, spare parts, food, and water in order to extend the range and duration of naval combat missions. However, since the end of the Cold War the role of replenishment ships has evolved and grown to include policing missions against terrorists, smugglers and pirates, and provide humanitarian relief (Hooton, 2010). Many also have hospital facilities, and are capable of providing medical and dental care to naval crew members. Transporting so much cargo requires tremendous capacity, and therefore JSS vessels can exceed 200m in length and accommodate more than 200 crew members (Blohm + Voss Naval, 2012; Naval Technology, 2012c; Royal Navy, 2012).These newer, and more capable, replenishment ships are now more commonly referred to as joint support ships.

As part of the National Shipbuilding Procurement Strategy (NSPS) the government of Canada has commissioned the procurement of two JSS vessels for the Royal Canadian Navy (RCN), with the option to build a third. The JSS will replace the more than forty-year-old Auxiliary Replenishment Oilers (AOR), HMCS *Protecteur* and HMCS *Preserver*. The JSS will have additional capabilities, including: underway support to Naval Task Groups, limited sealift capabilities, and support to forces on shore.

> **Underway support to naval task groups** refers to the transfer of liquid and solid supplies between ships at sea. It also includes the operation and maintenance of helicopters, and the provision of medical and dental services.
>
> **Limited sealift** is a feature that will allow JSS vessels to deliver a limited amount of cargo onshore, a useful attribute in uncertain or precarious security environments.
>
> **Limited support to forces on shore** allocates sufficient space and weight to include a future joint task force headquarters for command and control of forces deployed on shore (DND/CF, 2012).

The process to build the JSS started in 2004. Since the original request for procurement (RFP) was delivered in 2006 several delays and conceptual design changes have occurred. In 2008, the Canadian government decided the concept designs did not fit the cost and capability requirements (Pugliese, 2012). The ships are now part of the NSPS, and are once again in the concept design phase. The government plans to select a design in 2013, upon which the JSS will be built by Seaspan Shipyard in Vancouver. The RCN estimates the vessels will be completed in 2018 (Pugliese, 2012). [8]

Table 14: JSS Preliminary Project Milestones and Schedule

MILESTONE	DATE
Revised Project Approval (Definition)	June 2010
Project Approval (Implementation)	February 2014
Award of implementation Contract	March 2014
Initial Operating Capability – First Ship	Spring 2018
Final Operating Capability	Fall 2019

Source: Treasury Board of Canada, Secretariat (TBS, 2012a)

4.2. Joint Support Ship Value Chain

The value chain for the Joint Support Ships is found in Figure 17 Joint Support Ships, like other large, modern surface vessels, are built according to a modular production system, in which a small number of lead firms – the shipbuilder, a design team, and a small handful of systems integrators – control the design, construction and outfitting of the ship through the collaborative management a long, geographically disparate and complicated supply chain. These firms are the shipbuilding partners. For the Canadian JSS, the shipbuilding partners are:

- Seaspan/Vancouver Shipyards: shipyard/prime contractor
- Imtech Marine: platform systems integrator
- Thales: mission systems integrator
- STX Canada Marine Inc.: design and engineering
- Computer Sciences Canada, Inc.: integrated logistics support.

Below the shipbuilding partners for any given project are a number of component suppliers who provide specific subsystems. These firms do not see a shipbuilding project through from conception to completion, as the shipbuilding partners might, but rather serve as systems providers for specific systems. While the design firms act almost entirely within the design segment of the value chain, the shipbuilding partners will often assume roles and collaborate across multiple segments of the chain, including component production, distribution, assembly & integration and post-production services.

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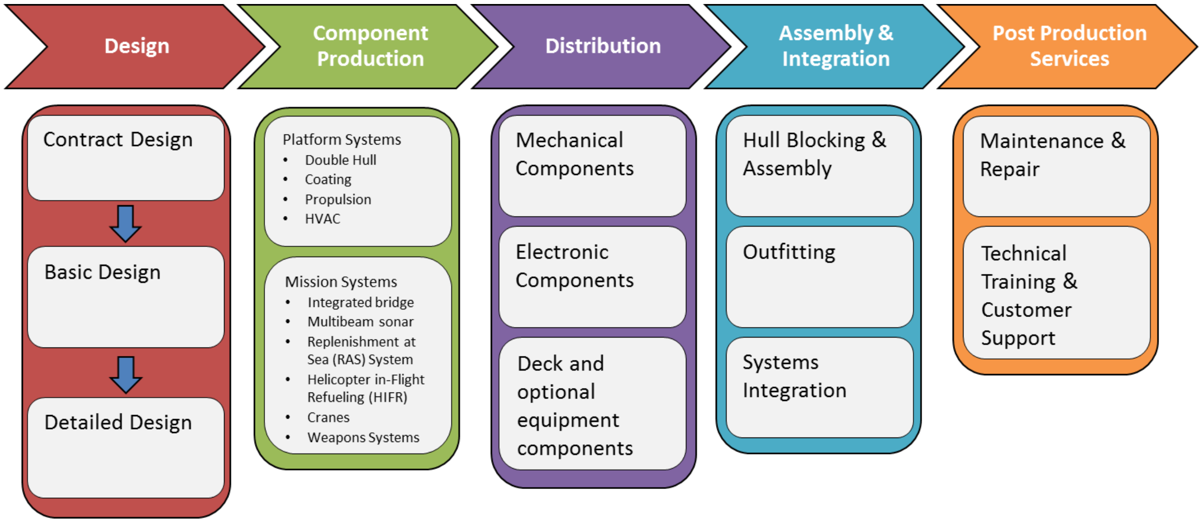
[8] Readers interested in the iterations of the Canadian JSS may refer to Defense Industry Daily's coverage on the project available at http://www.defenseindustrydaily.com/canada-issues-rfp-for-cdn-29b-joint-support-ship-project-updated-02392/, the Canadian Military Journal's archived coverage available at http://www.journal.dnd.ca/vo11/no1/13-shadwick-eng.asp, or Morris & Carran (2007) in citations.

Figure 17: Joint Support Ship Value Chain



Source: Duke CGGC

As shipbuilding has become more modular in recent decades, these firms have moved towards a new business model which emphasizes maintenance or life-cycle support more than direct product sales. This strategy allows equipment suppliers to maintain a longer-term relationship with clients and also allows shipbuilders to transfer liability for expensive systems over to suppliers (Emory's, 2012). Note that for some projects, a major marine equipment supplier may serve as a shipbuilding partner, such as the case of Imtech. While the shipbuilding partners may be seen as lead firms within the context of a particular project or set of projects (by virtue of their control over design specifications and component sourcing), large equipment suppliers act as lead firms within the global market for their particular subsystem (by virtue of their ability to control the production, marketing and repair of complicated technologies that are relatively difficult to codify).

The exact combination of subsystems and components to be found on any given JSS depend on the ship's intended mission. The initial 2006 contract design for the Canadian JSS called for an ambitious array of capabilities including full sealift support, amphibious support to operations onshore, and full roll-on roll-off (RO-RO), and lift-on lift-off (LO-LO) capabilities. However, the government later determined these designs exceeded the budget, and scaled back the range of capabilities for the current design. Therefore, we begin with a summary of the basic components that may be found on most naval support ships (Table 15). Items which are unique or especially important to JSS are listed in bold. Each of these components, of course, is itself composed of smaller components from screws to composite parts to circuit boards.

Table 15: General Components of Joint Support Ships (JSS)

Sub-system	Hull Materials	Navigation Electronics	Comm. Electronics	Platform Systems	Deck Equipment	Weapons Systems
Main Components	**High-strength, high tensile steel**	Gyro compass	Radio	Machinery Plant (prime mover)	**Replenishment at Sea (RAS) system**	**Close-in Weapons System (CIWS)**
	Protective Coating	GPS/ Positioning Heading	Satellite system	Propellers & Shaft	**Helicopter In-Flight Refueling (HIFR)**	12.7 mm (50 Cal) gun
		Navigation software	IT System (LAN)	Bow Thruster	**Winches**	
		Ice-Hazard Radar		Diesel or LNG generator	**Cranes and Booms**	
		Multi-beam Sonar		HVAC	Supplemental craft	
		Doppler speed log		Pollution Control		

Bold indicates unique aspects of the JSS discussed in the chapter

Source: Duke CGGC

The Canadian JSS, with an anticipated completion date of 2018, are once again in the conceptual design phase. Public Works and Government Services Canada (PWGSC) recently awarded contract designs to two firms: ThyssenKrupp Marine Systems (TKMS) along with subsidiary Blohm & Voss Naval, and BMT Fleet Technologies (IDR, 2012). The final detailed JSS design will depend on which contract design the Canadian Government chooses. If TKMS wins, the JSS will closely resemble the 20,240 ton Berlin class, examples of which currently serve in the German Navy. If BMT Fleet Technologies wins, they will continue their work with the RCN to develop a custom design for the ship.

4.2.1. Design

Design work is carried out by engineering and naval architecture firms. The specific components built into the JSS will depend on the range of capabilities established in the final detailed design. Depending on which concept design the government chooses, the naval architect for the JSS will either be ThyssenKrupp Marine Systems or BMT Fleet Technologies.

Joint support ship design must take into account the vessel’s intended mission. Since the detailed design of the ship has not yet been released, the following analysis speaks more broadly to the mission of replenishment vessels and joint support ships in general. To do so, we reviewed characteristics of the two potential designs – the Berlin class vessel and details of a BMT design considered for cost comparisons in the 2006 Canadian JSS design (see Figure 18) – as well as features of similar ships to be built over the coming decade. From this analysis we identified common trends, many of which we can assume will be relevant to the planned Canadian JSS.

The following describes some additional characteristics of joint support ships:

- **Double-hull vessels –** In 1990 the International Maritime Organization (IMO) and U.S. Coast Guard each approved regulations to make the transport of oil safer for the environment. This required that by 2010 all oil replenishment vessels have a double hull (Kimber & Vik, 2006). The double hull helps prevent an oil spill should the vessel have a collision.
- **Replenishment at Sea (RAS) capabilities –** The primary role of JSS is to replenish combat ships with fuel and other supplies. The transfer of goods from the JSS to the combat ship almost always takes place far out to sea and while the vessels are moving. Replenishment at Sea (RAS) systems – a mechanized configuration of masts, winches, cables, pulleys, pipes and – not only make this transfer possible, but also safe and efficient.
- **Helicopter In-Flight Refueling (HIFR) –**Joint support ships may be equipped with HIFR systems to refuel helicopters without having them land on the flight deck in rough seas. The system also enables JSS with limited flight deck space to quickly refuel additional helicopters if the flight deck is full.
- **Health care facilities –** The JSS need to support the personnel, and therefore are equipped with hospital, medical and dental capabilities.
- **Weapons systems –** Though classified as non-combat vessels, the JSS will be equipped with a Close-in Weapons System (CWIS). CWIS are an integrated system of radars, surface-to-air missiles, and automatic ship cannons used primarily for ship defence.

Figure 18: Design features Berlin Class Replenishment Vessel; BMT Aegir – 18R Fleet Support Vessel

	TKMS Berlin Class Replenishment Vessel	BMT Aegir – 18R Fleet Support Vessel
Specification	**Detail**	**Detail**
Crew	237 personnel	175 personnel
Length	173.7m	175 m
Beam	24m	25m
Draft	7.4m	9.2m
Displacement	20,000t	~17,000 t
Propulsion	2 x 7.2MW MAN Diesel 12V 32/40 diesel	2 x 8.7 MW Diesel engine shaft generators
	Single shaft with four-bladed controllable pitch propeller	Dual shaft with two four-bladed controllable pitch propellers
	2 Bow thrusters	1 x 1.5 MW bow thruster
Additional power	4 x 1,200 kW diesel generators	2 x 1.5 MW Auxiliary generators 4 x 500kW Emergency generators
Max Speed	20 knots	17 knots
Endurance	45 days	45 days
Bridge	Integrated bridge	Integrated bridge
Hull	Double hull in accordance with MARPOL	Double hull in accordance with MARPOL
Cargo Capacities	9,600 cubic meters fuel	13,800 cubic meters fuel
	550 cubic meters water	800 cubic meters water
	160t ammunition	1,000 square meters
	280t food; 100t dry stores	8 x 20 ft. refrigerated containers

	TKMS Berlin Class Replenishment Vessel	BMT Aegir – 18R Fleet Support Vessel
Cargo Deployment Systems	Replenishment at Sea (RAS) System	Replenishment at Sea (RAS) System including: • 4 A-beams for F44, F76, FW • 4 A-beams for solids (2 tons) • Stern refueling reel
	Two 24t cranes	1 x 20t Deck crane with 20m outreach
	Helicopter In-flight refueling-capabilities (HIFR)	
Hospital	45 general care beds, 4 intensive care beds	No Details
	Microbiological Laboratory	
Weapons Systems	Stinger surface to air missile	2 x Close-in Weapon System (CIWS)
	Four MLG 27mm auto-cannons	2 x 30 mm Guns
		Decoys
Aircraft Handling System	Flight deck for 2 helicopters	Flight Deck for 1 helicopter
	Hanger facility for embarked helicopters	Aircraft refueling and hangar

Source: BMT Defence Services, 2008; Naval Technology, 2012a

4.2.2. Component Production

Component and subsystem production covers an extremely diverse array of items which comprise the various subsystems of the vessel as well as the hull structure itself. This section of the value chain includes both the production of intermediate components, such as metal fittings, circuit boards and software code, as well as their combination into final components like winches, multi-beam sonars and GPS interfaces. Note, however, that in many cases these firms are not responsible for the distribution of their products to final buyers (in this case, Seaspan and its Tier 1 partners) or for systems integration. This section focuses on production within those subsystems that are most relevant to joint support ships.

The management of the various supply chains that feed into the JSS is being overseen by Seaspan for components relevant to the hull and much of the outfitting, while the systems integrators (Imtech and Thales) are responsible for sourcing high-tech and electronic components and subsystems. Imtech will integrate the platform systems, and Thales will integrate the mission systems.

4.2.2.1. Hull Fabrication

Steel

The hull of a JSS is constructed of the same basic materials as other vessels: steel and coatings. However, because the JSS will be ice-classed vessels (proposed PC5/1st year ice-capable), the steel and coatings used to build the hulls must have unique properties to withstand the severe cold and abrasion. Lloyd's Register and the Atlantic Bureau of Shipbuilders (ABS) certify two Canadian steel mills as capable of manufacturing steel grades suitable for polar class vessels: Essar Steel Algoma in Sault Ste. Marie, ON, and Gerdau Ameristeel in Whitby, ON (ABS, 2012a; Lloyd's Register, 2012) (see Table 16).

Table 16: Canadian Steel Mills Capable of Manufacturing High Strength Steels

Company	Location	Steel
Essar Steel Algoma	Sault Ste. Marie, ON	AH32, AH36, DH32, DH36, EH32, EH36, EH50
Gerdau Amersteel Corporation	Whitby, ON	AH27S, AH32, AH36

Source: Duke CGGC

In addition to traditional hull structures, JSS must have a double hull to help prevent accidental oil spills due to collision. The double hull extends the construction time from roughly 30 months to 40 months, and reduces cargo capacity by approximately 17 percent (U.S. Navy, 2007). The hull separation is slightly less than two meters, and can be restored to carry more fuel in the case of an emergency (U.S. Navy, 2007).

4.2.2.2. Platform System Components

Propulsion System

The propulsion system for any vessel consists of four components: prime movers, transmission systems, propellers, and shafts (Sodhi, 1995). Prime movers are the principal sources of power on joint support ships, and include diesel engines. Transmission systems transmit the energy from the prime mover to the components that propel the vessel: the shaft and propeller. The shafts on ice-classed vessels are larger than average in order to accommodate higher power and torque requirements (Sodhi, 1995). Propellers for the JSS may be either fixed-pitch or controllable-pitch (CCG, 2010).

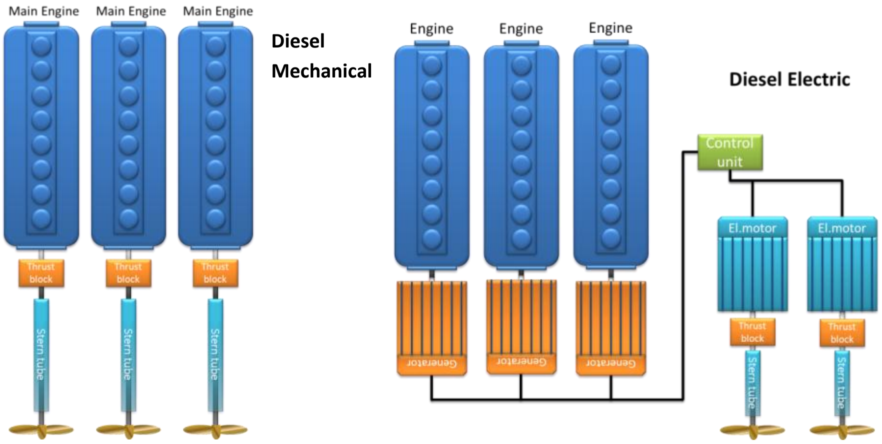
Engine ("Prime Movers")

Diesel engines are the most common prime movers on joint support ships. Diesel-mechanical systems consist of a diesel engine that directly powers the shaft and propeller. Diesel-electric systems change the way the diesel engine transmits power. Instead of directly powering the shaft and propeller, the diesel engine generates electricity for a power plant that fuels electric propulsion motors used to turn the shaft and propeller (Marine Insight, 2011; Patel, 2012). For most of the 20th century diesel-electric systems could not compete with diesel-mechanical. Eventually technological advances in diesel-electric systems improved, particularly in power electronics and motor drives, and made them more cost efficient. Both systems are still used widely on joint support ships.

Transmission Systems

The two types of transmission systems correspond with the propulsion system, and therefore are classified as mechanical and electric (Figure 19). Mechanical transmission systems transmit power from the diesel engine to a the stern of the ship via a shaft. The shaft passes through a gear box that reduces the RPM appropriate for the propellers. Another shorter shaft carries the reduced RPM to the propeller. In electric transmission systems, diesel engines turn turbines at a high RPM to generate electricity. The electricity is carried via cables to switchboards which transmit it to either transformers or frequency converters which isolate the current flow and achieve the proper voltage levels. The electricity then powers electric motors at the stern, which are connected to a shaft and fixed pitch propeller (MAN, 2012). These steps may be consolidated. For example, the electric motors may control the frequency and voltage necessary to turn the shafts and propellers (Patel, 2012).

Figure 19: Types of diesel propulsion systems most commonly used on joint support ships



Source: Shippipedia, 2012

Relevant firms

Firms that manufacture propulsion system components tend to fall in one of three categories of manufacturing capability. They either manufacture primarily diesel engines, primarily electric motors, or they act as entire propulsion system integrators that design and manufacture the entire system from diesel engines through the propellers (see Table 17). Firms that specialize in diesel engines include Caterpillar and Sulzer. TECO Westinghouse and Stadt specialize in electric motor components. Firms that manufacture entire propulsion systems include ABB, GE, MAN Diesel and Turbo, Rolls Royce, and Wartsila.

The Canadian JSS will have a propulsion system with an installed power of between 15 and 20 megawatts (MW). Currently, there are no facilities capable of manufacturing such a system in Canada (Morozewich, 2012). However, three firms that manufacture components of diesel-electric propulsion systems of this capacity have offices with operations in Canada: ABB, TECO Westinghouse, and Wartsila. ABB and TECO Westinghouse manufacture the electric motors. ABB manufactures a family of electric variable speed drives – called ACS 6000 – that range in power from three MW to 27 MW (ABB, 2011). Wartsila manufactures both the diesel motors that generate the electricity, as well as the electric motors.

Returning to the two likely JSS designs as a reference, we know the Berlin class replenishment vessel is powered by two 7.2MW engines manufactured by MAN Diesel & Turbo (Blohm + Voss Naval, 2012). The BMT Aegir class family offers designs for both diesel and diesel-electric systems, though the manufacturer details of such systems have not been released. The Canadian JSS is likely to be a diesel system, not diesel-electric (Hanlon, 2013).

Table 17: Propulsion firms

Propulsion Component	Manufacturing Firms	Manufacturing Locations
Diesel Engines/Generators	Caterpillar Sulzer	Germany Switzerland
Electric Motors	Stadt TECO Westinghouse	Norway U.S.A
Full Propulsion System Integrators	ABB G.E. MAN Diesel and Turbo Rolls Royce Wartsila	Switzerland U.S.A. Germany U.S.A.; U.K. Finland; China

Source: Duke CGGC

Auxiliary systems

Replenishment at Sea (RAS): The primary role of JSS is to replenish combat ships with fuel and other supplies. The JSS will have a RAS system which allows the vessel to easily transfer liquid and solid supplies to and from the other combat vessel. The underway RAS system is a mechanized configuration of masts, winches, cables, pulleys, pipes, and containers that are controlled by an operations console mounted above the deck. The system can move liquids such as fuel and potable water, and solids such as food, ammunitions and crew (see Figure 20). Hepburn Engineering (Ontario) manufactures a range of underway RAS systems, and has outfitted several vessels in the Royal Canadian Navy with these systems. The RAS system for the Berlin class vessels was supplied by Bosch Rexroth Naval Systems (Netherlands). Rolls Royce Marine (U.K., Singapore) also produces underway RAS systems.

Figure 20: Underway Replenishment at Sea (RAS) Systems

Source: Naval Technology, 2012b

Helicopter In-Flight Refueling (HIFR): The HFIR is a system of aerial refueling in which fuel is supplied to a hovering helicopter, typically through its cabin. HFIR systems are necessary when a ship is not equipped for landing helicopters. Emco Wheaton (US, with manufacturing in Ontario) and HeliFuel (Norway) provide HFIR systems to naval and coast guard customers.

Health Care facilities: The JSS may have hospital facilities ranging from 40-100 beds, depending on the final design. Suppliers of hospital equipment suited for the marine environment will provide the equipment necessary.

Table 18: Auxiliary System Manufacturers

Auxiliary System	Manufacturer	Location
Replenishment at Sea	Hepburn Engineering Bosch Rexroth Naval Systems Rolls Royce Marine	Ontario, Canada Netherlands U.K./Singapore
Helicopter In-Flight Refueling	Emco Wheaton HeliFuel	U.S.A Norway
Indal Technologies	Mississauga, ON	Helicopter haul-down systems

Source: Duke CGGC

4.2.2.3. Mission system components

Joint support ships require much of the same mission system components that other offshore vessels use. Navigation equipment such as radar and GPS, and communication equipment such as satellite phones, multi-purpose transceivers, and satellite internet will all be present on the JSS. Table 19 lists some of the relevant mission and electronic component suppliers for systems proposed for the JSS.

Table 19: Mission system component suppliers on JSS

Company	Location	Mission Systems
General Dynamics	Ottawa, ON Calgary, AB Dartmouth, NS	Passive and active sonars Acoustic processors Multi-function consoles CIWS
IBM	Markham, ON	Data links Computer systems
Kongsberg Mesotech	Port Coquitlam, BC	Multi beam sonar
L-3 Communications	U.S. (marine division)	Integrated bridge system software
Marport C-Tech	St. John's, NL	Multi beam sonar
Raytheon	Ottawa, ON Waterloo, ON Midland, ON Calgary, AB	Integrated bridge systems CIWS
Rutter Technologies	St. John's, NL	Sigma 6 radar (ice classification)
Thales Canada	Saint-Laurent, QC Ottawa, ON Quebec, QC Kingston, ON Burnaby, BC	Sonars Radars Radios C4IS CIWS

Source: Duke CGGC

C4IS and weapons system

C4IS: The C4IS sensor suite for the JSS will likely be provided by the mission systems integrator, Thales. The layout for the system may follow either the traditional sensor layout or use the "integrated mast" concept developed by Thales Netherlands and used by the Royal Netherlands Navy in its *Karel Doorman class* support ship and its *Holland class* offshore patrol vessels (GlobalSecurity, 2012).

The integrated mast is a design approach in which one central structure houses radar, optronic, and communication sensors and antennas, in addition to display cabinets and computer peripherals. The advantages of the integrated mast sensor concept are better operational performance, higher operational availability, reduced ship-building time, reduced maintenance requirements and reduced below-deck space requirements. Thales Netherland's I-Mast 400, consists of a SeaMaster 400 SMILE air warning radar, a SeaWatcher 100 active phased-array surface detection and tracking radar, and the GateKeeper infra-red/electro-optical (EO) warning system. With these systems, the ship is able to monitor 140 nautical miles using an Integrated Sensor and Communication Systems (ISCS), also developed by Thales Nederland (GlobalSecurity, 2012). Although the integrated mast is a complex system, Thales Nederland provides it for the Royal Netherlands Navy *Karel Doorman class* support ship.

Figure 21: MK-15 Phalanx (US) CIWS

Source: Global Security, 2012b

<u>Weapon system</u>: Though classified as non-combat vessels, proposed designs for the JSS include a Close-In-Weapon System (CIWS, pronounced "sea-whiz"). A gun-based CIWS is a combination of radars, computers, and large caliber automatic ship cannons. A variety of gun-based CIWS exist, including General Dynamics/Raytheon's MK15 Phalanx system, illustrated in Figure 21 above, and Thales' "Goalkeeper." Both systems can provide protection against modern, supersonic low flying anti-ship missiles. The Phalanx system can incorporate a missile-based system known as the RIM-116 Rolling Airframe Missile (RAM). The combination of the Phalanx and RAM, called SEARAM, provides defence against anti-ship missiles. Thales' Goalkeeper system will be used by the Netherlands on the *Karel Doorman class* joint support ship. A 2012 announcement by the Dutch Ministry of Defence stated that the Goalkeeper system will receive upgrades to its radar, mechanical systems, and tracking system to better counter anti-ship missiles and swarm attacks, extending its operational life to at least 2025 (Janes Defense, 2012).

4.2.2.4. Outfit & furnishings

Deck machinery

The JSS likely will have cranes capable of lifting 15-30 tonnes of cargo. Ship-to-shore cranes are manufactured by a number of producers, including Rolls-Royce Marine and Wartsila.

Coatings

Plating on modern icebreakers is painted with a protective coating that prevents corrosion, reduces friction, and facilitates icebreaking. There are six coatings commonly used to reduce friction on polar icebreaker hulls: Bitumastic, Epoxy, Polyethylene, Polyurethane, Teflon, and Teflon-filled polyurethane. Epoxy and polyurethane have been the most effective at reducing friction and enduring abrasion (SSC, 2011; Tawil, 2002). Table 20 lists the manufacturers of coatings approved for application on ice-classed vessels, including the JSS.

Table 20: Industry-approved Manufacturers of Hull Paints for Ice-classed Vessels

Company	HQ Location	Hull Coating
AzkoNobel/International Paint	UK	Intershield 163 Inerta 160
Chugoku Marine Paints Ltd.	Japan The Netherlands China Korea	Permax 1000 HB Permax 3000 S
Jotun Paints Ltd.	UK	MARATHON IQ
PPG Coatings SPRL/BVBA	Belgium China	SigmaShield 460 SigmaShield 1200
Sigma Samsung Coatings	Korea	SigmaShield 460
Subsea Industries NV	Belgium	Ecospeed

Source: Duke CGGC

4.2.3. Component Distribution

As shipbuilding has become increasingly modular, the major equipment suppliers have gained control over the distribution (as well as the maintenance and post-production services) of the major subsystems such as propulsion, electronic equipment and deck equipment. These “turnkey” equipment suppliers provide their product as a full package, which can then be “plugged in” or integrated into the final craft with minimal hassle or liability to the shipyard. This distribution arrangement is beneficial to the lead equipment suppliers, as they are able to realize greater economies of scope and scale. Shipyards benefit, as they can wait until vessels are nearly complete before installing and integrating the subsystem, thus minimizing liabilities during the construction phase.

4.2.4. Assembly and Integration

Hull Blocking and Assembly: Modern shipbuilding follows a modular production method. That is, hull blocks are constructed independently from one another before being assembled into the structure of the final craft. This allows the shipbuilder to construct hulls more quickly and to work on multiple projects at one time.

Outfitting: Once the hull is assembled, it must be outfitted with electrical equipment, deck equipment, other mission-specific equipment, supplemental craft and amenities for crew and medical staff.

Systems Integration: As with the construction of all large vessels, systems integration is an important and high-value-added activity for research vessels. As joint support ships have become more sophisticated, the role of the integrator has grown increasingly important. Not only must subcomponents within each of the various systems “talk” to one another, but increasingly subcomponents from distinct systems must be able to communicate as well. For example, in order to function properly the dynamic positioning feature of the navigation system must communicate seamlessly with both the electrical system and the propulsion system. For this reason, the role of the tier one integrators cannot be understated. The increased complexity of systems integration has created a trend to purchase entire systems packages from large vertically integrated companies such as Rolls Royce and Wartsila. Previously a shipbuilder might try to reduce costs by purchasing individual pieces of equipment and subsystems separately from dozens of different manufacturers. But the risk of incompatibility among those many systems is becoming prohibitively high. This risk grows with the life of the ship. After a year in service, a dynamic positioning system malfunction could be attributed to the system itself, or the electrical system or the propulsion system. There is much less risk that distinct complex systems will not communicate properly if a firm has already designed and proven effective an entire system package. It also ensures that the owner has only one company to call for in-service support, should something malfunction later in the life of the vessel. Owners are willing to pay a premium of between five and ten percent to avert this risk.

4.2.5. Post-Production Services

Once the JSS is finally delivered to the client, there remain a number of post-production activities that enhance the value that the ship owner derives from the ship. These include maintenance and repair operations on the hull and ship subsystems as well as technical training for and customer support for the operators of the vessel. The project’s 30 year in-service support contract will be completed as a separate contract, and is anticipated to being completed once the JSS project has entered the project implementation phase, currently scheduled for March 2014 (TBS, 2012a). The work will be carried out by DND, Seaspan, a tier one integrator, or specialized ISS/ILS contractor.

5. Polar Icebreaker

Prepared by Shawn Stokes

This chapter focuses on the value chain for the Canadian Polar Icebreaker. The first section of the chapter will describe the general purpose and characteristics of icebreakers, and an overview of the polar icebreaker called for under the NSPS. The second section examines the value chain for the icebreaker, a description of the proposed systems and subsystems unique to the vessel, and firms likely to supply them. The third section of the chapter investigates Nova Scotia's position in the value chain for the icebreaker, and describes the strengths, weaknesses, opportunities, and threats for Nova Scotia in the polar icebreaker value chain.

5.1. Ship Purposes and Characteristics

Polar Icebreakers are ships designed for the sole purpose of moving through ice-covered waters. Unlike regular ships, icebreakers can move through layers of ice up to nine feet thick (Madrigal, 2012). They are smaller than traditional cargo ships, measuring approximately 200 - 500 feet long, and capable of 100-200 personnel (McCarthy, 2009). For a ship to be considered an icebreaker, it must have three features: a reinforced hull, an ice-clearing shape, and the power to push through the ice (AMSA, 2009). The strengthened double hulls require a specialized steel to crush ice and withstand extremely low temperatures (Ward, 2001). Instead of a normal V-shaped bow, icebreaker bows are rounded and spoon-shaped (Madrigal, 2012). While this facilitates icebreaking, it is a poor design for the open sea, which is why traditional polar icebreakers lack stability when out of their intended element (Blaine, 2011; Juurmaa et al., 2001). The largest class of polar icebreakers, sometimes called "heavy", typically require more than 45,000 break horsepower (BPH), or 34 megawatts (MW), to push them through the ice (O'Rourke, 2012).

Figure 22: Notional View of the Canadian Polar Icebreaker

Source: Canadian Coast Guard, 2012b (CCG, 2012b)

Figure 22 illustrates the notional view of the Canadian Polar Icebreaker. The purpose of the Canadian Icebreaker is to deliver Government of Canada programs in the Arctic and to support programs with modular mission payload. To achieve this purpose, the Icebreaker will be capable of unrestricted autonomous operations in the Canadian Arctic and adjacent waters for nine months of the year, typically May – January (CCG, 2012b). The geographical range of operations is defined as the Canadian EEZ plus the continental shelf, and can include regions as far north as the North Pole, to the south and west as far as Bering Straits, and to the east the area around Greenland. The Icebreaker will be designed to break first year and multiyear ice up to 2.5m thick, capable of safely over-wintering, and capable of occasional transit of tropical waters. These capabilities will require a specially designed hull (PC2) and winterized equipment to protect machinery and personnel from the cold. Additional specifications for the Canadian Icebreaker are provided in Table 21.

To move through ice, icebreakers use their weight and the laws of physics. When the vessel rides its rounded bow up on top of the ice, it pushes the stern deeper into the water. Buoyancy then pushes the stern back up, creating extra leverage that forces the weight of the bow down onto the sheets of ice. The bow breaks the ice and pushes it out to the side away from the propellers (Gordon, 2012; Madrigal, 2012). When moving through sheets of ice, polar icebreakers can create wide navigation channels up to three times their width so that other larger boats may pass (Madrigal, 2012).

The size of a polar icebreaker is defined by its length, beam, depth, and draft. The beam is the width of the ship at its widest point, the depth is the distance between the keel and the deck, and the draft is the depth of the keel below the waterline (Mulherin et al., 1994). The length of polar icebreakers ranges from 40 meters to 156 meters (McCarthy, 2009; Sodhi, 1995). The other dimensions are often measured in ratios to the length of the ship. The mean length to beam ratio for polar icebreakers 40-140 meters ranges from 3.6 to 4.6. The depth and draft ratios are 8.9-8.2 and 11.4-12.2, respectively (Sodhi, 1995).

Table 21: Icebreaker overview

Type of Vessel	Canadian Polar Icebreaker
Purchaser	Canadian Coast Guard
Shipyard	Vancouver Shipyards, Inc., Vancouver
Shipbuilder	Seaspan Marine Corporation
Designer	STX Canada Marine
Launch year	2017
Length	120-140m
Displacement	16,000 tons
Accommodations	100 (60 crew, 40 mission personnel)
Endurance	270 days
Speed	18 knots maximum / 3 knots icebreaking
Installed power	40-50 MW
Propulsion	Diesel electric with azimuthing and single bow thrusters

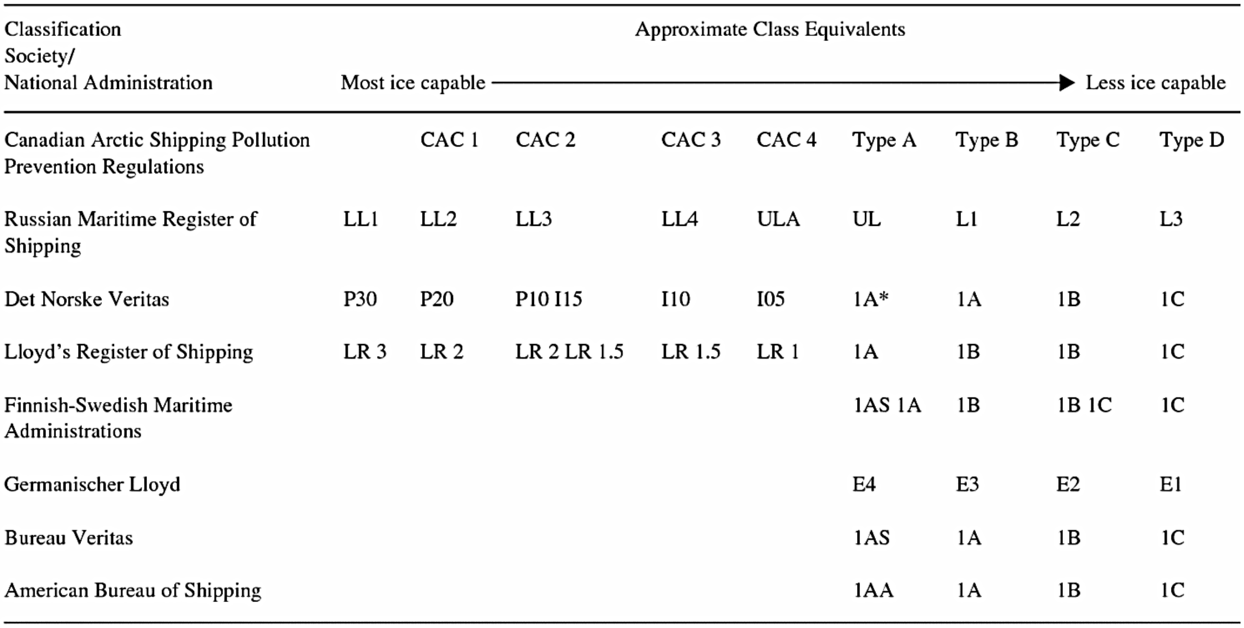
Source: Canadian Coast Guard, 2012b (CCG, 2012b)

Constraints inherent to the locations and conditions in which icebreakers work determine their size. For example, ships intended for the Arctic Northern Sea Route (NSR) may have a maximum draft of 12.5 meters and a capacity of 50,000 dead weight tons (DWT), much smaller than vessels that use the deeper Suez or Panama Canal routes (Moe & Jensen, 2010). The specific operating objectives will also determine the dimensions of the ship. For example, Russian polar icebreakers are often used as escorts for other ships, and therefore tend to have a wider beam than those operated by other countries (Mulherin et al., 1994).

Polar icebreakers provide a variety of services. They are used to escort vessels through frozen shipping channels, provide sealift services to remote communities, explore hard-to-reach oil and gas reserves, aid in search and rescue missions, facilitate scientific research, and transport tourists (CCG, 2012a; Doyle, 1990; Revkin, 2008). Demand for icebreakers is projected to grow as rising temperatures cause polar ice to recede and open up more navigable passages in the Arctic (Kaste, 2011).

It is difficult to know the exact number of polar icebreakers in the global fleet, as definitions of icebreaking vessels vary (see Table 22). The most comprehensive list of all icebreaking vessels catalogs more than 115 operating globally under the ownership of 17 countries (Riska, 2011). However, many of these are smaller vessels that operate in rivers and lakes, as opposed to just those capable of traversing the Polar Regions. The U.S. Coast Guard currently has 77 icebreakers capable of operating in Polar Regions (USCG, 2012). Russia owns far more than any other country. It is the only country with nuclear-powered icebreakers – of which it currently owns six – and also owns the largest polar icebreaker, 50 Years Since Victory (Bukharin, 2006). Completed in 2007, the 25,000 ton vessel is 160 meters long and powered by a 49 MW nuclear reactor (McCarthy, 2009; Riska, 2011). Other countries with noteworthy polar icebreaker fleets include Finland, Canada, Sweden, and the United States (Riska, 2011; USCG, 2012).

Table 22: Various Icebreaker Class Systems Used Around the World



Classification Society/ National Administration	Approximate Class Equivalents								
	Most ice capable →								Less ice capable
Canadian Arctic Shipping Pollution Prevention Regulations		CAC 1	CAC 2	CAC 3	CAC 4	Type A	Type B	Type C	Type D
Russian Maritime Register of Shipping	LL1	LL2	LL3	LL4	ULA	UL	L1	L2	L3
Det Norske Veritas	P30	P20	P10 I15	I10	I05	1A*	1A	1B	1C
Lloyd's Register of Shipping	LR 3	LR 2	LR 2 LR 1.5	LR 1.5	LR 1	1A	1B	1B	1C
Finnish-Swedish Maritime Administrations						1AS 1A	1B	1B 1C	1C
Germanischer Lloyd						E4	E3	E2	E1
Bureau Veritas						1AS	1A	1B	1C
American Bureau of Shipping						1AA	1A	1B	1C

Source: National Research Council, 2007

Icebreaking technology has evolved considerably since the first paddlewheel-driven river icebreakers of the 1830s (Sodhi, 1995). Because polar icebreakers are very expensive to build and have operating lives of several decades, icebreaker technology evolved slowly over time, though at times in great leaps. Russia developed the first polar icebreaker, Yermak, in 1899 (Lockerby, 2011). Since then Canada, Finland, Germany, Japan, Russia, and the United States have significantly advanced icebreaker technology. Icebreakers fall under the same six classification societies as other marine vessels, as well as three national sets of rules – Canadian, Finnish-Swedish, and Russian – established to regulate navigation in ice- covered waters (Sodhi, 1995). The most fundamental set of classifications is the polar class notation established by the International Association of Classification Societies (IACS) (see Table 23). These classifications influence many aspects of the ship design, including factors such as steel grade, steel plate thickness, hull strengthening, corrosion protection, output power, shaft size, and propeller type (IACS, 2011). The proposed Canadian Icebreaker will be a PC2.

Table 23: IACS Polar Class Notations

Polar Class	Ice Description (based on WMO Sea Ice Nomenclature)
PC 1	Year-round operation in all Polar waters
PC 2	Year-round operation in moderate multi-year ice conditions. *(proposed ice-class for Canadian Polar Icebreaker)*
PC 3	Year-round operation in second-year ice which may include multi-year ice inclusions
PC 4	Year-round operation in thick first-year ice which may include old ice inclusions
PC 5	Year-round operation in medium first-year ice which may include old ice inclusions
PC 6	Summer/autumn operation in medium first-year ice which may include old ice inclusions
PC 7	Summer/autumn operation in thin first-year ice which may include old ice inclusions

Source: IACS, 2011

The Polar Icebreaker, with an anticipated completion date of 2017, is currently in the detailed design phase (CCG, 2012b). Preliminary project approval was granted in 2009, vessel construction is to occur from Fall 2015-Summer 2017, with a vessel delivery target date in Fall 2017. (Please see Table 24.) However, changes in the preliminary production schedule already are emerging. A May, 2012 presentation by Brian Carter, President of Seaspan Shipyards notes a production begin date for the Polar Icebreaker around 2018 (Carter, 2012).

Table 24: Polar Icebreaker – preliminary project schedule

MILESTONE	DATE
Preliminary Project Approval	Sep-09 (completed Jun-09)
Complete Conceptual Design Work	Jan-11 (completed Feb-11)
Completion of Design/ Delivery of Construction Specification	Oct-13
Effective Project Approval	Fall 2013
Award Construction Contract	Spring 2014
Production Engineering and Materials Procurement	Spring 2014 - Fall 2017
Vessel Construction	Fall 2015 - Summer 2017
Vessel Delivery	Fall 2017

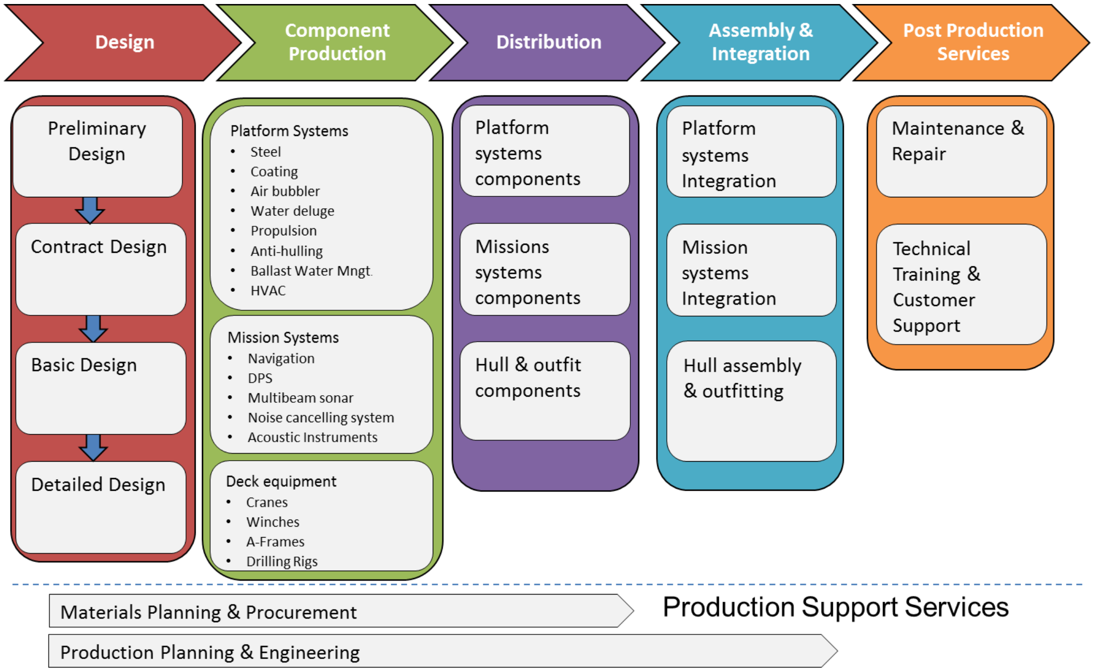
Source: CCG, 2012b

5.2. Icebreaker Value Chain

The value chain for the Polar Icebreaker is found in Figure 23. Polar icebreakers, like other large, modern surface vessels, are built according to a modular production system, in which a small number of lead firms – the shipbuilder, a design team, and a small handful of systems integrators – control the design, construction and outfitting of the ship through the collaborative management a long, geographically disparate and complicated supply chain. These firms are the shipbuilding partners. For the Canadian polar icebreaker, the shipbuilding partners are: Seaspan/Vancouver Shipyards (shipyard), Imtech (high-tech systems integrator), Thales (electronics systems integrator), STX Canada Marine Inc. (design and engineering), Computer Sciences Canada, Inc. (logistics and business services). Together, these firms manage the Polar Icebreaker production projects.

Below the shipbuilding partners for any given project are a small number of marine equipment suppliers who control the systems integration of particular subsystems. These firms do not see a shipbuilding project through from conception to completion, as the shipbuilding partners might, but rather serve as systems integrators for complex systems. Typically, one firm will serve as the integrator for platform systems, and another will manage the mission specific systems. Platform systems include components such as propulsion, electrical, and hotel services (dining, medical facilities, etc.), and mission specific systems consist of components such as command and control, navigation, underwater acoustics, and deck equipment.

Figure 23: Polar Icebreaker Value Chain



Source: Duke CGGC

As shipbuilding has become more modular in recent decades, these firms have moved towards a new business model which emphasizes maintenance or life-cycle support more than direct product sales.

This strategy allows equipment suppliers to maintain a longer-term relationship with clients and also allows shipbuilders to transfer liability for expensive systems over to suppliers (Ecorys, 2012). Note that for some projects, a major marine equipment supplier may serve as a shipbuilding partner, such as the case of Imtech. Whereas the shipbuilding partners may be seen as lead firms within the context of a particular project or set of projects (by virtue of their control over design specifications and component sourcing), large equipment suppliers act as lead firms within the global market for their particular subsystem (by virtue of their ability to control the production, marketing and repair of complicated technologies that are relatively difficult to codify).

Since the detailed design of the ship has not yet been released the following analysis speaks more broadly of icebreakers in general. To do so, we studied trends in icebreakers built over the last ten years, older icebreakers that were retrofitted with upgrades, and perhaps most important, designs for new icebreakers that will be built over the next decade. Table 25 lists the countries and consortiums with plans to build polar icebreakers in the coming decade, along with the basic details of ship design.

Table 25: Planned Icebreakers 2013-2017

Ship	Owner	Design	Features	Year
Aurora Borealis	European Science Foundation	199m Traditional hull Icebreaking: 2.5m Research Vessel	81MW Diesel-electric Crew capacity: 120 Two moon pools Industrial Drilling Rig	N/A
N/A	China	120m Double-acting hull Icebreaking: 1.5m Research Vessel	Aker Arctic design Crew capacity: 90	2014
Vitus Bering/Aleksey Chirikov	Sovkomflot (Russian shipping company)	99m Traditional hull Icebreaking: 1.7m Multipurpose Vessel	18MW Diesel-electric Oil/Gas Supply for Exxon Rescue capacity for 195 Firefighting capability	2013
N/A	Russia	146m Double-acting hull Icebreaking: 2m Multipurpose Vessel	25MW Diesel-electric	2015
LK-60	Russia	173m Traditional hull Icebreaking: 3m Multipurpose Vessel	60MW Nuclear Beam: 34m Crew capacity: 38	2017
N/A	U.S.A.	N/A	N/A	N/A

Source: Duke CGGC

From our analysis of current icebreakers we identified common trends, many of which we can assume will be relevant to the planned Canadian polar icebreaker. Table 26 presents a summary of the main components that may be found on most polar icebreakers. Items which are unique or especially important to polar icebreakers are listed in bold. Each of these components, of course, is itself composed of smaller components from screws to composite parts to circuit boards. As discussed in further detail below, the exact combination of subsystems and components to be found on any given icebreaker depend on the ship's intended mission.

Table 26: Summary of Components Commonly Found on Polar Icebreakers

	Hull Materials	Navigation Electronics	Comm. Electronics	Electrical Equipment	Propulsion System	Deck Equipment	Lab Space
Main Components	**High-strength, high tensile steel**	Gyro compass	Radio	Diesel or LNG generator	**Machinery Plant (prime mover)**	Winches	Wet Lab
	Protective Coating	GPS & Navigation software	Satellite system	Switchboard	Propellers/ shaft/Bow Thruster	Cranes and Booms	Chemical Lab
	Water Deluge System	**Ice-hazard Radar**	IT System (LAN)	Wiring	**Water desalination plant**	A-Frame	Hydrology Lab
	Hull Bubbler System	Dynamic Positioning System			**Pollution Control**	Ground Tackle	Computer Lab
		Doppler speed log			**Coring drill**	Supplemental craft	Refrigerator
		Multi-beam sonar			**Anti-rolling** **Anti-hulling**	Trawling Net	Storage Equipment
		UAVs (Drones)			HVAC		Staging Bay

Source: Duke CGGC (**Bolded** indicates components that are especially relevant to icebreakers.)

5.2.1. Design

Design work is carried out by engineering and naval architecture firms. Naval architect STX Canada Marine will lead the icebreaker design team. Another design firm, Aker Arctic, will provide support in assessment of ice loads, development of the hull form and structure, propulsion conceptual design and description s of winterization principles (Aker Arctic, 2012). Together these firms will use the Canadian Coast Guard's conceptual design to develop a comprehensive design for the shipbuilder, Seaspan Vancouver Shipyards. This process is expected to take between 18 and 24 months to complete (Aker Arctic, 2012).

Polar icebreaker design must take into account the vessel's intended mission, which depends largely on if the vessel is nationally-owned or privately-owned. Modern nationally-owned icebreakers are used to protect national sovereignty, conduct research, clear channels for navigation, and are often designed to carry out a combination of all three objectives. Privately-owned icebreakers are most often commissioned by oil and gas companies, and are used to explore and extract resources. Nationally-owned icebreakers used for research will optimize the ability of the vessel to collect record and analyze a variety of types of data. In terms of vessel arrangement, this implies plenty of laboratory space and, generally, a trawl deck. During the design phase, the naval architect must also decide whether to include a drop keel for the data-gathering devices. Drop keels can be raised into the hull of the ship or lowered several meters below the keel in order to mitigate the effects of undersea noise. Characteristics of subsystems that are not directly related to the structure of the hull structure itself must also be incorporated into design considerations. For example, naval architects must define characteristics of the vessel propulsion systems in order to minimize unwanted noise while also generating enough power to overcome drag from trawling nets.

The following describes additional characteristics of research polar icebreakers:

- Laboratory spaces: polar icebreaker research vessels contain laboratories for the collection and analysis of scientific data. A given research vessel may have several labs, each of which is equipped with an array of sophisticated measurement devices and analytical equipment, from centrifuges to salinometers to computers uploaded with specialized software packages. Again, the precise set of laboratories that are included within a given vessel design will depend on the mission of the craft. Types of laboratories which may be found on research icebreakers include: wet labs, chemistry laboratories, hydrological laboratories and computer labs for the analysis and storage of data. In addition, research vessels may contain refrigeration equipment for the storage of specimens that are to be brought back to shore for further study. Finally, research vessels sometimes include staging bays (or moon pools), which are used to launch ROVs, deploy divers, pass ship-based drilling equipment, or deploy drilling rigs.
- Core Sampling: The Polar Icebreaker, like other modern research icebreakers, will have the capability to drill down into the ocean floor to take sediment samples of several meters in length. Considerable space has been reserved on the starboard side of the Polar Icebreaker for a piston corer.
- Trawling Deck: Trawling decks are home to the nets and the mechanical deck equipment (winches and A-frames or gantries) which are used in trawling operations to gather aquatic specimen, such as fish or plankton, for on-board study. The trawling deck is a feature common to most polar icebreaker research vessels.

5.2.1.1. Trends in design

As global warming thins Arctic ice and provides new opportunities for navigation in the Polar Regions, naval architects are quickly evolving the design of polar icebreakers. The following section describes some of these design trends, including double acting ships, multipurpose vessels, specialized vessels, noise management, and pollution management (see Table 27).

Table 27: Summary of Recent Icebreaker Design Trends

Design Trend	Description	Advantages
Double Acting Ships	• Use 360-degree rotating aziumuthing propellers to move forward and backward • Have a traditional V-shaped bow capable of running ahead in open water, and a rounded stern capable of breaking ice astern	• Solves the problem of instability and poor performance in open water • Eliminates the need for anti-rolling ballast systems
Multipurpose Vessels	• Vessels designed with capability to carry out several missions • One ship may be able to clear navigation channels in ice, conduct geological research, execute deep water offshore drilling, and protect national sovereignty	• National owners can achieve multiple objectives with one vessel • Consolidate capital and human resources into one vessel instead of three or four
Specialized Vessels	• Vessels designed to carry out one specific mission. Examples include: • Icebreaker with rounded side to clear 40 m wide navigation channels	• Less expensive than traditional icebreakers • Provide solutions to private sector challenges and ambitions

Design Trend	Description	Advantages
	• Deep water drilling vessel for resource exploration and extraction • Liquid Natural Gas (LNG) transport vessel	
Noise Management	• Borrowing techniques from cruise liners, designs use sound dampening materials and consider strategic placement of engines • Fitting acoustic devices to a drop keel brings them below interference from hull noise and air bubbles	• Improved research and data collection • Facilitates improved data collection while ship is in motion
Pollution Management	• New (and pending) regulations for operating in the Arctic will require new technologies • Emissions reductions in nitrogen oxides (NOx), sulfur oxides (SOx), and particulate matter (PM) require catalytic converters • Improved ballast water management will require ballast water is treated with approved system before being discharged	• Cleaner Arctic environment with reduced introduction of greenhouse gasses in the polar regions • Safer marine environment with less risk of introducing invasive non-native species • Tremendous market opportunity for systems integrators in the shipbuilding industry

Source: Duke CGGC

- Double-acting ships: The latest trend in propeller choice, the azimuthing thruster, or azipod, has revolutionized icebreaking technology and solved the problem of poor performance in open water. Capable of rotating 360 degrees around a vertical axis, Azipod propellers have allowed the creation of double acting ships – icebreakers that have a traditional bow capable of running ahead in open water, and a rounded stern capable of breaking ice astern (see Figure 24) (Juurmaa et al., 2001). As of 2008, fifteen icebreakers had been fitted with azimuthing thrusters, and several more are under construction (ABB, 2008b). The icebreakers most likely to use azimuthing thrusters are vessels that will spend a considerable time outside of the polar regions, and therefore want the stability a traditional hull offers in open sea. However, modern icebreakers that will be located almost exclusively in the polar regions, such as the one proposed in the NSPS, find fixed-pitch propellers with an icebreaking hull to be the optimal design.

Figure 24: Double-acting Icebreakers: Astern on ice (left) and forward in open water (right)

Source: Juurmaa et al., 2001

- Multipurpose vessels: As modular systems have increasingly come to define the design and construction of polar icebreakers and other ships, there have been several new vessels which combine some research functions (especially surveying and hydrological data collection) with other missions. For example, the proposed 200 meter-long, ERI *Aurora Borealis*, to be operated by the European Science Foundation, combines the functions of an icebreaker, drilling platform and research vessel within one ship (Alfred Wegner Institute 2012). Another example, the 134 meter-long South African Polar Supply and Research Vessel, which was delivered this year, will be capable of serving as an icebreaker, research vessel, expedition vessel, supply vessel and cruise ship (Wingren 2012). The very high capital and time costs required to build an icebreaker may be a factor driving this trend, as owners want to maximize their investment by increasing the vessel's utility.

- Specialized vessels: Just as there is a trend toward multipurpose icebreakers, there is also a trend toward highly specialized polar icebreakers. Aker Arctic has a concept for an icebreaker designed to clear 40 meter-wide navigation channels through ice, thus accomplishing a feat that now requires two traditional icebreakers (see Figure 25). The vessel uses rotating azimuthing thrusters to push the ship sideways and break ice with its rounded side (Wilkman, 2006). Aker Arctic is also designing icebreakers especially for the purpose of exploring and extracting resources from the Arctic. They have designs for heavy duty icebreaking drilling rigs and liquid natural gas (LNG) carriers to safely transport LNG back from the Arctic (Wilkman, 2006).

Figure 25: Sideways channel-clearing Icebreaker concept

Source: Aker Arctic Technology

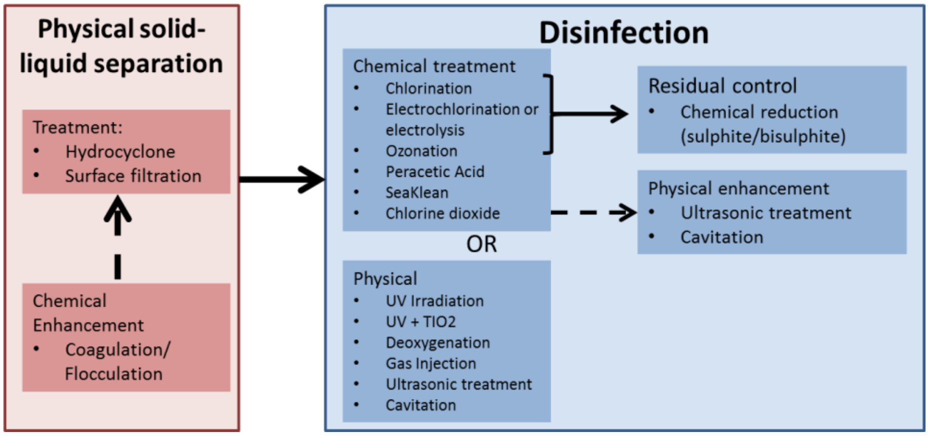
- Noise management: Since acoustic equipment is generally in-use at all hours of the day, ambient internal noise can interfere with the collection of data and must therefore be minimized and controlled. While much of the work of addressing underwater noise targets the propulsion system, aspects of the design process can also help to reduce unwanted acoustic interference. Such design approaches use techniques borrowed from cruise liners, since such vessels are arranged and equipped so that passenger noise is naturally acoustically dampened and include the use of sound-dampening materials and ship designs which arrange noisy rooms (such as the mess hall or recreational areas) in such a way that ambient noise is less likely to interfere with acoustic sensing devices (NOC 2012).

Placing acoustic instrumentation on a drop keel, especially large, low-frequency transceivers, provides several advantages over the traditional approach of fitting them to the bottom of the hull itself (NOC 2012). By fitting devices to a drop keel, the crew can keep them safely below bubble streams which run across the hull when the ship is in motion. This reduces interference when the ship is in motion. Drop keels also make it possible to maintain, replace, or switch out transducers, without the need for divers or dry-docking the ship. The drop keel also allows the delicate acoustic transducers to be withdrawn into the hull when the ship is breaking ice to protect them.

- Pollution management: Organizations such as the European Union (EU), Environmental Protection Agency (EPA) and International Maritime Organization (IMO) recently passed regulations for vessels that operate in the Arctic, and further regulations are being developed. Some regulations will restrict the amount of nitrogen oxides (NOx), sulfur oxides (SOx), and particulate matter (PM) allowed to be emitted from vessels (EPA, 2010; EU, 2010; Jensen, 2007). As a result, new icebreaker designs call for additional equipment such as catalytic converters, and existing vessels are undergoing upgrades to adhere to the new guidelines (Marinelog, 2011). Other designs include additional emission-reducing liquid natural gas (LNG) generators to power the ship's electrical system (IMR, 2009).

Other significant regulations include an international effort to reduce the spread of invasive marine species through improved ballast water management (BWM) (IMO, 2011). It is estimated that international compliance to these new regulations will spur investments of US$34.1 billion dollars in upgrades over the next decade (Royan, 2010). To prepare for this market opportunity, 55 firms have developed various types of BWM systems, all of which use a two-step process (see Figure 27). First, the ballast water must be filtered to remove solids from the ballast water. Then the water is disinfected with either a chemical treatment such as chlorination or ozonation, or with a physical treatment such as UV irradiation or deoxygenation (Lloyd's Register, 2011a).

Figure 26: Two-step Process of Ballast Water Treatment and Management



Source: Duke CGGC, based on Lloyd's Register, 2011a

5.2.2. Component Production

Component and subsystem production covers an extremely diverse array of items which comprise the various subsystems of the vessel as well as the hull structure itself. This section of the value chain includes both the production of intermediate components, such as metal fittings, circuit boards and software code, as well as their combination into final components like winches, multi-beam sonars and GPS interfaces. Note, however, that in many cases these firms are not responsible for the distribution of their products to final buyers (in this case, Seaspan and its Tier 1 partners) or for systems integration. This section focuses on production within those subsystems that are most relevant to polar icebreakers.

The management of the various supply chains that feed into the polar icebreaker is being overseen by Seaspan for components relevant to the hull and much of the outfitting, while the systems integrators (Imtech and Thales) are responsible for sourcing high-tech and electronic components and subsystems. Imtech will integrate the platform systems, and Thales will integrate the mission systems.

5.2.2.1. Hull fabrication

The hull of a polar icebreaker is constructed of the same basic materials as other vessels: steel and coatings. However, because icebreakers operate in conditions far more extreme than other vessels, the steel and coatings used to build icebreaker hulls must have unique properties to withstand the severe cold and constant abrasion. In addition to traditional hull structures, some icebreakers incorporate auxiliary devices into the hull, such as air bubbler systems and water deluge systems that facilitate icebreaking.

Steel

The structure of a polar icebreaker consists almost entirely of steel. There are three steel components critical to a reliable icebreaker hull: plating, framing, and welding (Sodhi, 1995). After the selection of steel, welding is the most important component for a reliable structure, as it must withstand corrosion from seawater and stresses from cargo, waves and ice (Mulherin et al., 1994). Because 95 percent of all defects originate in welding zones, the importance of highly skilled welders cannot be understated (Sodhi, 1995). Plating contributes the most weight to a polar icebreaker. Engineers can reduce the weight of the vessel by thinning the plates and increasing the framing, but this increases fabrication costs (Sodhi, 1995). The framing supports the plating and resists loads by bending. Inspections show that the supporting frames are damaged far more often than the hull plating (Sodhi, 1995).

Vessels built before the mid-1970s were made with normal shipbuilding steel. Since then shipbuilders use newly-developed pliable and corrosion-resistant steels with a high yield point to better tolerate extreme cold and constant abrasion (PAME, 2010). The International Association of Classification Societies (IACS) has established two sets of regulations for classes of steel required for polar class vessels (see Table 28 and Table 29). The first is based on the anticipated range of temperature in which the vessel will operate. The second is based on the anticipated exposure areas of the ship will have to cold and abrasion. Areas of the vessel subjected to the least exposure (e.g. plating on cargo holds) require material class one, and those subjected to the most exposure (e.g. bow) require material class two or three (IACS, 2011). The overlap can lead to inefficient results, such as requiring higher steel grades for some non-safety components than for the hull itself (SSC, 2011).

Table 28: IACS Steel Grade Requirements, by Temperature

	-20/-25C		-26/-35C		-36/-45C		-46/-55C	
Plate Thickness t [mm]	**MS**	**HT**	**MS**	**HT**	**MS**	**HT**	**MS**	**HT**
t ≤ 10	A	AH	B	AH	D	DH	D	DH
10 < t ≤ 15	B	AH	D	DH	D	DH	D	DH
15 < t ≤ 20	B	AH	D	DH	D	DH	E	EH
20 < t ≤ 25	D	DH	D	DH	D	DH	E	EH
25 < t ≤ 30	D	DH	D	DH	E	EH	E	EH
30 < t ≤ 35	D	DH	D	DH	E	EH	E	EH
35 < t ≤ 45	D	DH	E	EH	E	EH	Ө	FH
45 < t ≤ 50	E	EH	E	EH	Ө	FH	Ө	FH

Source: IACS, 2011

Table 29: IACS Steel Grade Requirements, by Material Class

	Material Class I				Material Class II				Material Class III					
	PC 1-5		**PC 6&7**		**PC1-5**		**PC 6&7**		**PC 1-3**		**PC 4&5**		**PC 6&7**	
Plate Thickness t [mm]	**MS**	**HT**	**MS**	**HT**	**MS**	**HT**	**MS**	**HT**	**MS**	**HT**	**MS**	**HT**	**MS**	**HT**
t≤10	B	AH	B	AH	B	AH	B	AH	E	EH	E	EH	B	AH
10 < t ≤ 15	B	AH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
15 < t ≤ 20	D	DH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
20 < t ≤ 25	D	DH	B	AH	D	DH	B	AH	E	EH	E	EH	D	DH
25 < t ≤ 30	D	DH	B	AH	E	EH2	D	DH	E	EH	E	EH	E	EH
30 < t ≤ 35	D	DH	B	AH	E	EH	D	DH	E	EH	E	EH	E	EH
35 < t ≤ 40	D	DH	D	DH	E	EH	D	DH	F	FH	E	EH	E	EH
40 < t ≤ 45	E	EH	D	EH	E	EH	D	DH	F	FH	E	EH	E	EH
45 < t ≤ 50	E	EH	D	DH	E	EH	D	DH	F	FH	F	FH	E	EH

Source: IACS, 2011

The most demanding design specifications require high strength, high tensile (HT) steel. Lloyd's Register and the Atlantic Bureau of Shipbuilders (ABS) certify two Canadian steel mills as capable of manufacturing steel grades suitable for polar class vessels: Essar Steel Algoma in Sault Ste. Marie, ON, and Gerdau Ameristeel in Whitby, ON (ABS, 2012a; Lloyd's Register, 2012a). Though design specifications for the Canadian polar icebreaker are not finalized, preliminary discussions with industry leaders suggest enhanced-grade capabilities will require high-strength high-tensile EH50 or equivalent grade steel (Stenta, 2012). See Table 26 for a list of Lloyd's certified steel mills capable of manufacturing EH 50 grade steel. The Canadian steel mills do not have the capacity to manufacture this grade of steel. However, representatives from Essar Steel Algoma stated they would develop the capacity to produce EH50 if the design calls for it (Stenta, 2012).

Table 30: Steel Mills Capable of Manufacturing High Strength Steels

Company	Location**	Steel
Essar Steel Algoma	Canada (ON)	AH32, AH36, DH32, DH36, EH32, EH36, EH50*
Gerdau Amersteel Corporation	Canada (ON)	AH27S, AH32, AH36
Industeel	Belgium	High Strength/High Tensile Steel (EH 50 or higher)
JFE Steel Corporation	Japan	High Strength/High Tensile Steel (EH 50 or higher)
Kobe Steel Co	Japan	High Strength/High Tensile Steel (EH 50 or higher)
Nippon Steel Co	Japan	High Strength/High Tensile Steel (EH 50 or higher)
SSAB EMEA AB	Sweden	High Strength/High Tensile Steel (EH 50 or higher)

Source: Lloyd's Register, 2012a

* Will develop EH50 capacity with IRB offset investments

**Representatives from leading shipbuilders noted Chinese steel lacks consistency and reliability. Therefore Chinese steel mills are not included

Coatings

Plating on modern icebreakers is painted with a protective coating that prevents corrosion, reduces friction, and facilitates icebreaking. There are six coatings commonly used to reduce friction on polar icebreaker hulls: Bitumastic, Epoxy, Polyethylene, Polyurethane, Teflon, and Teflon-filled polyurethane. Epoxy and polyurethane have been the most effective at reducing friction and enduring abrasion (SSC, 2011; Tawil, 2002). In addition to simply providing protection, there are several other factors shipbuilders must consider when selecting the optimal hull coating:

- Be smooth
- Not inhibit the possibility of repairs after installation
- Have good wear resistance
- Application method must be practicable in yard construction
- Have good bond strength with the base material
- Applicable on a large scale
- Give good corrosion protection for the base material
- Should have antifouling properties (with limits of environmental issues)
- Sustain high normal pressures
- Be reasonably priced
- Withstand the deformations of the base material
- Maintain its properties in the arctic environment
- Withstand low temperatures, temperature changes and temperature gradients (SSC, 2011)

Lloyd's Register recognizes only six firms that manufacture hull coatings suitable for ice class vessels: AkzoNobel/International Paint, PPG Coatings, Sigma Samsung Coatings, Chugoku Paints, Jotun Paints, and Subsea Industries (Lloyd's Register, 2012b). (Please see Table 31.) AkzoNobel/International Paint Eastern Canada is the only Lloyd's Register-approved coating manufacturer with a location in Canada. They manufacture the Inertia 160, an abrasion resistant epoxy, low in volatile organic compounds (VOC), designed for ice going vessels in temperatures as low as minus 50 degrees Celsius (Kramer, 2009). It has been applied on many icebreakers, including the *Canadian Coast Guard Ship (CCGS), Des Groseilliers (Kramer, 2009).* Subsea Industries recently developed a coating called Ecospeed that has been applied to a few recently-built icebreakers. It is a non-toxic "Surface Treated Composite (STC) consisting of a high volume of glass platelets in a vinyl ester resin" (Maritime Executive, 2011; World Maritime News, 2011). It is designed to be a more durable coating than traditional paints, as it is flexible and adheres to the natural movements of the hull. Unlike traditional hull protective paints, its application does not require highly specialized equipment or a specific temperature zone (Maritime Executive, 2011).

Table 31: Industry-approved Manufacturers of Hull Paints for Polar Class Vessels

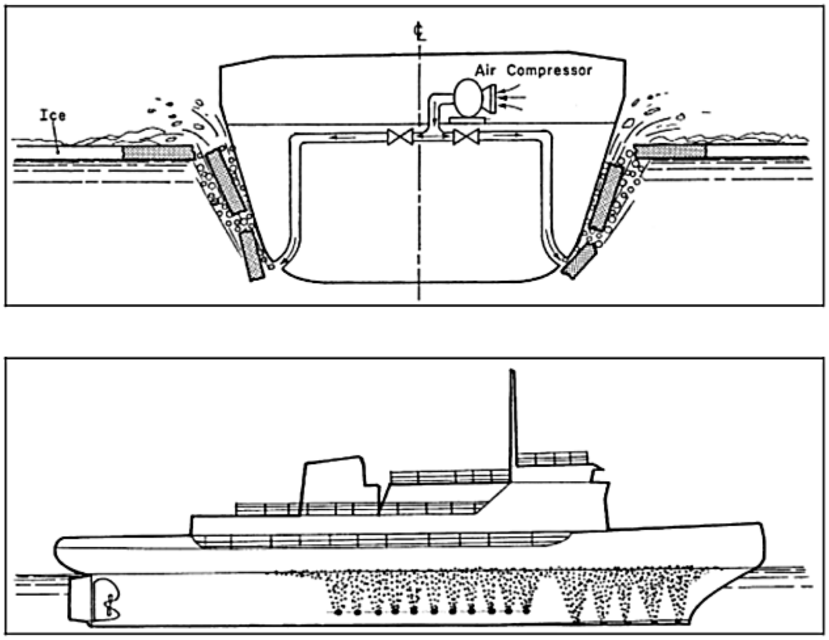
Company	HQ Location	Hull Coating
AkzoNobel/International Paint	UK; Canada (NS)	Intershield 163 Inerta 160
Chugoku Marine Paints Ltd.	Japan The Netherlands China Korea	Permax 1000 HB Permax 3000 S
Jotun Paints Ltd.	UK	MARATHON IQ
PPG Coatings SPRL/BVBA	Belgium China	SigmaShield 460 SigmaShield 1200
Sigma Samsung Coatings	Korea	SigmaShield 460
Subsea Industries NV	Belgium	Ecospeed

Source: Duke CGGC

Hull bubbler systems

Hull bubbler systems reduce friction from ice by creating a continuous thin layer of air and water between the hull and the ice. (Please see Figure 27.) Air compressors force air through small nozzles below the waterline on the ship's sides. The air bubbles rise up through the water and lubricate the surface of the ship below and above the waterline (CCG, 2010b). Wartsila manufactured the first systems, which were installed on Baltic icebreakers in the 1970s (CCG, 2010b). Air bubbler systems have been proven effective, and been installed on a number of polar icebreakers including the CCGS Henry Larsen, CCGS Sir Humphrey Gilbert, and USCGC Mobile Bay (Quinton & Lau, 2006). Ship designers are now considering air bubbler systems to achieve other objectives. Aker Arctic is installing them as noise reduction barriers on new ice class research vessels (Aker Arctic, 2007). Mitsubishi recently developed a hull bubbler system, though rather than used to break ice, it is intended to increase fuel efficiency by up to six percent (Quick, 2012).

Figure 27: Hull Bubbler System



Source: Tawil, 2002

Water wash systems

Water wash systems – also referred to as hull deluge systems – spray water over the ice from nozzles on the bow above the waterline. (Please see Figure 28.) This floods the ice ahead of the vessel, removes the snow and creates a lubricating surface between the hull and ice (CCG, 2010b). The icebreakers USCGS Healy and Swedish Oden have water wash system to help them break ice (Berkson & DuPree, 1998; SWEDARP, 2008). In many cases, such as the USCGS Healy, the bow thrusters may be designed so that they may rotate to serve as a water wash system (Berkson & DuPree, 1998).

Figure 28: Hull Water Wash System

Source: Kamome, 2009

Table 32: Leading Manufacturers of Hull Bubbler and Hull Water Wash Systems

Company	HQ Location	Hull Equipment
Wartsila	Finland	WABS (Wartsila Air Bubbler System)
Kamome Propellers	Japan	Hull Water Wash System
Mitsubishi Heavy Industries	Japan	MALS (Mitsubishi Air Lubricating System)

Source: Duke CGGC

5.2.2.2. Platform systems

There are four platform system components unique to the polar icebreaker value chain: propulsion system, anti-roll and anti-hull devices, desalination plants, and HVAC.

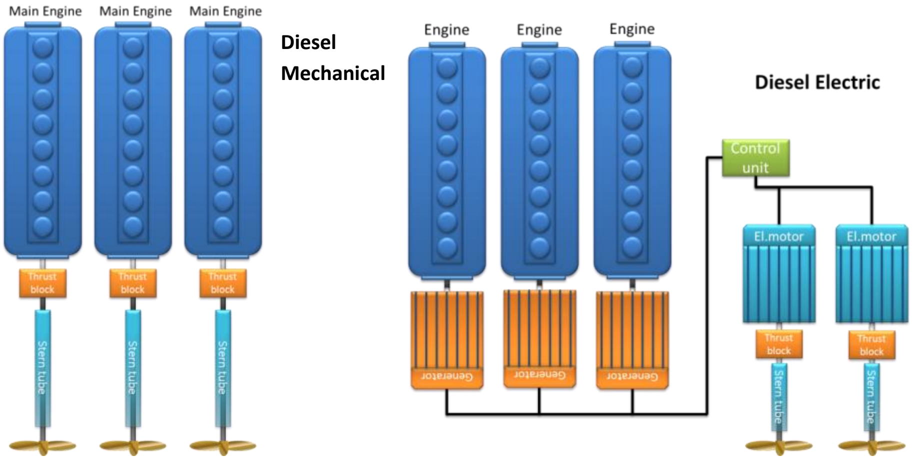
5.2.2.2.1. Propulsion System

The propulsion system for any vessel consists of four components: prime movers, transmission systems, propellers, and shafts (Sodhi, 1995). Prime movers are the principal sources of power on icebreakers, and include diesel engines, gas turbines, and nuclear-powered steam turbines. (CCG, 2010a). Transmission systems transmit the energy from the prime mover to the components that propel the vessel: the shaft and propeller. The shafts on icebreakers are larger than average in order to accommodate higher power and torque requirements (Sodhi, 1995). Icebreaker propellers may be either fixed-pitch or controllable-pitch (CCG, 2010a). Propulsion systems for icebreakers should be capable of rapid and frequent variation of power and direction (ABS, 2012b).

Prime Movers

There are three prime mover types: nuclear, diesel, and liquid natural gas. Of these, diesel engines are the most commonly used on icebreakers, and can be classified as either diesel-mechanical or diesel-electric (CCG, 2010a). Diesel-mechanical systems consist of a diesel engine that directly powers the shaft and propeller. Diesel-electric systems change the way the diesel engine transmits power. Instead of directly powering the shaft and propeller, the diesel engine generates electricity for a power plant that fuels electric propulsion motors used to turn the shaft and propeller (Marine Insight, 2011; Patel, 2012). For most of the 20th century diesel-electric systems could not compete with diesel-mechanical. Eventually technological advances in diesel-electric systems improved, particularly in power electronics and motor drives, and made them more cost efficient. Moreover, modern diesel-electric systems have numerous advantages for icebreakers that require frequent changes in speed and direction (Patel, 2012). As such, they have been the system of choice for icebreakers since the 1980s (Adnanes, 2003; Patel, 2012).

Figure 29: Types of diesel propulsion systems most commonly used on icebreakers

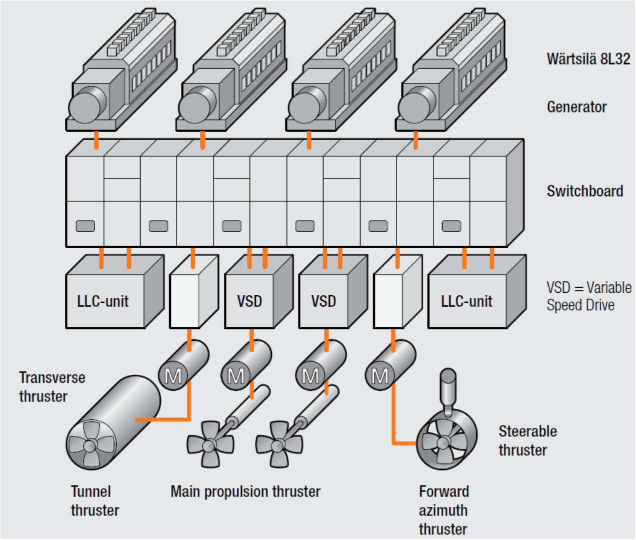


Source: Shippipedia, 2012

Transmission Systems

The two types of transmission systems correspond with the propulstion system, and therefore are classified as mechanical and electric. Mechanical transmission systems transmit power from the diesel engine to a the stern of the ship via a shaft. The shaft passes through a gear box that reduces the RPM appropriate for the propellers. Another shorter shaft carries the reduced RPM to the propeller. In electric transmission systems, diesel engines turn generators at a high RPM to generate electricity. The electricity is carried via cables to switchboards which transmit it to either transformers or frequency converters which isolate the current flow and achieve the proper voltage levels. The electricity then powers electric motors at the stern, which are connected to a shaft and fixed pitch propeller (MAN, 2012). These steps may be consolidated. For example, the electric motors may control the frequency and voltage necessary to turn the shafts and propellers (Patel, 2012).

Figure 30: Diesel–electric propulsion systems with electric transmission components



Source: Wartsila, 2012

Shafting

Icebreakers require large shafts – between 380 and 980 mm – to withstand the engine power necessary to break through ice, and are designed so that the propeller should fail before the shaft (Sodhi, 1995). They are generally made of forged carbon steel, though at times low alloy steel forgings are used, yielding substantial reductions in weight.

Propellers

Traditionally, both fixed-pitch and controllable-pitch propellers have been installed on polar icebreakers, along with side thrusters for increased maneuverability (Adnanes et al., 1997; Sodhi, 1995). Non-reversing transmission systems such as those with diesel-mechanical propulsion use controllable-pitch propellers, and reversing diesel-electric-propelled vessels use fixed pitch propellers. There are three things to consider when designing an icebreaker propeller: selection of material, loads and strength requirements, and effects of nozzles (Sodhi, 1995).

Icebreaker propellers are most commonly made of stainless steel or bronze. Propeller loads are determined by how the propellers engage with ice, an event classified as either milling or impact. Ice milling occurs when large chunks of ice get wedged between the propeller and the hull. This puts tremendous pressure on the propeller and can be very damaging. Ice impact is more common and occurs when smaller chunks of ice pass through the propeller and are thrusted out radially (Sodhi, 1995). To withstand this interaction with ice, especially ice milling, propellers are often fitted with nozzles that act as a protective collar against the largest blocks of ice. However, they are often clogged with ice, in which case a swift reversal of thrust is necessary to expell it (ABS, 2012b). Propeller nozzles also provide the additional benefit of added thrust, and therefore also reduce the ships strength requirments.

Finally, small propulsion systems called thrusters are installed on the sides of the icebreaker bow and stern. Thrusters help maneuver and position the vessel in difficult ice-packed environments, and when the vessel is operating the dynamic positioning (DP) system, keep the icebreaker in a stationary position (Ward, 2001). Sometimes rotating thrusters installed on the bow of the icebreaker can double as a hull washing system. Leading manufacturers of bow thruster systems include ABB, Wartsila, Rolls Royce, and Brunvoll.

Relevant firms

Firms that manufacture propulsion system components tend to fall in one of three categories of manufacturing capability. They either manufacture primarily diesel engines, primarily electric motors, or they act as entire propulsion system integrators that design and manufacture the entire system from diesel engines through the propellers (see Table 33). Firms that specialize in diesel engines include Caterpillar and Sulzer. TECO Westinghouse and Stadt specialize in electric motor components. Firms that manufacture entire propulsion systems include ABB, GE, MAN Diesel and Turbo, Rolls Royce, and Wartsila.

The Canadian polar icebreaker will have a fully integrated diesel-electric propulsion system with an installed power of between 40 and 50 megawatts (MW) (CCG, 2012b). Currently, there are no facilities capable of manufacturing such a system in Canada (Morozewich, 2012). However, three firms that manufacture components of diesel-electric propulsion systems of this capacity have offices with operations in Canada: ABB, TECO Westinghouse, and Wartsila. ABB and TECO Westinghouse manufacture the electric motors. ABB manufactures a family of electric variable speed drives – called ACS 6000 – that range in power from three MW to 27 MW (ABB, 2011). They have been installed on icebreakers such as the USCGS Mackinaw, and the double acting Finish icebreakers, Tempura and Mastera (ABB, 2008a, 2011). TECO Westinghouse manufactured the electric propulsion system for the icebreaker USCGS Healy (Thompson, 2010). Wartsila manufactures both the diesel motors that generate the electricity, as well as the electric motors. The propulsion system for the icebreaker CCGS Henry Larsen is a Wartsila-built system (Lundquist, 2011).

Table 33: Propulsion firms

Propulsion Component	Manufacturing Firms	Manufacturing Locations
Diesel Engines/Generators	Caterpillar Sulzer	Germany Switzerland
Electric Motors	Stadt TECO Westinghouse	Norway U.S.A
Full Propulsion System Integrators	ABB G.E. MAN Diesel and Turbo Rolls Royce Wartsila	Switzerland U.S.A. Germany U.S.A.; U.K. Finland; China

Source: Duke CGGC

5.2.2.2.2. Auxiliary systems

Ballast – Heeling and Anti-rolling systems: Heeling systems induce the rolling motion of the ship. To do so, a system of ballasts and pumps located on each side of the ship move water back and forth to rock the boat. Heeling systems are used to facilitate the stern-to-bow rocking motion icebreakers use to break ice (Mulherin et al., 1994). They also help free icebreakers when the vessels become stuck in ice. Anti-rolling systems are similar to heeling systems, but used when the icebreaker is in open sea. Instead of inducing movement, anti-rolling systems counter the movement of the open sea and stabilize the rounded-bow vessel when it rolls back and forth. Leading firms that manufacture heeling and anti-rolling systems include Frank Mohn AS (FRAMO), Hoppe Bordmesstechnik, Rolls Royce, and Vega Americas. Table 34 lists companies producing anti-rolling, desalination plants and HVAC.

Table 34: Significant Auxiliary Systems on Polar Icebreaker

Company	HQ Location	Below Deck Component
	Heeling/Anti-Rolling Systems	
Flume	U.S.A.	HEEL-AWAY Anti-heeling System
Frank Mohn AS	Norway	FRAMO Anti-heeling System
Hoppe Bordmesstechnik	Germany	MOCON ART Anti-heeling System
Rolls Royce	U.S.A. U.K.	Rolls Royce Anti-heeling System Parametric Roll Prevention System (IPRP)
Vega Americas	U.S.A.	Vega Anti-heeling System

Company	HQ Location	Below Deck Component
Water Desalination Plants		
FCI Watermakers	U.S.A.	Reverse Osmosis Desalination Plant
Lifestream	U.S.A.	Reverse Osmosis Desalination Plant
Racor Village Marine Tech	U.S.A.	Reverse Osmosis Desalination Plant
Water Standard	U.S.A.	Reverse Osmosis Desalination Plant
Heating, Ventilation and Air Conditioning		
Bronswerk Marine	Canada	HVAC
Aircraft		
Aeryon Labs Inc	Waterloo, ON	Drones

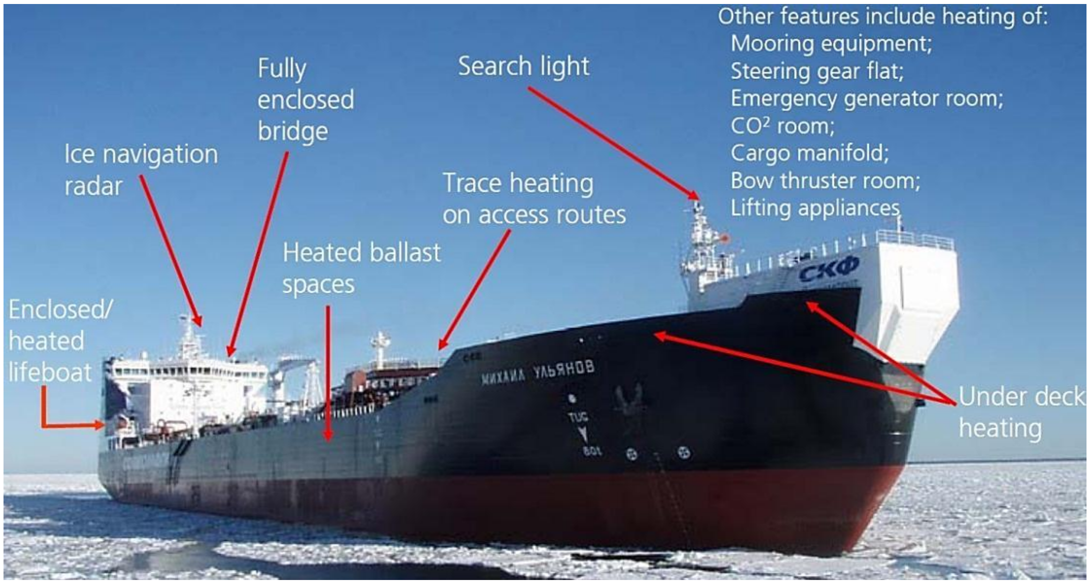
Source: Duke CGGC

Desalination Plants: Polar icebreakers travel to some of the most remote and hostile areas of the world, and often do not return to restock provisions for months at a time. To supply fresh potable water for dozens of crew members and scientists, Icebreakers use massive on-board reverse osmosis desalination plants. Ship designers must ensure proper measures to guarantee seamless production of fresh water. Reverse osmosis systems are susceptible to low temperatures and require preheating arrangements. The tanks should be strategically placed away from the vessel's sides to prevent freezing. Fresh water pipes must be insulated and heat traced with heating elements, and pipes exposed to freezing temperatures must be fitted with drain cocks, or valves, at the lowest point of the piping arrangement (ABS, 2010). Lifestream, a U.S.- based firm recently equipped the icebreaker USCGS Polar Star with a new desalination plant capable of producing almost 40 cubic meters of freshwater a day (Lifestream Watersystems, 2011). Other firms that provide desalination plants include FCI Watermakers, Village Marine Tech (VMT), and Water Standard.

Heating Ventilation and Air Conditioning (HVAC): An important but often overlooked subcomponent of polar icebreakers is the heating, ventilation and air conditioning (HVAC) system. The system must be able to heat accommodations to at least 20 degrees Celsius at the minimum anticipated temperature (MAT) the vessel will encounter, and humidity must be kept between 30 and 70 percent (ABS, 2010). Beyond below-deck accommodations, there are further requirements for many other parts of the ship (see Figure 31). In addition to the enclosed bridge, deck machinery operating rooms must be heated to at least 20 degrees Celsius (ABS, 2010). All electric motors on deck must be equipped with anti-condensation heaters. De-icing and heat tracing coils must be installed along areas of the deck mandated by Fire Safety Systems Requirements (ABS, 2010). Ballast tanks on vessels with service design less than minus 30 degrees Celsius require steam or thermal oil heating coils (ABS, 2010).

Bronswerk Marine is a Canadian firm likely to install the heating system on the Canadian polar icebreaker. In anticipation of the ships to be built at ISI, the firm has expanded to open an additional facility in Nova Scotia. Representatives from Bronswerk noted they are taking actions to position themselves as the HVAC supplier for the ships built at Seaspan Shipyards in Vancouver.

Figure 31: Multiple areas of Icebreaker that require heating



Source: Lloyd's Register, 2011.

<u>Auxiliary vessels:</u> Polar icebreakers include several supplemental craft, including arctic survey boats and rescue boats. Icebreakers with research capabilities may use ROVs and AUVs to carry additional underwater instrumentation to gather scientific data.

<u>Unmanned Aerial Vehicles (Drones)</u>: Polar icebreakers may soon use video-capable drones for additional navigation assistance. The technology was recently used in January 2012 on the icebreaker USCGS *Healy* as it assisted with a fuel delivery to Nome, Alaska. Manufactured by Waterloo, Ontario-based Aeryon Labs Inc., the 2.5 pound drone flew ahead of the vessel and sent video images to provide an aerial view of the ice ahead (Aeryon Labs, 2012; Madrigal, 2012).

5.2.2.3. Mission systems

Polar icebreakers require many of the same mission systems that other offshore vessels use. Navigation equipment such as radar and GPS, and communication equipment such as satellite phones, multi-purpose transceivers, and satellite internet are all present on icebreakers. However, ice hazard radar may improve how icebreakers navigate through ice. Table 35 lists some of the relevant electronic component firms for icebreakers.

Table 35: Significant Mission Systems Found on Polar Icebreakers

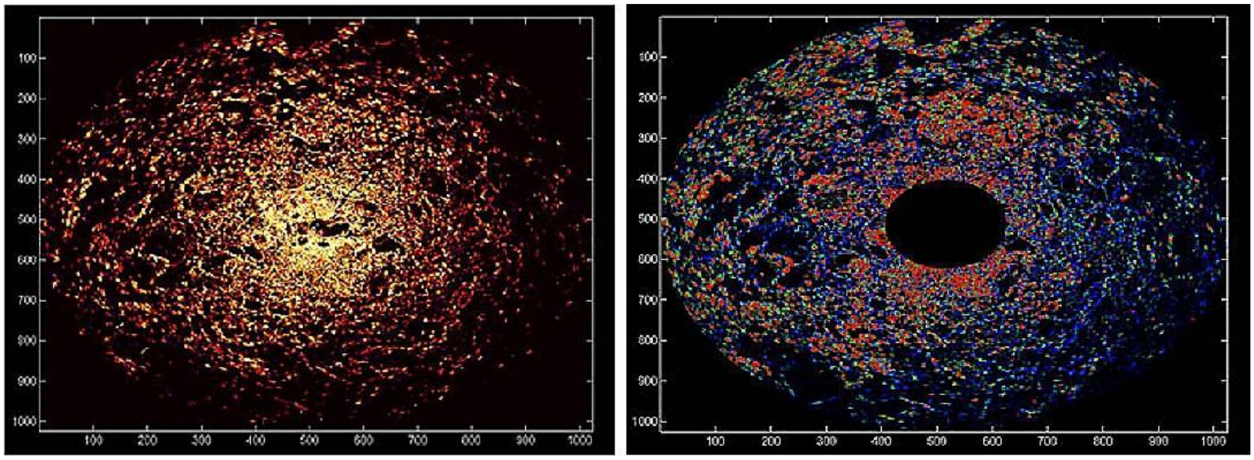
Company	Location	Mission system component
IBM	Markham, ON	Data links Computer systems
Indal Technologies	Mississauga, ON	Helicopter haul-down systems
Knudsen Engineering	Perth, ON	Echo sounders
Kongsberg Mesotech	Port Coquitlam, BC	Multi beam sonar

Company	Location	Mission system component
L-3 Communications	U.S. (marine business)	Integrated bridge system software
Marport C-Tech	St. John's, NL	Fish monitoring sensors Multi beam sonar
Raytheon	Ottawa, ON Waterloo, ON Midland, ON Calgary, AB	Integrated bridge systems
Rutter Technologies	St. John's, NL	Sigma 6 radar Ice hazard radar
Thales Canada	Saint-Laurent, QC Ottawa, ON Quebec, QC Toronto, ON Kingston, ON Burnaby, BC	Sonars Radars Radios

Source: Duke CGGC

Ice Hazard Radar: Ice hazard radar is a cross-polarized high-speed marine radar system that allows the simultaneous collection of both horizontal and vertical radar polarizations (see Figure 32). This produces high resolution images of ice, and provides a clear contrast between dangerous multi-year ice and other sea ice. The technology is being developed by a joint effort with the Canadian Coast Guard Icebreaking Program and Rutter Inc., and received financial support from Transport Canada (TC) and the Program of Energy Research and Development (PERD) through the Canadian Hydraulics Centre (CHC) of the National Research Council (O'Connell, 2011).

Figure 32: Standard Marine Radar v. Cross-Polarized (Ice Hazard) Radar



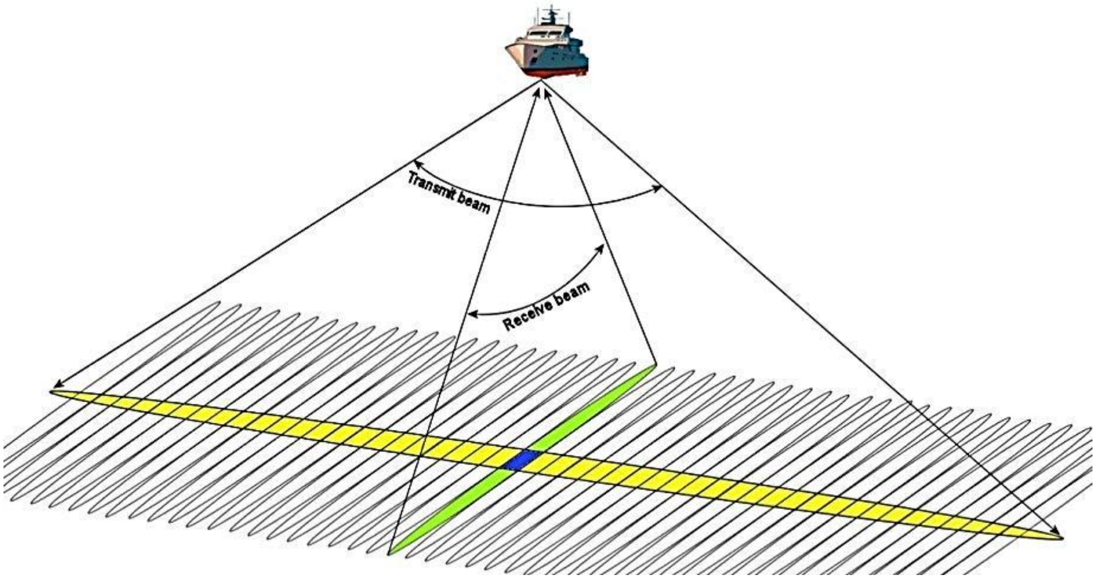
Note: Picture on left is by standard marine radar, illustrating no differentiation between first-year and multi-year ice. Picture on right is by cross-polarized radar, where red areas indicate hazardous multi-year ice.
Source: O'Connell, 2011

Additional Electronic Equipment for Research Icebreakers

Polar icebreakers intended for research carry a wide variety of technologies onboard in order in order to gather scientific data. Acoustic devices, including multi-beam sonar, side-scan sonars, sub-bottom profilers and towed arrays, use sonar technology to survey fish populations and identify items on the ocean floor. CTD (conductivity, temperature and depth) devices gather information about water conditions via a series of instruments and samplers which are connected to the boat via a data-transmitting cable leading to a CTD winch. In addition to these data-gathering devices, research vessels contain computers and digital interfaces for the recording, integration and analysis of digitally gathered data, wet and dry laboratory space for chemical and biological research, and freezers for the storage of specimen.

- Acoustic sampling equipment: Acoustic sampling devices, such as fish-finding sonar equipment, are sensors which use sonar technology to detect and quantify fish and other marine organisms. An acoustic transducer sends out a focused pulse of sound. When this sound wave meets an object, such as a fish or the ocean floor, some of it is reflected back to the research vessel where it is detected by a profiler and coded by a data management system. Acoustic sampling techniques have become popular in research vessel design because, unlike trawling, this data collection strategy does not involve disturbing fish populations. As mentioned above, precise acoustic sampling requires the dampening of underwater noise, so that the sound waves emitted by the propulsion system do not interfere with those projected by the acoustic sampling equipment.
- Multi-beam Sonar: Another device used widely on icebreaking research vessels is the multi-beam sonar, a device critical to mapping the undersea floor. Unlike a traditional echo sounder, multi-beam sonar can plot hundreds of points in a line perpendicular to the vessel with each ping (see Figure 33).

Figure 33: Multi-beam Sonar



Source: AML Oceanographic, 2012.

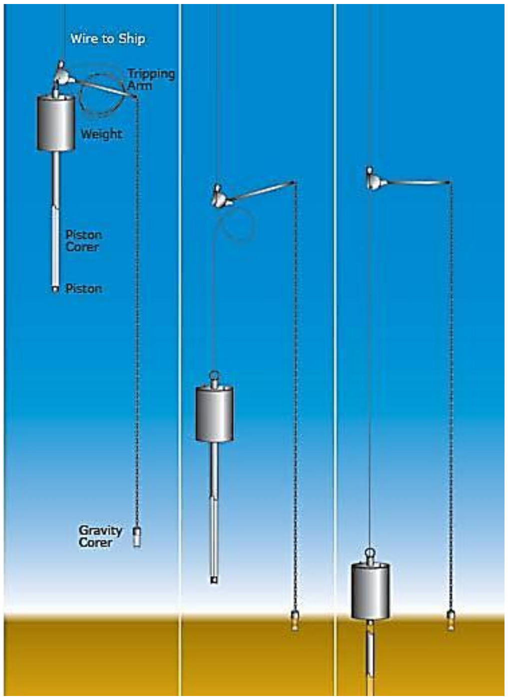
- Other underwater sensors and instrumentation: Research vessels contain a wide variety of acoustic and non-acoustic devices that allow the crew to gather physical, chemical, biological and ecological data. For more information on these instruments, please refer to Chapter 4 of the Duke CGGC report, *Nova Scotia's Ocean Technologies* (2012).

5.2.2.4. Outfit & furnishings

Deck equipment and machinery: Polar icebreakers feature a broad array of sophisticated deck equipment which allows researchers to deploy supplemental craft and underwater instrumentation. Deck equipment includes the set of winches, cranes, booms and frames found on the deck of the vessel. This deck equipment must be fashioned of cold-resistant high strength/high tensile steel, and capable of supporting several tons of force. On a research vessel, such equipment has a number of applications. For example, winches and A-frames may be used for trawling operations in fisheries research missions. Trawling generates enormous drag, so trawling vessels, including fisheries research vessels and other research vessels, must contain engines and a propulsion system which can overcome this decelerating force. Launch and recovery systems (LARS) are used to raise and lower autonomous underwater vehicles (AUVs) and remote-operated vehicles (ROVs) collecting scientific data. In these cases, the cables which are wound around the winches contain delicate wiring which can be easily damaged if the winch does not wind and unwind the cable precisely. Winches must be able to wind cables with both precision and speed. Finally, cranes and booms may be used for hauling collected specimens or for maneuvering supplemental craft. Nova Scotia's Focal Technologies (Moog) manufacturers the slip-ring assemblies for many of the research winch systems in the world.

Drilling rigs: Many modern research polar icebreakers are equipped with drilling rigs and piston corers that can drill down into the ocean sea floor and take core samples, similar to that depicted in Figure 34, as well as a purpose-designed handling system to deploy and retrieve the corer. The operation calls for driving a heavy tube into the seafloor in order to collect long core samples of sediment. The piston mechanism used in this type of corer allows researchers to capture samples in areas where the seafloor sediment is especially soft (WHOI, 2012). Note that other coring technologies, such as box corers or multi-corers may be used during some Icebreaker missions. These systems are smaller and lighter and do not require as much consideration in the deck design as the piston corer. Some research icebreakers, such as the *Nathaniel B. Palmer* and the proposed *Aurora Borealis*, are built to accommodate larger drilling rigs. Note that the Bedford Institute of Oceanography has the capacity to curate and analyze core samples.

Figure 34: Core sampling/piston corer



Source: Woods Hole Oceanographic Institution, 2012

Leading manufacturers include Benthic Geotech, BGS, and Marum. Other sea floor drilling rigs such as those developed by Perry Slingsby and the Monterrey Bay Aquarium Research Institute are maneuvered with remotely operated vehicles (ROV). Larger drilling rigs such as those on the research icebreaker *Nathaniel B. Palmer* are deployed through a moon pool in the hull of the vessel. The proposed research icebreaker *Aurora Borealis* will have one capable of drilling 5,000 meters below sea level, and 1,000 meters below the ocean floor (ESF, 2010). Seacore Ltd. and G.E. manufacture drilling rigs such as these.

Table 36: Relevant Drilling Rigs and Manufacturers

Company	Location	Drilling Rig Component
Fugro Seacore	U.K.	Moon Pool-deployed Industrial Drilling Rigs
G.E.	U.S.A.	Moon Pool-deployed Industrial Drilling Rigs
Perry Slingsby	U.K.	ROV-operated Drilling Rigs
Monterray Bay Aquarium	U.S.A.	ROV-operated Drilling Rigs
Benthic Geotech	Australia	Winch-deployed Drilling Rigs
British Geological Survey (BGS)	U.K.	Winch-deployed Drilling Rigs
Marum	Germany	Winch-deployed Drilling Rigs

Source: Duke CGGC

Laboratory equipment: In addition to underwater instrumentation, polar icebreakers with research capabilities are outfitted with a great deal of laboratory equipment for the collection, recording and analysis of research data. Common laboratory spaces include a hydrological research laboratory, a chemical laboratory and wet lab space. In addition, large research vessels also require a large computer lab which will allows for the control of underwater instrumentation, ROVs and AUVs as well as the integration and analysis of data from these multiple sources. Finally, a large freezer space is necessary to preserve samples for further study upon returning to shore.

5.2.3. Component Distribution

As shipbuilding has become increasingly modular, the major equipment suppliers have gained control over the distribution (as well as the maintenance and post-production services) of the major subsystems such as propulsion, electronic equipment and deck equipment. These “turnkey” equipment suppliers provide their product as a full package, which can then be “plugged in” or integrated into the final craft with minimal hassle or liability to the shipyard. This distribution arrangement is beneficial to the lead equipment suppliers, as they are able to realize greater economies of scope and scale. Shipyards benefit, as they can wait until vessels are nearly complete before installing and integrating the subsystem, thus minimizing liabilities during the construction phase.

5.2.4. Assembly and Integration

- Hull Blocking and Assembly: Modern shipbuilding follows a modular production method. That is, hull blocks are constructed independently from one another before being assembled into the structure of the final craft. This allows the shipbuilder to construct hulls more quickly and to work on multiple projects at one time.
- Outfitting: Once the hull is assembled, it must be outfitted with electrical equipment, deck equipment, mission-specific equipment, supplemental craft and amenities for crew and scientist accommodations.
- Systems Integration: As with the construction of all large vessels, systems integration is an important and high-value-added activity for research vessels. From the perspective of a multipurpose polar icebreaker in particular, however, the integration of a large number of different equipment and instruments into a single system is a unique challenge. As icebreakers have become more sophisticated, integration has grown increasingly important. Not only must subcomponents within each of the various systems “talk” to one another, but increasingly subcomponents from distinct systems must be able to communicate as well. For example, in order to function properly the dynamic positioning feature of the navigation system must communicate seamlessly with both the electrical system and the propulsion system. For this reason, the role of the tier one integrators cannot be understated.

5.2.5. Post-Production Services

Once the research vessel itself is finally delivered to the client, there remain a number of post-production activities that enhance the value that the ship owner derives from the ship. These include maintenance and repair operations on the hull and ship subsystems as well as technical training for and customer support for the operators of the vessel. The post production service arrangement for the polar icebreaker is yet to be determined. The work will likely be carried out by one of the following entities: the Canadian Coast Guard, Seaspan, or the tier one integrators.

6. Science Research Vessels

Prepared by Andrew Guinn

This chapter focuses on the value chains for science research vessels. The National Shipbuilding Procurement Strategy (NSPS) calls for the construction of four vessels whose primary purpose is scientific research: three Offshore Fisheries Science Vessels (OFSVs) and one Offshore Oceanographic Science Vessel (OOSV). The chapter will first describe the purposes and characteristics of research vessels in general. It will then provide an overview of the two research vessel types called for under the NSPS. Next, the chapter will describe the main subsystems and components that will be included on the OOSV and OFSV, with special attention paid to those components which have special relevance to research vessels. Finally, it will describe the position of Nova Scotia firms with respect to research vessel value chains as well as the strengths and weaknesses of these firms to participate in research vessel value chains.

6.1. Ship Purposes and Characteristics

Research vessels (RVs) are a type of ship whose primary purpose is the collection of data for scientific purposes. There are several categories of research vessels which are distinguished by the type of mission that the vessel mainly undertakes: fisheries survey research, nautical charting, environmental monitoring and oceanographic research (NOC, 2012). Oceanographic research can be further sub-divided into five categories: physical, biological, chemical, geological and geophysical, and atmospheric (NAS 2009). Ships collecting data within one of these fields of research are defined as research vessels. Research vessels generally range in size from 15 meters to 150 meters (Oceanic 2012). There are currently 870 vessels throughout the world undertaking scientific research (Oceanic 2012), though this figure includes multipurpose vessels which may share research objectives with other mission profiles such as icebreaking or passenger transportation.

Research vessels can be classified as either offshore vessels or inshore vessels. Offshore research vessels are capable of surviving in the open seas for multiple weeks and the design of such vessels must include not only sophisticated equipment and laboratory space for the data collection and analysis but also accommodations for crew and scientists, including a mess hall and recreational facilities, as well as ample storage areas. Offshore RVs whose mission profile extends into polar waters must also be ice-classed, either as double-hulled icebreakers or as ice-strengthened vessels. Inshore RVs, on the other hand, operate in coastal water and are therefore much smaller than offshore vessels. These are intended for relatively short missions of one day to two weeks. This chapter will focus on technologies relevant to offshore research vessels.

The design and outfitting of a given research vessel are largely functions of the types of missions that the ship is expected to undertake, though such considerations are complicated by the fact that research vessels are often expected to be able to undertake multiple mission types simultaneously. For example, vessels primarily used for oceanographic research may also be equipped with charting equipment for ocean floor mapping. Increasingly, vessels are being produced which combine research capabilities with non-research missions. For example, the recently delivered S.A. Agulhas, built by STX Finland for the

South African National Antarctic Program, is a large, ice-strengthened polar research vessel that has extensive passenger amenities and will also be used as a supply vessel (Wingrin, 2012).

Research vessels carry a wide variety of technologies onboard in order in order to facilitate the mission of gathering scientific data (see Table 37). Acoustic devices, including multi-beam sonar, side-scan sonars, sub-bottom profilers and towed arrays, use sonar technology to survey fish populations and identify items on the ocean floor. CTD (conductivity, temperature and depth) devices gather information about water conditions via a series of instruments and samplers which are connected to the boat via a data-transmitting cable leading to a CTD winch. Another common activity conducted from research vessels is bottom sampling, the collection of geological or biological samples and other objects from the ocean floor using remotely operated vehicles or human divers. Water column sampling (which can take the form of tow net samplers, buoy-based vertical line passive samplers, mesh screen samplers or water bottle samplers) gather biological and hydrological samples simultaneously at multiple depths. Buoys and other deployable probes gather hydrographic, atmospheric and sonar data and remotely send the recorded information to the research vessel. Also, research vessels are generally capable of deploying remotely operated vehicles (ROV) and autonomous underwater vehicles (AUV), which gather and record hydrological and geological information, and carry equipment for staging diving missions for the collection of scientific data. In addition to these data-gathering devices, research vessels contain computers and digital interfaces for the recording, integration and analysis of digitally gathered data, wet and dry laboratory space for chemical and biological research, and freezers for the storage of specimen. Compared to other similarly-sized ships, research vessels also feature a broad array of sophisticated deck equipment which allows researchers to deploy supplemental craft and underwater instrumentation. In order to support these scientific functions, research vessels exhibit unique design, propulsion systems and outfitting characteristics, discussed in greater detail below.

Table 37: Typical technologies onboard science research vessels

Technology driver	Type of science mission				
	Physical	**Biological**	**Chemical**	**Geophysical**	**Atmospheric**
Atmospheric measurement capability	x	x	x		x
AUV/glider/UAV stowage and handling	x	x	x	x	x
Capability to service observatories	x	x	x	x	
Clean laboratory space		x	x	x	x
Controlled temperature laboratory space		x	x		
Dynamic positioning	x	x	x	x	
High data rate communication	x	x	x	x	x
Hull mounted and deployable sensors*	x	x	x	x	x
Low radiated noise	x	x		x	
Low sonar self-noise	x	x		x	
Manned submersible use		x	x	x	
Mooring/buoy deployment and recovery	x	x	x	x	x
Multi-channel seismic	x			x	

Technology driver	Type of science mission				
	Physical	Biological	Chemical	Geophysical	Atmospheric
Ocean drilling and coring				x	
Precise navigation	x	x	x	x	x
ROV stowage and handling	x	x	x	x	
Towing nets and/or vehicles	x	x	x	x	x
Underway scientific seawater supply	x	x	x	x	x
Watercatching/water column sampling	x	x	x	x	x
* Deployable sensors include centerboards, stalks, and towed sensors that can be lowered beneath the level of interference caused by bubble sweepdown related to ship motion.					

Source: NAS, 2009

The NSPS includes four large research vessels in its non-combat package: one Offshore Oceanographic Science Vessel (OOSV) and three Offshore Fisheries Science Vessels (OFSV). The other large non-combat vessel, the polar icebreaker, will also have scientific research capabilities). These two types of vessels will both be capable completing out multi-week, offshore research missions. The OOSV is the larger of the two vessel types and will be equipped to carry out sophisticated physical, chemical and biological sampling and analysis, contribute to ecosystem research and conduct surveying for hydrographic charts and oceanographic engineering projects. The OFSV will be a smaller vessel type, capable of shorter times at sea, which will be primarily used for fishery and ecosystem research.

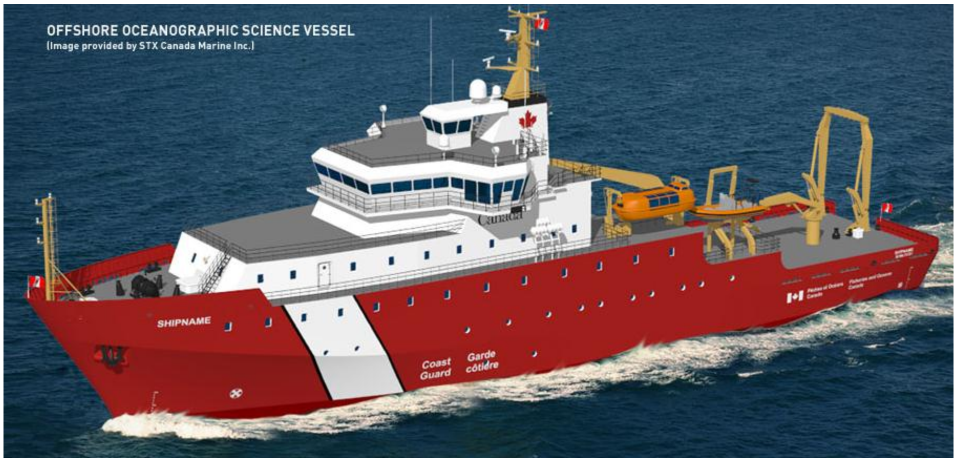
6.1.1. Offshore Oceanographic Science Vessel

The Offshore Oceanographic Science Vessel (OOSV) is the larger of the two types of research vessels that the Canadian Coast Guard (CCG) is procuring through the National Shipbuilding and Procurement Strategy. This vessel will replace the Halifax-based CCGS *Hudson*, which conducts oceanographic data collection, for example doing surveys of the water column and the ocean floor. This information is used by ecosystems researchers and by the oil & gas and mining industries. It is also used in documentation that Canada uses to justify its claims under the Law of the Sea (Third United Nations Convention on the Law of the Sea, or UNCLOS III) for areas in excess of 200 miles from the coast. The *Hudson* has been in service since 1964 and is becoming increasingly expensive to maintain and operate. The CCG currently operates one other offshore oceanographic research vessel on the West coast, the CCGS *John P. Tully*, which was built in 1985 and re-commissioned in 1995. See Figure 35 for a notional image of the OOSV.

The OOSV will be used for the following purposes:

- “conduct multi-disciplinary physical, chemical, and biological oceanographic expeditions;
- observe global and regional oceanographic circulation and interactions;
- contribute to the assessments of resources and impacts to the various marine ecosystems;
- support marine geology; and
- contribute to data gathering for hydrographic charts, oceanographic engineering, establishment of internal and international marine boundaries and for other government departments and research organizations.” (Fisheries and Oceans Canada 2011)

Figure 35: Notional view of OOSV



Source: CBC, 2011b from STX Canada Marine

Given the broad mission profile expected of the OOSV, the vessel has is being designed with flexibility in mind. This will be reflected especially in the layout of the deck, which will remain large and open, with multiple locations for fitting winches and several configurations for setting up deck equipment. Every time the ship comes in to change its crew assignment on board, the operators can remove all the equipment on the deck and put on a new suite of winches and measurement instruments, allowing researchers to do multiple activities either concurrently or in sequence with each other. The vessel will also be equipped with wet lab space and instruments for water column sampling and core sampling. It will be able to operate in ice-infested waters; though will not have true icebreaking capabilities (Fisheries and Oceans Canada 2010).

Table 38: OOSV Vessel Information

Type of Vessel	Offshore Oceanographic Research Vessel
Purchaser	Canadian Coast Guard
Shipyard	Vancouver Shipyards, Inc., Vancouver
Shipbuilder	Seaspan Marine Corporation
Designer	STX Canada Marine
Launch year	2017
Length	78.1m
Displacement	3680 tons
Accommodations	56 (33 crew, 23 scientists)
Endurance	84 days (requires resupply after 42 days)
Installed Power	3870 kW (3 x 1290 kW)
Propulsion	Diesel electric with azimuthing and single bow thrusters

Source: Canadian Coast Guard (CCG, 2012b)

Highlight's from the project's preliminary schedule is provided in Table 39. STX Corporation was awarded a design contract worth $2.48 million for the OOSV in 2010 (CCG, 2012b). STX also designed the *John P. Tully*. Construction is expected to begin in late 2012 or early 2013 and continue through

2014 (Shaw, 2012). However, changes in the preliminary production schedule already are emerging. A May, 2012 presentation by Brian Carter, President of Seaspan Shipyards, notes a production begin date for the OOSV to follow after completion of the three OFSV around 2015 (Carter, 2012). As the OOSV will be larger and more complicated than the OFSV, this sequencing allows the shipyard to learn from the OFSV construction process. The approved budget for the OOSV project is $144.4 million (CCG, 2012b).

Table 39: OOSV Preliminary Project Schedule

MILESTONE	DATE
Preliminary Project Approval	July 2008
Contract Award for Design	October 2010
Contract Award for Construction	Summer 2012
Vessel Delivery	Late 2014

Source: Treasury Board of Canada, Secretariat (TBS, 2012b)

6.1.2. Offshore Fisheries Science Vessel

The NSPS calls for the procurement of three OFSVs. These ice-classed vessels (PC7) will replace *the CCGS Wilfred Templeman*, *CCGS Alfred Needler*, *CCGS Teleost*, and *CCGS W.E. Ricker*, which were commissioned in the 1970's and 1980's. Two of the new vessels will be deployed to Canada's East Coast, with the remaining vessel to be based on the West Cast. These vessels will do biological sampling using either commercial size trawling equipment or smaller research nets. They will gather information not on the physical properties of the water or sea floor but rather on the ecosystems of the ocean. This information is used to set quotas on commercial and recreational fishing activity, identifying species at risk, looking at pollution, and monitoring the management of the marine system. Like the OOSV, the OFSV will be built by Seaspan Marine Corporation at Vancouver Shipyards.

Figure 36: Notional view of OFSV

Source: Best and Johnston 2012

The OFSV will be used for the following purposes:

- "conduct fishing and acoustic surveys of fish and invertebrates;
- collect information on the distribution, abundance and biology of species to be used in stock assessments for new and existing fisheries, and in studies supporting the assessments; and
- collect physical, chemical, and biological oceanographic data to monitor changes in marine ecosystems and their impact on fisheries resources and ecosystem health." (Fisheries and Oceans Canada 2011)

The primary missions of the OFSVs will be fisheries science (70%), oceanography (20%) and hydrography (or charting) (5%). Secondary missions, comprising the remaining 5% of activities, will include search-and-rescues, fishery patrols for conservation and protection, minor maritime security and support for other government departments and agencies (Best and Johnston 2012).

The hull and deck of the OOSV has been arranged to resemble a large commercial trawler, though the OOSV will of course have a more sophisticated suite of equipment for gathering scientific data. The hull of the OFSV is based on that of the NOAAS *Oscar Dyson*, a fisheries research vessel owned by the United States National Oceanographic and Atmospheric Administration (Best and Johnston 2012). The vessel will come equipped with a trawl deck and several permanently fixed winches for conducting fishing surveys. Aside from trawl surveys, the OFSV will be able to perform water column sampling. It will also be equipped with wet labs to analyze living specimens and chemical samples. These vessels will incorporate more noise-reducing technology than the OOSV (Fisheries and Oceans Canada 2010).

Table 40: OFSV Vessel Information

Type of Vessel	Offshore Fisheries Science Vessel
Purchaser	Canadian Coast Guard
Shipyard	Vancouver Shipyards, Inc., Vancouver
Shipbuilder	Seaspan Marine Corporation
Designer	Robert Allan, Ltd.
Launch year	2014-2015
Length	55.0m
Displacement	2602 tonnes
Accommodations	34 (21 crew, 13 scientists)
Endurance	31 days
Installed Power	4500 kW (3 x 1500 kW)
Propulsion	2250 kW (integrated electric with single bow thruster)

Source: Canadian Coast Guard (CCG, 2012b)

Vancouver-based Robert Allan, Ltd., Canada's oldest privately owned naval architecture consultant, and Alion Science and Technology (Canada) Corporation have been awarded the $2.9 million design contract for the fisheries vessels in a joint venture (Canadian Coast Guard 2010). Construction of the OFSVs will extend from 2013 through 2015 (Best and Johnston 2012). The approved budget for the OFSV project is $244 million (CCG, 2012b). The project's major milestones are provided in Table 41 below.

Table 41: OFSV Preliminary Project Schedule

MILESTONE	DATE
Preliminary Project Approval	October 2005
Contract Award for Design	October 2010
Design Contract Completion	Winter 2012
Effective Project Approval	Spring 2012
Contract Award for Construction	Summer 2012
First Two Vessels Delivery	2014
Delivery of final OFSV	2015

Source: Treasury Board of Canada, Secretariat (TBS, 2012b)

6.2. Research Vessels Value Chain

Research vessels, like other large, modern surface vessels, are built according to a modular production system, in which a small number of lead firms – the shipbuilder, a design team, and a small handful of systems integrators – control the design, construction and outfitting of the ship through the collaborative management a long, geographically disparate and complicated supply chain. These firms are the shipbuilding partners. For the research vessels, the shipbuilding partners are:

- Seaspan/Vancouver Shipyards: shipyard/prime contractor
- Imtech: platform systems integrator
- Thales: mission systems integrator
- STX Canada Marine Inc.: design and engineering (OOSV)
- Alion and Robert Allan, Ltd.[9]: design and engineering(OFSV)
- Computer Sciences Canada, Inc.: logistics and business services.

For a given shipbuilding project, below the prime contractor one typically finds a small number of marine equipment suppliers who control the systems integration of particular subsystems. These firms do not see the project through from conception to completion, as the shipbuilding partners do, but rather serve as systems integrators for specific complex systems. Typically, one firm will serve as the integrator for platform systems, and another will manage the mission specific systems. Platform systems include components such as propulsion, electrical, and hotel services (dining, medical facilities, etc.), and mission specific systems consist of components such as command and control, navigation, underwater acoustics, and deck equipment. While the design firms act almost entirely within the Design segment of the value chain, they interact with the prime contractor and the client in the selection of specific components which must be accommodated in the design. The shipbuilders and integrators will often assume roles and collaborate in each of the subsequent four segments of the chain: Component Production, Distribution, Assembly & Integration and Post Production Services.

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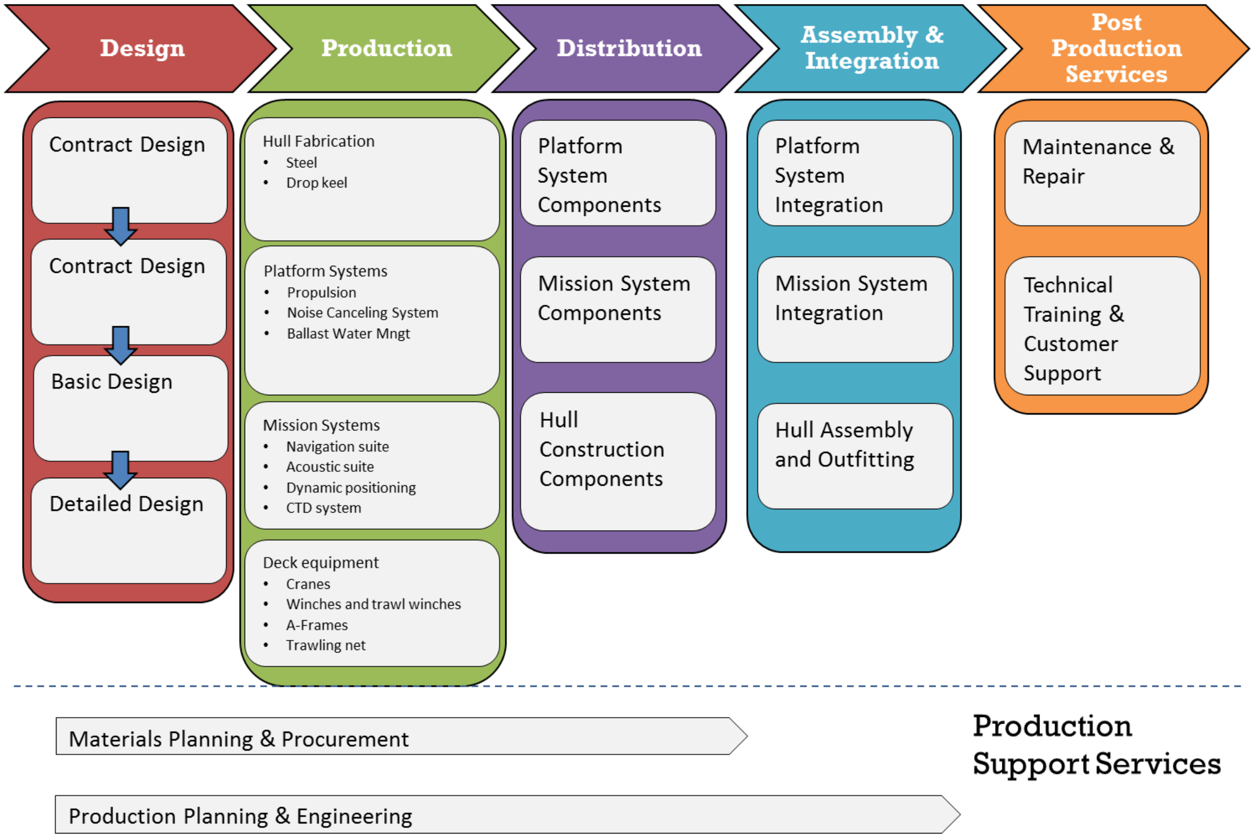
[9] Alion, a US-based ship design firm operating through its Canadian subsidiary (Alion Canada), and Robert Allan, Ltd., have formed a joint venture called RALion. RALion is Seaspan's design partner for OFSV early design phases. STX Marine is the design partner for later phases of the OFSV, according to industry sources. Note that this joint venture is also designing a research vessel for Australia (Alion 2012).

Figure 37: Research Vessel Value Chain



Source: Duke CGGC

As shipbuilding has become more modular in recent decades, these suppliers have moved towards a new business model which emphasizes maintenance or life-cycle support more than direct product sales. This strategy allows equipment suppliers to maintain a longer-term relationship with clients and also allows shipbuilders to transfer liability for expensive systems over to suppliers (Ecorys 2012). Note that for some projects, a major marine equipment supplier may serve as a shipbuilding partner, such as the case of Imtech with regard to the OOSV and OFSV, signifying a larger project management role and a greater degree of risk-sharing. Whereas the shipyard may be seen as lead firms within the context of a particular project or set of projects (by virtue of their control over design specifications and component sourcing), large equipment suppliers act as lead firms within the global market for their particular subsystem (by virtue of their ability to control the production, marketing and repair of complicated technologies that are relatively difficult to codify).

Both the OOSV and the OFSV are in the early stages of design, though some information is available regarding the design of the OFSV (see Best and Johnson, 2012). Since the detailed designs of the ships have not yet been released the following analysis speaks more broadly of research vessels in general. In our research, we studied trends in research vessels built over the last ten years as well as available specifications for research vessels which will be built in the coming years. Table 42 lists a sample of the countries and consortia which have recently built or will soon build fisheries or oceanographic research vessels.

Table 42: Recently built fisheries and oceanographic vessels

Ship	Owner	Design	Features	Year
Bell M. Shimada	NOAA (USA)	63.8m Double Hull Fisheries Vessel	ICES acoustic standards Crew capacity: 39	2010
Sonne II	Germany	87m Hull Oceanographic Research	Low-level noise Dynamic positioning Energy efficiency	2013
N/A	Mexico	Fisheries Research Vessel	Construction by Astilleros Armon Vigos in Spain	2013 /2014
AGOR 28	UNOLS (USA)	70 m Hull Oceanographic research	Bubble-diverting hull form Power monitoring systems for high efficiency	2014
Sikuliaq	NSF (USA)	77m Hull Ice transit: 2 ft (PC 5) Oceanographic Research	Dynamic Positioning 187 sq. m lab area Advanced acoustic suite for polar research	2014
R/V Investigator	CSIRO (Australia)	89m Oceanographic research, surveying	Ice-strengthened hull Design by RALion Constructed in Singapore	2013

Source: Duke CGGC

From this analysis of recent and current research vessel projects, we have identified common trends which are assumed to be relevant to both the OOSV and OFSV projects. Table 43 presents components found on most research vessels. Each of these components, of course, is itself composed of smaller components from screws to composite parts to circuit boards. The exact combination of components to be found on any given ship depend on the ship's mission; in fact, some equipment, such as cranes, winches, laboratory gear and supplemental craft may be swapped in and out of various research vessels according to mission requirements.[10]

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[10] See Appendix B for a list of components that will likely be included on the OFSV, as indicated by concept design documents made available by RALion. Detailed design information for the OOSV is not yet publicly available.

Table 43: Components of Large Research Vessels

Sub-system	Navigation Electronics	Comm. Electronic	Electrical Equipment	Mechanical Equipment	Deck Equipment	Lab Space	Research Equipment
Main Components	Gyro compass	Transceivers	Diesel generator	Machinery Plant	Winches	Wet Lab	Acoustic devices
	GPS	Radio	Switchboard	Propellers	Cranes and Booms	Chemical Lab	AUV/ROV
	Navigation software	Satellite system	Wiring	Propeller shaft	A-Frame	Hydrology Lab	Water Column Sampler
	Radar			Bow Thruster	Ground Tackle	Computer Lab	Probes
	Dynamic Positioning System			Freshwater System	Supplemental craft	Refrigerator	
	Doppler speed log			Pollution Control	Trawling Net	Storage Equipment	
	Positioning Heading					Staging Bay	

Source: Duke CGGC, based on review of similar vessels

6.2.1. Design

Design work is carried out by engineering and naval architecture firms. The design of research vessels must take into account the many scientific missions that the vessel will host. Thus, research vessel design must optimize the ability of the vessel to collect, record and analyze a variety of types of data. In terms of vessel arrangement, this implies plenty of laboratory space and an appropriate deck arrangement including research winches and, in the case of the fisheries vessels, trawling equipment. During the design phase, the naval architect must also decide whether to include a drop keel, which can be outfitted with data-gathering devices. It has been decided that the OFSV will have a drop keel (Best and Johnson, 2012), though relevant design documents are unavailable to confirm that the OOSV design will also include a drop keel. Note that characteristics of subsystems that are not directly related to the structure of the hull itself must also be incorporated into design considerations. For example, naval architects must define characteristics of the vessel propulsion systems in order to minimize unwanted noise while also generating enough power to overcome drag from towed equipment.

Both vessels have gone through the preliminary design phase. During this phase of the design stage, the BMT Group, a private naval architecture firm, worked closely alongside Canadian Coast Guard (CCG) engineers in creating a conceptual layout for the vessels, based on anticipated mission requirements. Currently, RALion and STX Marine are completing the contract designs for the OFSV and OOSV, respectively. Aside from mission-based technological considerations (to be discussed below), cost-reduction is an important factor in the contract design phase, as the conceptual vessels proposed by the CCG were roughly 30% above budget (Shaw 2012, Best and Johnston 2012).

Naval architects must keep laboratory space and deck arrangement in mind when designing research vessel layout:

- Laboratory spaces: Offshore research vessels contain laboratories for the collection and analysis of scientific data. A given research vessel may have several labs, each of which is equipped with an array of sophisticated measurement devices and analytical equipment, from centrifuges to salinometers to computers uploaded with specialized software packages. Again, the precise set of laboratories that are included within a given vessel design will depend on the mission of the craft. Types of laboratories which may be found on research vessels include: wet labs, chemistry laboratories, hydrological laboratories and computer labs for the analysis and storage of data. In addition, research vessels may contain refrigeration equipment for the storage of specimens that are to be brought back to shore for further study. Finally, research vessels sometimes include staging bays (or moon pools), which are used to launch ROVs, deploy divers or pass ship-based drilling equipment.

- Deck arrangement: The deck is home to the nets and the mechanical deck equipment (winches and A-frames or gantries) which constitute an important component of the mission equipment for both vessels. Winches and A-frames allow the crew to deploy and recover sensors, water column sampling devices and trawling nets and thus are critical to the data-gathering missions of both vessel types. Reflecting the ship's highly flexible mission profile, the OOSV's deck arrangement is being designed so as to maximize modularity. That is, many of the winches will be detachable, so that the suite of deck equipment may be customized to the scientific mission at hand. Winches on the OFSV, on the other hand, will be almost entirely fixed in place because these vessels are expected to face a less variable mission profile. Fixed winches are also able to bear a greater load than removable winches – an important consideration given that the trawling operations to be carried out by the OFSV demand a powerful winch system.

6.2.1.1. Trends in Design

Figure 38: Trends in Research Vessel Design

Design Trend	Description	Advantages
Multipurpose Vessels	• Vessels designed with capability to carry out several missions • One ship may be able to clear navigation channels in ice, conduct geological research, execute deep water offshore drilling, and protect national sovereignty	• National owners can achieve multiple objectives with one vessel • Consolidate capital and human resources into one vessel instead of three or four
Noise Management	• Borrowing techniques from cruise liners, designs use sound dampening materials and consider strategic placement of engines • Fitting acoustic devices to a drop keel brings them below interference from hull noise and air bubbles	• Improved research and data collection • Facilitates improved data collection while ship is in motion
Pollution Management	• New (and pending) regulations for operating in the Arctic will require new technologies	• Cleaner Arctic environment with reduced introduction of greenhouse

Design Trend	Description	Advantages
	• Emissions reductions in nitrogen oxides (NOx), sulfur oxides (SOx), and particulate matter (PM) require catalytic converters • Improved ballast water management will require ballast water is treated with approved system before being discharged	gasses in the polar regions • Safer marine environment with less risk of introducing invasive non-native species • Tremendous market opportunity for systems integrators in the shipbuilding industry
Propulsion System Innovations	• Improvements in diesel electric systems allow ships using AC propulsion technology improved noise management performance (currently only DC systems meet ICES standards) • Improvements in dynamic positioning technology	• Improved data collection capabilities without sacrificing efficiency • Dynamic positioning allows research vessels to remain stationed at a field site for several days in order to gather data • Dynamic positioning systems operate with improved efficiency
Polar Capability	• Use of ice-strengthened hull • Inclusion of drop keel	• Allows for research into pressing questions related to global climate change • Allows for the exploration of new fossil-fuel energy sources • Improved acoustic surveying performance in polar waters

Source: Duke CGGC

- Multipurpose vessels: As modular systems have increasingly come to define the design and construction of research vessels and other ships, there have been several new vessels which combine some research functions (especially surveying and hydrological data collection) with other missions. For example, the 200 meter-long, ERI *Aurora Borealis*, operated by the European Science Foundation, combines the functions of an icebreaker, drilling platform and research vessel within one ship (Alfred Wegner Institute 2012). Another example, the 134 meter-long South African Polar Supply and Research Vessel, which was delivered this year, will be capable of serving as an icebreaker, research vessel, expedition vessel, supply vessel and cruise ship (Wingren 2012).

- Noise management: Noise dampening (or acoustic dampening) technology, which reduces the effects of engine vibrations on ship passengers and the ship's environment, has become an important driver of design innovations in the shipbuilding industry, within both the market for new research vessels as well as the maintenance, repair and overhaul (MRO) subsector. Since acoustic equipment is generally in-use at all hours of the day, ambient internal noise can interfere with the collection of data and must therefore be minimized and controlled. While much of the work of addressing underwater noise targets the propulsion system, aspects of the design process can also help to reduce unwanted acoustic interference. Such design approaches use techniques borrowed from cruise liners, since such vessels are arranged and equipped so that passenger noise is naturally acoustically dampened and include the use of sound-dampening materials and ship designs which arrange noisy rooms (such as the mess hall or recreational areas) in such a way that ambient noise is less likely to interfere with acoustic sensing devices (NOC 2012).

Another design-related approach to mitigating the effects of underwater noise is the inclusion of one or more drop keels, which can be raised into the hull of the ship or lowered several meters below the keel. Placing acoustic instrumentation, especially low-frequency transceivers which are relatively large, on a drop keel has several advantages over the traditional approach of fitting them to the bottom of the hull itself (NOC 2012). By fitting devices to a drop keel, the crew can keep them safely below bubble streams which run across the hull when the ship is in motion. This reduces interference when the ship is in motion. Drop keels also make it possible to maintain, replace or switch out transducers without dry-docking the ship or using divers. Recent changes in the regulatory environment have pushed shipbuilders to adopt noise dampening technology, due to the impact that long-term exposure to engine noise can have on crew members' hearing. Engine noise can also have damaging environmental effects, as noise radiating into harbors or below the ship can disturb fish behavior and migration patterns. In 2002, the European Union passed Directive 2002/49/CE, which sets standards for the evaluation and management of environmental noise (Beltrán 2012). This directive has been followed by a number of standards issued by organizations ranging from the International Maritime Organization (IMO A.468 (XII) Regulation) and the International Organization for Standardization (ISO Standard 6954/2000 and ISO Standard 2922). While most vessels still lack acoustic dampening, fishing research vessels have been ahead of the curve in adapting the technology, due to the fact that engine noise can significantly disturb natural fish behavior (Beltrán 2012). As for ISO standards, ISO/PAS 17208-1:2012 provides procedures for the measurement of underwater sound from ships.

With respect to research vessels in particular, the International Council for Exploration of the Seas (ICES) Cooperative Research Report No. 209 contains a set of guidelines for underwater noise limits (ICES 1995) that are commonly referenced in research vessel ship designs. The report, however, does not provide strong recommendations for *how* to reduce underwater noise; it merely suggests an acoustic signature for naval architects to use as a benchmark. Furthermore, some naval architects are beginning to question the validity of ICES, as the proposed standards may only apply to the observation of a small handful marine species.

- Pollution management: Organizations such as the European Union (EU), Environmental Protection Agency (EPA) and International Maritime Organization (IMO) recently passed regulations for vessels that operate in the Arctic, and further regulations are being developed. Some regulations will restrict the amount of nitrogen oxides (NOx), sulfur oxides (Sox), and particulate matter (PM) allowed to be emitted from vessels (EPA, 2010; EU, 2010; Jensen, 2007). As a result, new icebreaker designs call for additional equipment such as catalytic converters, and existing vessels are undergoing upgrades to adhere to the new guidelines (Marinelog, 2011). Other designs include additional emission-reducing liquid natural gas (LNG) generators to power the ship's electrical system (IMR, 2009).

Other significant regulations include an international effort to reduce the spread of invasive marine species through improved ballast water management (BWM) (IMO, 2011). It is estimated that international compliance to these new regulations will spur investments of US$34.1 billion dollars in upgrades over the next decade (Royan, 2010). To prepare for this market opportunity, 55 firms have developed various types of BWM systems, all of which use a two-step process. First, the ballast water must be filtered to remove solids from the ballast water. Then the water is disinfected with either a chemical treatment such as chlorination or ozonation, or with a physical treatment such as UV irradiation or deoxygenation (Lloyd's Register, 2011a).

- While the design of propulsion systems themselves is the responsibility of lead firms in the propulsion subsector (firms like Wärtsilä and ABB), designers must determine the characteristics of the particular systems that will be included on the ship that they are designing. The mission profiles of most research vessels can make this task difficult because they produce extremely operating conditions, including: 1) long periods at cruising speed while traveling to a research site or performing multi-beam sonar activities; 2) multiple days at the research site using dynamic positioning system control; 3) the slow speed towing of large, high-drag scientific equipment and trawling nets; 4) quiet modes when low noise levels are required for fisheries or other specialized research (Rolland and Clark 2010). Currently, the only ICES-compliant systems use DC diesel electric systems, but firms are conducting R&D in order to design ICES-compliant AC systems. In addition, advances in propeller design and the double-raft mounting of generators are reducing the amount of ambient noise produced by propulsion systems.

- Polar research: Research vessels have also been increasingly used for polar research, requiring the use of ice-breaking or ice-strengthened hulls in some new research vessels. This technology trend has been driven not only by advances in ice-strengthening technology but also due to new research tendencies within the scientific community, specifically related to global environmental change. According to the United States-based University-National Oceanographic Laboratory System (2011), "high priority research questions with important ramifications for understanding global environmental change remain, such as the need to understand oceanographic processes that are increasingly tied to long-term stability of polar ice sheets. Addressing these questions requires enhanced access to ice-covered regions."

  Performing research in ice-infested waters, however, requires more than simply ice-strengthened hauls. Bubbles and ice in cold waters can interfere with surveying and other types of data collection. Multi-beam and side-scan sonar systems for the R/V *Sikuliaq* (currently under construction for the United States National Science Foundation), will be mounted on an ice-hardened drop keel (a retractable centerboard) in order to address the challenges of surveying in polar waters (Davis 2010). The Chinese State Oceanic Administration, Chinese Arctic and Antarctic Administration and the Polar Research Institute of China recently jointly commissioned a polar research vessel design from Aker Arctic (which is owned by STX), indicating Chinese interest in polar oceanographic research (Marine Link 2012).

6.2.2. Component Production

Component and subsystem production covers an extremely diverse array of items which comprise the various subsystems of the vessel as well as the hull structure itself. This section of the value chain includes both the production of intermediate components, such as metal fittings, circuit boards and software code, as well as their combination into final components like winches, multi-beam sonars and GPS interfaces. Note, however, that in many cases these firms are not responsible for the distribution of their products to final buyers (in this case, Seaspan and its Tier 1 partners) or for systems integration. See Appendix 2 for a list of the known components which will be included on the OFSV. This section focuses on production within those subsystems that are most relevant to research vessels.

With respect to the OOSV and OFSVs, the management of the various supply chains that feed into the final vessel is being overseen by Seaspan for components relevant to the hull and much of the outfitting, while the systems integrators (Imtech and Thales) are responsible for sourcing high-tech and electronic components and subsystems.

6.2.2.1. Platform systems

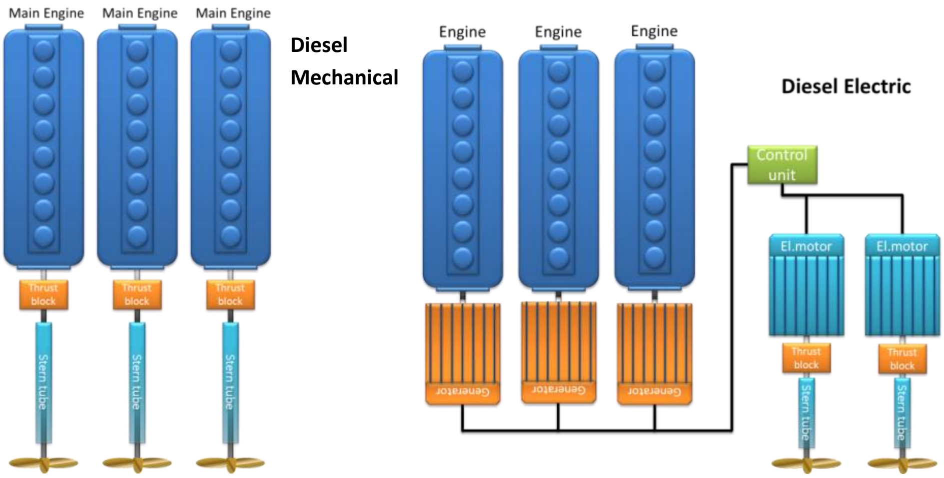
Propulsion System: The propulsion system for any vessel consists of four components: prime movers, transmission systems, propellers, and shafts (Sodhi, 1995). Prime movers are the principal sources of power on any vessel, and include diesel engines, gas turbines, and nuclear-powered steam turbines (CCG, 2010a). It is also possible that the OFSV will be fitted with hydrogen fuel cell technology. Both the OOSV and OFSV will use diesel electric engines. Alion Science and Technology, Seaspan's design partner for the OFSV, has been awarded an R&D contract by Public Works and Government Services Canada to investigate the possibility of a hybrid hydrogen fuel cell/diesel electric propulsion system for the OFSV, indicating that the fisheries vessels may use both diesel electric engines and fuel cells to generate power (Thomson, 2012; CASR, 2012). Transmission systems transmit the energy from the prime mover to the components that propel the vessel: the shaft and propeller. Propellers for research vessels may be either fixed-pitch or controllable-pitch (Roland and Clark, 2010).

The propulsion systems of research vessels must be able to meet the following operating conditions:

- Long periods at cruising speed transiting to a research site or performing multibeam sonar surveys
- Multiple days on station with propulsion and thrusters under dynamic positioning system control
- Trackline following at high and low speeds with propulsion and with and without bow or stern thrusters
- Slow speed towing of large, high drag scientific equipment
- Precise speed control
- Quiet modes when low noise levels are required to support fisheries or special research

Prime Movers: There are three main prime mover types: nuclear, diesel, and liquid natural gas. Of these, diesel engines are the most commonly used on research vessel, and can be classified as either diesel-mechanical or diesel-electric (Roland and Clark, 2010). Diesel-mechanical systems consist of a diesel engine that directly powers the shaft and propeller. Diesel-electric systems change the way the diesel engine transmits power. Instead of directly powering the shaft and propeller, the diesel engine generates electricity for a power plant that fuels electric propulsion motors used to turn the shaft and propeller (Marine Insight, 2012). For most of the 20th century diesel-electric systems could not compete with diesel-mechanical. Eventually technological advances in diesel-electric systems improved, particularly in power electronics and motor drives, and made them more cost efficient. Moreover, modern diesel-electric systems have numerous advantages for vessels that require frequent changes in speed and direction (Roland and Clark, 2010). The OOSV use medium-speed diesel generators, while the OFSV will use high-speed diesel generators, which are less efficient but can be better accommodated by the vessel's smaller size.

Figure 39: Common diesel propulsion systems used on research vessels

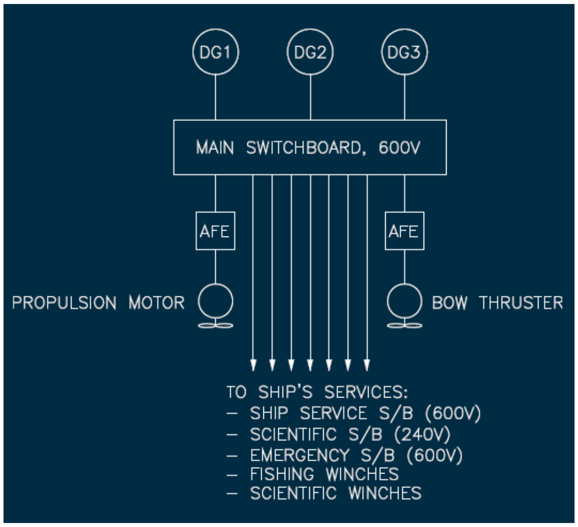


Source: Shippipedia, 2012

It is possible that the OFSV will use a hybrid propulsion system, in which a hydrogen fuel cell will be paired with a diesel electric engine. Beyond the fact that Alion, part of the joint venture working with Seaspan on the OFSV design, has been awarded the R&D contract by Public Works Canada, little information is currently available about the prospect of a hybrid propulsion system. The announcement of the R&D contract was made in late September, 2012 (Thomson 2012). The main advantage of hydrogen fuel cell technology is not the improvement of performance but rather the reduction of environmentally harmful emissions (CASR, 2012).

Transmission Systems: The two types of transmission systems correspond with the propulsion system, and therefore are classified as mechanical and electric. Mechanical transmission systems transmit power from the diesel engine to a the stern of the ship via a shaft. The shaft passes through a gear box that reduces the RPM appropriate for the propellers. Another shorter shaft carries the reduced RPM to the propeller. In electric transmission systems, diesel engines turn generators at a high RPM to generate electricity. The electricity is carried via cables to switchboards which transmit it to either transformers or frequency converters which isolate the current flow and achieve the proper voltage levels. The electricity then powers electric motors at the stern, which are connected to a shaft and fixed pitch propeller (MAN, 2012). These steps may be consolidated. For example, the electric motors may control the frequency and voltage necessary to turn the shafts and propellers (Patel, 2012).

Figure 40: Proposed diesel-electric propulsion system for OFSV



Source: Best and Johnson, 2012

Shafting: Fisheries science vessels, since they must deploy large nets, tend to use single (as opposed to double) shafting. Having two propellers is more difficult to properly balance the thrust of the vessel and can lead to netting getting tangled in the propellers. In fact, the CCG had to reduce the maneuverability requirements of the OFSV because it would have been extremely difficult to meet the initial requirements using a single-shaft design. Meeting maneuverability requirements for the OOSV was much easier. The OOSV is likely to use an azimuthing drive, which is steerable, rather than a traditional shafting system.

Propellers: Traditionally, both fixed-pitch and controllable-pitch propellers have been installed on polar icebreakers, along with side thrusters for increased maneuverability and dynamic positioning. Propellers are attached to the shafts in order to provide propulsion when the motor is engaged. They are most generally made of stainless steel or bronze.

Small propulsion systems called thrusters on the bow of both the OOSV and OFSV. Thrusters help maneuver and position the vessel in adverse conditions. When the vessel is operating the dynamic positioning (DP) system, the bow thruster, used alongside the helps to keep the vessel in a stationary position (Ward, 2001). Leading manufacturers of bow thruster systems include ABB, Wartsila, Rolls Royce, and Brunvoll.

6.2.2.1.1. Platform system firms

Firms that manufacture propulsion system components tend to fall in one of three categories of manufacturing capability. They either manufacture primarily diesel engines, primarily electric motors, or they act as entire propulsion system integrators that design and manufacture the entire system from diesel engines through the propellers (see Table 44). Firms that specialize in diesel engines include

Caterpillar and Sulzer. TECO Westinghouse and Stadt specialize in electric motor components. Firms that manufacture entire propulsion systems include ABB, GE, MAN Diesel and Turbo, Rolls Royce, and Wartsila.

Currently, there are no facilities capable of manufacturing large marine propulsion systems in Canada. However, three firms that manufacture components of diesel-electric propulsion systems of this capacity have offices with operations in Canada: ABB, TECO Westinghouse, and Wartsila. In addition, Rolls Royce operates a facility in Vancouver which manufactures azimuthing drives.

Table 44: Propulsion firms for Science Vessels

Propulsion Component	Manufacturing Firms	Manufacturing Locations
Diesel Engines/Generators	Caterpillar Sulzer	Germany Switzerland
Electric Motors	Stadt TECO Westinghouse	Norway U.S.A
Full Propulsion System Integrators	ABB G.E. MAN Diesel and Turbo Rolls Royce Wartsila	Switzerland U.S.A. Germany U.S.A.; U.K. Finland; China

Source: Duke CGGC

Desalination Plants: Research vessels must spend several days or weeks at field sites in order to gather scientific data. To supply fresh potable water for dozens of crew members and scientists, research vessels use on-board reverse osmosis desalination plants. Ship designers must ensure proper measures to guarantee seamless production of fresh water. Firms that provide desalination plants include FCI Watermakers, Village Marine Tech (VMT), Lifestream, and Water Standard.

Heating Ventilation and Air Conditioning (HVAC): Like other modern ships, the NSPS research vessels will include heating ventilation and air conditioning (HVAC) systems. Bronswerk marine is a Canadian firm likely to install the heating system on the Canadian polar icebreaker. Representatives from Bronswerk noted they are taking actions to position themselves as the HVAC supplier for all NSPS ships built at Seaspan Shipyards in Vancouver.

Table 45: Manufacturers for below deck components on science vessels

Company	HQ Location	Below Deck Component
Water Desalination Plants		
FCI Watermakers	U.S.A.	Reverse Osmosis Desalination Plant
Lifestream	U.S.A.	Reverse Osmosis Desalination Plant
Racor Village Marine Tech	U.S.A.	Reverse Osmosis Desalination Plant
Water Standard	U.S.A.	Reverse Osmosis Desalination Plant
Heating, Ventilation and Air Conditioning		
Bronswerk Marine	Canada	HVAC

Source: Duke CGGC

Auxiliary Systems

Supplemental craft: Research vessels carry several supplemental craft, including ROVs and AUVs to gather scientific data, small craft such as emergency life boats and, in some cases, helicopters. ROVs and AUVs are virtually always found on modern offshore oceanographic and fisheries research vessels (UNOLS 2012), and emergency life boats are, of course, mandatory. The concept design specifications for the OOSV also call for the inclusion of helicopter landing capability.

6.2.2.2. Mission systems

Research vessels require many of the same electric components that other offshore vessels use. For example, navigation equipment such as radar and GPS, and communication equipment such as satellite phones, multi-purpose transceivers, and satellite internet are all present on research vessels. Modern research vessels also include sophisticated sonars, probes and data logging devices. Table 46 lists some of the relevant electronic component firms, including the locations of Canadian offices.

Table 46: Canadian manufacturers of mission system components found on research vessels

Company	Location	Product
Furuno	U.S.	Fish monitoring sensors Sonar devices Integrated bridge system Communications devices
IBM	Markham, ON	Data links Computer systems
Knudsen Engineering	Perth, ON	Echosounders
Kongsberg	Port Coquitlam, BC Dartmouth, NS St. Johns, NL	Multi beam sonar Dynamic positioning system
L-3 Communications	US (Marine business)	Integrated bridge system software Dynamic positioning system
Marport C-Tech	St. John's, NL	Fish monitoring sensors Multi beam sonar CTD devices Integrated bridge system software
MetOcean	Dartmouth, NS	CTD devices Sonars
Omega	Montreal, QU	Data loggers CTD devices
Raytheon	Ottawa, ON Waterloo, ON Midland, ON Calgary, AB	Integrated bridge systems Dynamic positioning system
Simrad	Dartmouth, NS	Sonars Fish monitoring sensors

Company	Location	Product
Sonardyne	locations in US, UK.	Data loggers Sonars Dynamic positioning system
Thales Canada	Saint-Laurent, QC Ottawa, ON Quebec, QC Toronto, ON Kingston, ON Burnaby, BC	Sonars Radars Radios

Source: Duke CGGC

Dynamic Positioning

Dynamic positioning systems allow for the simultaneous and automatically controlled use of fixed pitched propellers and bow or stern thrusters in order to hold the vessel stationary. The dynamic positioning control system calculates the forces that the thrusters must produce in order to control the vessel's motion and communicates with the propulsion system so as to hold the ship immobile. Dynamic positioning has become a standard feature for large research vessels which must remain at a field site for several days in order to gather data (Roland and Clark, 2010). It is also commonly used on drill ships, cruise ships, survey ships and supply ships. Both the OOSV and OFSV will be equipped with dynamic positioning systems.

Research instrumentation

Research vessels carry a wide variety of technologies onboard in order in order to gather scientific data. Acoustic devices, including multi-beam sonar, sub-bottom profilers and towed arrays, use sonar technology to survey fish populations and identify items on the ocean floor. CTD (conductivity, temperature and depth) devices gather information about water conditions via a series of instruments and samplers which are connected to the boat via a data-transmitting cable that leads to a CTD winch. In addition to these data-gathering devices, research vessels contain computers and digital interfaces for the recording, integration and analysis of digitally gathered data, wet and dry laboratory space for chemical and biological research, and freezers for the storage of specimen. For more information on these instruments, please refer to Chapter 4 of the Duke CGGC report, *Nova Scotia's Ocean Technologies* (2012).

Acoustic sampling equipment: Acoustic sampling devices are sensors which use sonar technology to detect and quantify fish and other marine organisms. An acoustic transducer sends out a focused pulse of sound. When this sound wave meets an object, such as a fish or the ocean floor, some of it is reflected back to the research vessel where it is detected by a profiler and coded by a data management system. Sonar devices, which are intended to locate ocean life, use higher frequencies while devices used to measure the depth of the seafloor emit lower-frequency sound waves. Sub-bottom profiles, which are used to identify rocks or layers of sediment under the seafloor, are specially calibrated so as to provide greater penetration (NOC, 2012; Kongsberg, 2012).

Sonars and echo sounders are used to create a profile of the water column and the ocean floor. Sonars look at items in the water column (fish, structures, objects), while echo sounders measure from the sea floor. Sonars and echo sounders may be single- or multi-beam. Multi-beam sonar, unlike single-beam sonar, can plot hundreds of points in a line perpendicular to the vessel with each ping.

Acoustic sampling techniques have found a number of applications in fisheries research vessels. In some cases, using sonar technology to locate and measure properties of fish populations is preferable to trawling strategies, unlike trawling; this data collection strategy does not involve disturbing fish populations. Sonar devices may also be used to aid trawling operations. For example, trawling sonars, which are attached to trawling nets, measure the depth of the ocean floor (or the ocean surface) relative to the net. The data collection strategies used in fisheries research depends on the nature of the inquiry; is the researcher interested in the locations of fish populations or properties of the fish which must be observed directly? Precise acoustic sampling is aided by the dampening of underwater noise, so that the sound waves emitted by the propulsion system do not interfere with those projected by the acoustic sampling equipment. Hence, the OFSV will be designed in order to minimize acoustic interference. The OOSV, whose acoustic suite will be oriented more towards measuring properties of the seafloor, does not require the same level of acoustic dampening. Major manufacturers of acoustic equipment include Martec, Furuno, Kongsberg and Simrad. Acoustic sampling may also include acoustic modems to communicate with bottom sensors such as Ocean Tracking Network (Hanlon, 2013).

CTD sensors: CTD sensors are used in determining essential physical properties of sea water, including the distribution and variation of water temperature, salinity, and density. They are one of the main strategies that contemporary oceanographic researchers conduct water column sampling, that is, the measurement of water properties at various depths. CTD sensors comprise a set of small bottles which contain probes that record data. These bottles are affixed to a large metal rosette wheel which is lowered into the water. Data is transmitted back to the vessel via a specialized CTD cable, allowing scientists to observe water properties at various depths in real-time. Depending on the depth of the water column being sampled, a CTD cast generally takes between two and five hours. In order for scientists to gather precise measurements, Acoustic Doppler Current Profilers (ADCPs), devices which measure horizontal velocity, are attached to the CTD scanner. Smaller CTD devices may also be deployed on AUVs or buoys which record data onto small data loggers which are recovered by scientists and uploaded to the ship-based data logger (WHOI 2012). An ADCP may also be fitted to the hull of the research vessels (Hanlon, 2013).

Data logger: Data loggers are electronics devices that automatically record, with respect to both time and location, scientific data which is transmitted by scientific instruments. In the case of scientific instruments that are deployed by AUVs or ROVs, data loggers are generally highly specialized, designed to record specific types of information (CTD data or acoustic data). Larger shipboard data loggers, generally embedded in personal computer-based software, tend to be multi-purpose, capable of recording multiple types of data (Omega, 2012; H-Scientific, 2012). Manufacturers include Omega and National Instruments.

Laboratory Equipment: In addition to the underwater instrumentation described above, research vessels carry a great deal of laboratory equipment for the collection, recording and analysis of research data. Common laboratory spaces on research vessels are a hydrological research laboratory, a chemical laboratory and wet lab space (WHOI, 2012; NOC, 2012). In addition, large research vessels also contain a computer lab which will allows for the control of underwater instrumentation, ROVs and AUVs as well as the integration and analysis of data from these multiple sources. Both the OOSV and OFSV will also be equipped with a large freezer, which allows researchers to preserve samples for further study upon returning to shore. Laboratory areas on research ships must serve as an adequate space for using scientific equipment, and also allow researchers to quickly and securely stow this equipment – which is in some cases sharp, heavy or otherwise unwieldy – when it is not in use. Hold-downs are therefore necessary components in research vessel laboratories. There is a growing trend toward having mobile laboratories built into standard 20 or 40ft ISO containers and carried aboard research vessels as required (Hanlon, 2013).

Laboratory spaces, like crew accommodations, are constructed along with the hull. Much of the laboratory equipment, on the other hand, is carried onto the vessel by scientific crews when they begin a mission and removed once the mission has completed. This trend has been made possible by changes in research instrumentation technology. Fewer and fewer of the tools used for data collection and storage are found in permanently installed equipment on the vessel; rather, they are increasingly embedded within personal computers and modular data collection devices, affording newer research vessels a more flexible mission profile. This tendency towards modularity has been enabled by the movement towards using ROVs, AUVs and towed arrays for data collection and in the installation of drop keels, which allow researchers to relatively quickly and easily customize the suite of ship-board scientific instrumentation.

According to the available design documents, the OFSV will contain a wet lab space as well as a control lab, which will contain the computer systems used to operate and retrieve data from acoustic devices, probes, ROVs and AUVs (Best and Johnston, 2012). Refer to Appendix B for a list of known laboratories and laboratory equipment to be found on the OFSV.

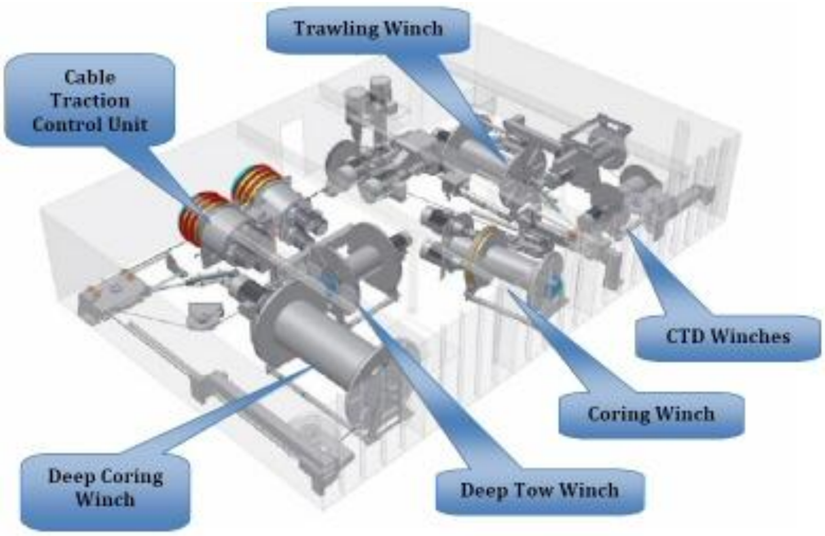
6.2.2.3. Outfit & furnishings – Deck equipment

Deck equipment includes the set of winches, cranes, and frames found on the deck of the vessel. On a research vessel, such equipment has a number of applications. For example, winches and A-frames may be used to conduct trawling operations in fisheries research missions or to raise and lower autonomous underwater vehicles (AUVs) and remote-operated vehicles (ROVs) deployed for data collection. Many of the winches on the OOSV will be removable so that oncoming crews can customize the suite of handling equipment to the mission at hand. Many of these winches are owned by the CCG, which owns and maintains a winch pool for use by researchers. The CCG reports that the winch pool is currently sufficient to serve the needs of the scientific community for the foreseeable future; hence, no new winches will be procured for the winch pool through the NSPS. Winches on the OFSV will be more specialized and significantly heavier than those on the OOSV so as to accommodate trawling operations. Therefore, new winches will need to be purchased for the three fisheries vessels.

Winches: Winches consist of the following components: a frame, a drum around which the winch cable is wound, and a motor to turn the drum. Winches must be able to wind cables with both precision and speed, presenting a unique engineering problem. The cables which wound around the drum are made of wiring which can be easily damaged if the winch does not wind and unwind the cable correctly. Components winches include the slip ring assembly and hydraulic power unit (HPU), both of which can be supplied by Nova Scotia companies (Moog and Hawboldt, respectively). Winches come in several varieties, each designed for particular applications:

- CTD winch: CTD winches are used to deploy CTD sensors. CTD cables are especially delicate, due to the embedded wiring which relays real-time data back to the research vessel. Hence, CTD winches must be specially designed in order to minimize the possibility of damaging cabling.
- Trawling winch: Trawling winches are used to deploy trawling nets used in commercial fishing operations and fisheries research. Trawling nets generate tremendous drag, so trawling winches must be extremely massive and capable of towing and retrieving large weights.
- Piston corer: The design of the OOSV calls for a piston corer similar to that found on the Polar Icebreaker (discussed on pg. 101). Piston coring involves driving a heavy tube into the seafloor in order to collect long core samples of sediment. The piston mechanism used in this type of corer allows researchers to capture samples in areas where the seafloor sediment is especially soft (WHOI 2012). The OOSV will be able to take especially long coring samples (up to 30 meters). Such large corers and their associated handling equipment generally cannot be bought off-the-shelf but are rather purpose-built by government research institutes or private manufacturers.
- Towing winch: Towing winches are used to deploy acoustic devices and other sensors used to gather data. Like CTD winches, these must accommodate delicate cables that contain wiring used to transmit data back to on-board data logging systems.

Figure 41: Winches installed in the RRS James Cook Oceanographic Research Vessel



Source: NOC, 2012

A-frames and cranes: Research vessels are fitted with A-frames and LARS to deploy overboard equipment. A-frames are for general purpose use and must be capable of bearing several tons of force to accommodate both the weight of the equipment itself and the dynamic loads produced by the motion of the ship (NOC, 2012). Launch and recovery systems (LARS) are used to deploy and retrieve specialized equipment such as CTD sensors, AUVs, and ROVs.

Table 47: Manufacturers of Deck Equipment

Company	Location	Deck Equipment
Hawboldt Industries	Chester, NS	Winches A-frames Cranes
Rapp Marine Group	Norway	Winches
Rolls Royce	US; UK	Winches A-frames Cranes
Dynacon, Inc.	US	Winches A-frames
Moog (Focal Technologies)	Dartmouth, NS	Slip Ring Assemblies
Wartsila	Finland	Winches A-frames

Source: Duke CGGC

6.2.3. Component Distribution

As shipbuilding has become increasingly modular, the major equipment suppliers have gained control over the distribution (as well as the maintenance and post-production services) of the major subsystems such as propulsion, electronic equipment and deck equipment. These “turnkey” equipment suppliers provide their product as a full package, which can then be “plugged in” or integrated into the final craft with minimal hassle or liability to the shipyard. This distribution arrangement is beneficial to the lead equipment suppliers, as they are able to realize greater economies of scope and scale. Shipyards benefit, as they can wait until vessels are nearly complete before installing and integrating the subsystem, thus minimizing liabilities during the construction phase.

6.2.4. Assembly and Integration

Hull Blocking and Assembly: Modern shipbuilding follows a modular production method. That is, hull blocks are constructed independently from one another before being assembled into the structure of the final craft. This allows the craft to construct hulls more quickly and to work on multiple projects at one time.

Outfitting: Once the hull is assembled, it must be outfitted with electrical equipment, deck equipment, other mission-specific equipment, supplemental craft and amenities for crew and scientist accommodations. Components for outfitting the science vessels are covered under section 6.2.2.3.

6.2.5. Post-Production Services

Once the research vessel itself is finally delivered to the client, there remain a number of post-production activities that enhance the value that the ship owner derives from the ship. These include ISS (in-service support, i.e. maintenance and repair operations on the hull and ship subsystems) as well as technical training for and customer support for the operators of the vessel. The post production service arrangement for the OOSV and OFSV is yet to be determined. The work will likely be carried out by one of the following entities: the Canadian Coast Guard, Seaspan, or the tier one integrators.

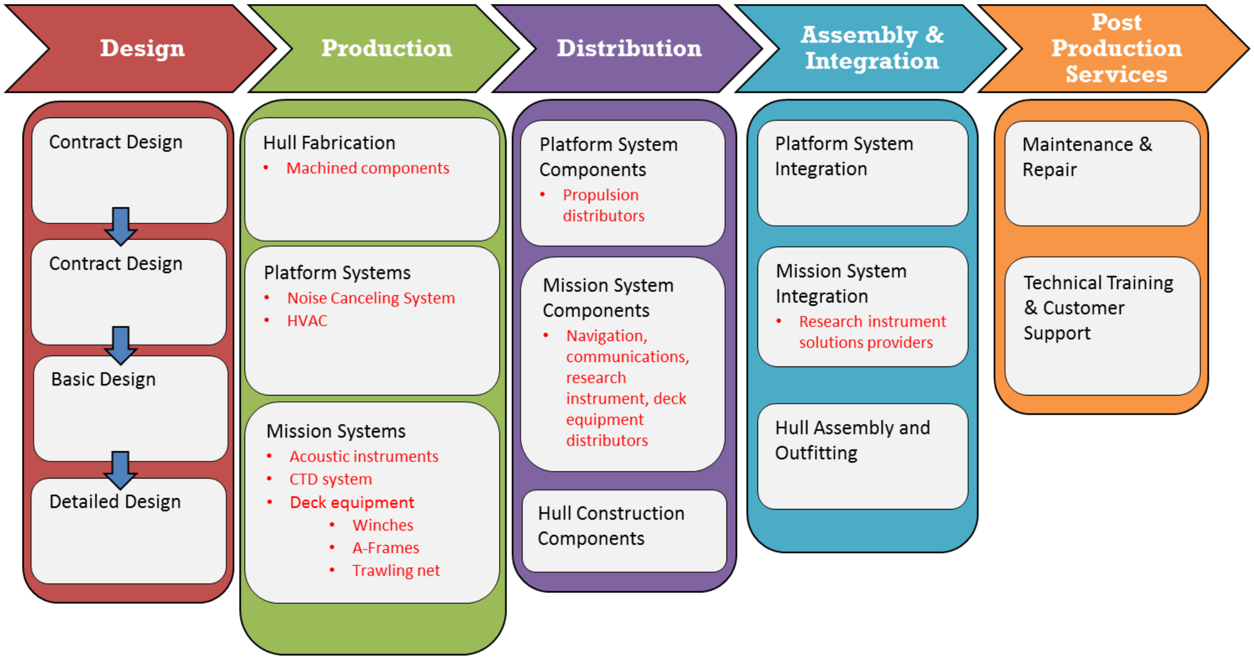
In-service support costs are expected to average CAD 700k per year for the OOSV and CAD 600k per year for each of the OFSVs, plus an inflation factor of 5% per year (DFO, 2012). These costs include painting, overhaul, spare parts, salaries of the ship's crew doing the work, and equipment replacement. Note that, unlike the Navy, the Coast Guard tends to perform most routine maintenance in-house. Costs related to inspection services, which can be expensive, are also included in these figures. Usually, the Coast Guard uses Transport Canada for inspections, but this organization will soon stop offering inspection services. Other options for inspection work include the classification societies, a private contractor or upgrading the Coast Guard's workforce in order to perform inspections in-house.

6.3. Nova Scotia and the Research Vessel Value Chain

6.3.1. Nova Scotia's Position in the Research Vessel Value Chain

Nova Scotia firms occupy several segments within the research vessel value chain (See Figure 42). Those companies which are active in the production segment, which provides relatively more value-added than distribution operations, are especially concentrated within the research instrumentation sub-segment. These companies produce a wide array of instruments for the collection, storage and analysis of oceanographic and ecosystem data, including CTD sensors, cameras, buoys, a data loggers (including software for integrated data logging and analysis), and a wide variety of acoustic devices (again, including software integration).

Figure 42: Nova Scotia's Position in the Science Vessel Value Chain



Source: Duke CGGC

Actors in the value chain include both MNCs and local firms. MNCs active in Nova Scotia include MAN Diesel & Turbo, Wartsila, ABB, Bronswerk, General Dynamics, Kongsberg Mesotech, Lockheed Martin Canada, Inc., MOOG Components Group (Focal Technologies), Ultra Electronics Maritime Systems and Rolls Royce Canada. As indicated in Table 48, MNCs are primarily concentrated in the distribution segment of the value chain, though Ultra Electronics Maritime Systems and MOOG have some production capabilities; General Dynamics and Lockheed Martin have systems integration capabilities; Kongsberg provides post-production services, such as maintenance and customization services. MOOG's manufacturing capabilities include the production of fiber optic cables, electric and fluid slip rings, and multiplexers. Bronswerk, a HVAC manufacturer, recently opened a production facility near Irving Shipyards in order to participate better in NSPS projects, and, as its manufacturing activities provide significant Canadian content, may be well positioned to participate in the Seaspan Vessels. Table 48 provides a list of Nova Scotia companies relevant to research vessel value chains. Rolls-Royce Canada (formerly ODIM) designs and builds Moving Vessel Profiler (MVP) and LARS at their Dartmouth, NS facility.

There are a number of local firms relevant to research vessel value chains as well. Hawboldt, for example, produces launch and recovery systems (LARS), A-frames and winches, including trawling winches, research winches and towing winches. Such deck equipment is critical to the ability of modern research vessels to complete their missions, given the increasing use of deployed equipment (CTD sensors, ROVs and towed acoustic arrays) for data collection. A handful of local companies including Crimond Enterprises, Rainbow Net and Rigging, and Pesca Trawl produce trawl nets used in commercial trawling operations and ecosystems research. Local firms producing scientific research instrumentation and relevant components include Akoostix, Jasco Research, Nortek Scientific, XEOS, Vemco Ltd., ODIM Brooke Ocean (Rolls Royce Canada), Instrument Concepts, Omnitech Inc., Satlantic Inc., Geospectrum Technologies, IKB Technologies Ltd., MetOcean Data Systems Ltd. and Welaptega. For a more detailed discussion of these firms and the technologies in which they specialize, refer to Chapter 4 of the Duke CGGC (2012a) Ocean Technologies Report.

Table 48: Nova Scotia research vessel value chain companies

Company	Product or Service	Value Chain Position
ABB	Platform systems (propulsion)	Distribution
Akoostix Inc.	Research software and solutions	Production, integration
Babcock Canada	In-Service Support	Post-Production
Bronswerk Marine	HVAC	Production
Crimond Enterprises, Ltd.	Trawling nets	Production
General Dynamics Canada	Mission systems	Distribution, integration
Geospectrum Technologies	Research instruments	Production
Hawboldt Industries	Deck equipment, LARS, propellers	Production
IKB Technologies Ltd./Seistec	Research instruments	Production
Instrument Concepts	Research instruments	Production
Jasco Research	Noise control, research inst.	Research, production
Kongsberg Maritime Canada	Mission systems, deck equipment	Distribution, post-prod’n
Lockheed Martin	Mission systems	Distribution, integration
Lunenberg Ind. Foundry & Engineering	Propellers, shafts	Production
MAN Diesel & Turbo	Platform systems (propulsion)	Distribution
MetOcean Data Systems Ltd.	Research instruments	Production
Focal Tech/MOOG Components Group	fiber optic cables, slip rings, multiplexers	Production
Nortek Scientific	Research instruments	Production
Omnitech Inc.	Research instruments	Production
Pesca Trawl	Trawling nets	Production
Rainbow Net & Rigging Limited	Trawling nets	Production
Rolls Royce Canada (ODIM)	Research instruments, MVP and LARS	Production
Romor Atlantic, Ltd.	Research instruments	Distribution, post-prod’n
Satlantic Inc.	Research instruments	Production
Ultra Electronics Maritime Systems	Mission systems, research inst.	Production, distribution
Vemco Ltd. (Amirix Systems Inc.)	Research instruments	Production
Wartsila	Platform systems (propulsion/ballast mgt)	Distribution
Welaptega	Research instruments	Production
XEOS	Research instruments	Production

Source: Duke CGGC

6.3.2. SWOT Analysis of Nova Scotia Companies

Table 49 presents a SWOT analysis of Nova Scotia's position in the research vessel value chain.

Table 49: SWOT Analysis of Nova Scotia's Position in the Science Vessel Value Chain

Strengths	*Weaknesses*
• Many local firms active in research instrumentation/marine acoustics sector • Concentration of human capital • Universities and public research • Proximity to Arctic	• Few MNCs active in production • Mostly SMEs • Commercialization funding • Distance from West Coast market
Opportunities	***Threats***
• Growing need for polar and climate research • Increasing demand from South American, Asian, and African markets • Upgrading into other segments of the value chain	• Consolidation of production by non-Canadian MNCs • Strong competition from U.S., Nordic and West Coast Canadian countries in research instrumentation

Source: Duke CGGC

Strengths

Nova Scotia possesses a number of assets to support its participation not only in the NSPS research vessel projects but in research vessel value chains more generally. Primarily, the province is home to a sizeable and dynamic cluster of companies active in the research instrument sector, for which a primary source of demand is the global fleet of research vessels. Nova Scotia hosts both lead firms and numerous SMEs that participate along the value chain as manufacturers, systems integrators, software providers, distributors. Marine acoustics is a very strong capability in the region, both in the private sector and the public sector (DRDC-Atlantic and regional universities). Such clusters are rare. Nova Scotia is home to firms in other sectors important to research vessels, as well, especially deck equipment such as winches and A-frames.

In addition, many of the technicians, scientists, and engineers needed to work in this sector already live in the province, thanks to strong educational programs at local community colleges and universities, which offer qualifications ranging from a welding certificate to a degree in Computer Engineering to a Ph.D. in Oceanography. The local innovation system also includes the Bedford Institute of Oceanography, which conducts ocean-related scientific research, DRDC Atlantic, which conducts acoustics, marine materials and ship dynamics research, and the Halifax Marine Research Institute (HMRI), a public-private research institute which promotes marine R&D with an eye to commercial applications. These organizations serve as important sources of information to local firms regarding technology trends relevant to research vessels.

Finally, Nova Scotia's proximity to the Arctic is a key strength for local firms. Access to Arctic waters provides relatively easy opportunities for local firms to test new products designed for use in polar climates. In addition, as the Arctic warms, Nova Scotia firms, especially those in the research instrumentation sector, are well positioned to take advantage of demand in the growing offshore oil industry and the shipping industries in the Arctic.

Weaknesses

Nova Scotia faces a handful of weaknesses with respect to its ability to upgrade within the research vessel value chain. First, few local MNC offices engage in production activities and instead provide primarily distribution services.[11] With respect to the NSPS, this limits the Canadian content provided by these firms, which make them less appealing as suppliers from an IRB perspective. Furthermore, process innovations in manufacturing industries are often tied to co-location of engineering and production assets; without a strong basis in production, the "deep pockets" for R&D usually associated with MNCs are unlikely to benefit Nova Scotia.

Indeed, many of Nova Scotia's locally owned companies are SMEs, which presents some challenges, especially with respect to accessing new markets. SMEs in general tend to have less cash available to invest in R&D activities. Our interviews suggested that local SMEs' ability to innovate is somewhat hampered by the lack of funding for technology commercialization. While HMRI may, in the medium- to long-run, play a role in filling this gap, in the meantime local firms may struggle to keep up with innovations developed in the US and the Nordic countries.

Finally, Nova Scotia's distance from the West Coast could make participation in NSPS contracts especially difficult. The research vessels to be constructed under the NSPS will be built by Seaspan Marine, Inc. in British Columbia. Hence, the main market opportunities for Nova Scotia firms who wish to participate in NSPS research vessel value chains are distant. This presents challenges from both a communications and logistical perspective, but institutional characteristics of Seaspan's operations present further difficulties. Seaspan has chosen to partner with two foreign-owned systems integrators (Imtech and Thales), which have their own preferred supply chain partners, for the selection and installation of mission and platform systems. Gaining access to these supply chains could be difficult.

Opportunities

The impact of climate change on the world's oceans is an important driver of demand for research vessels. Research vessel fleet renewals not only in Canada but also in the US, Europe, China and other emerging economies, have incorporated as a major objective the improvement of climate research capabilities in their procurement strategies. Receding sea ice has also generated demand for enhanced surveying capabilities, so that Arctic countries can defend continental shelf claims. In addition, climate change has also opened up new areas of the world's oceans to offshore oil and gas exploration. Firms seeking to develop oil and gas deposits in the Arctic and sub-Arctic will be a key source of market

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[11] Of the 21 multinational companies active in the shipbuilding-relevant subsystems, Lockheed Martin, L-3, General Dynamics, Rolls Royce, and Ultra Electronics have significant local Nova Scotia manufacturing and R&D capability.

demand for underwater surveying in the coming years. As sovereign nations and private firms expand their fleets of icebreakers, surveying vessels and ecosystem research vessels to understand and exploit the implications of climate change, companies in the research vessel value chain – particularly those producing underwater instruments – are likely to face increased demand, provided that they are able to remain on the technological frontier.

The fastest growing markets for research vessels and related scientific instruments are non-Western economies, including Russia, Indonesia, Brazil, and China. Brazil's demand is driven especially by its development of the Pre-Sal oil and gas fields off its Southeastern Coast, while China seeks to enhance its research and surveying capabilities as a rising global power. Nova Scotia firms should look to these emerging markets as sources of demand for their technologies.

Finally, Nova Scotia firms face a number of opportunities to upgrade into new sections of the research vessel value chain. This is especially true of those companies producing underwater instruments. Such companies might upgrade forward in the chain, into systems integration, or backward into design; both segments of the value chain create opportunities for increasing upgrading companies' value-added. Systems integration involves the bundling of various components into a "complete system;" with respect to research vessels, this might involve the linking of sensors, winch systems and data loggers into a bundle which can be easily "plugged in" to the vessel as a new crew boards. Demand for systems integration services is growing in multiple sectors of the economy, including the shipbuilding and offshore industries. As research vessels demand technological innovations related to acoustic dampening and pollution control, companies in the research instrument portion of the value chain are well positioned to participate in research and development services related to the vessel design. Jasco, for example, is a Nova Scotia company which both produces underwater instrumentation and also provides acoustic analysis relevant to naval architects.

Threats

As MNCs active in the shipbuilding, marine and defence sectors consolidate operations and integrate vertically, SMEs – such as those which characterize large portions of Nova Scotia's firms in the research vessel value chain – may face growing difficulty accessing markets. Over the last ten to fifteen years, many MNCs, including Rolls Royce and General Dynamics, have grown through acquisitions of smaller firms in order to expand their offerings across different end-markets while simultaneously consolidating their R&D efforts.[12] By expanding product offerings, these MNCs have also been able to bundle products and offer systems integration services. By turning to MNCs with systems integration capabilities, shipyards are able to reduce the number of suppliers that they directly interact with, reducing their risk. This tendency has led to the increasing presence of a few large multinationals in a wide range of instrument markets once populated by several specialized, small firms. If Nova Scotia firms do not develop ties to MNCs or build their own systems integration capabilities, they may find it difficult to participate in new markets.

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[12] As pointed out by one of our reviewers, MNC's are attracted by Canadian funding available to sustain R&D and conduct it in Canada. Variation exists among provinces, however, in supporting R&D funding, with Nova Scotia recently falling behind Newfoundland in funding marine R&D.

Second, firms in Nova Scotia face stiff competition from other countries' shipbuilding and marine technology industries. The United States, Norway, the U.K., Germany, France and Finland host highly competitive and technologically sophisticated MNCs with production and product development networks that span not only their home countries but oftentimes the entire world. Many of these companies have also been able to expand in scope by supplying to related industries including energy, aerospace and defence. In order to survive in this global environment, Nova Scotia's firms will need to identify a handful of niches with high growth potential, such as integrated research instrumentation, in which they can remain competitive in terms of both cost and innovation.

7. Findings and Recommendations

CGGG was asked to make recommendations in three key areas:

- Supporting Nova Scotia companies
- Moving into higher value-added activities
- Regional value chain development activities

7.1. Supporting Nova Scotia companies

7.1.1. Connect with key players in the value chain

Findings

- The value chain is governed by the shipyard, systems integrators and top-tier suppliers. The focus of these main players at the top of the production hierarchy is meeting technical specifications (standards and certifications are important in shipbuilding), cross-vessel systems compatibility, Canadian content, cost, and avoiding delays.
- The primes and many of the systems integrators have web portals for collecting information about potential supply chain partners.
- While supplier web portals are important, buyer-supplier relationships often are a function of past experience with a supplier, their ability to meet delivery times and specification, cost, and amount of local content.
- Developing the relationship between a buyer and supplier is an important aspect of business development. Meeting a supplier at an industry event and establishing a connection focused on joint gains yields better results than simply entering information on their supply chain web portal.

Recommendations

Since the overwhelming majority of the supply chain for the NSPS vessels is under the control of platform and mission systems integrators (and their suppliers), attention of the private sector and government should be focused on how companies enter the supply chain of these value chain actors. In researching how supply chain partnerships are developed between big and small firms, Duke CGGC found that:

- 50% of firms use the same partners over and again;
- Of the remaining 50% looking for new partners:
    - Two-thirds of firms relied on contacts developed through informal networking (company reputation, word-of-mouth) of which one-third were developed through industry conferences.
    - Remaining one-third used web search and industry databases.

The findings have several implications. First, companies should take advantage of industry events in which the major players are participating. These events can lift the companies out of the crowd of potential suppliers. Industry days with the tiered suppliers are extremely helpful for potential suppliers because they provide information relevant for entering the supply chain of a specific company, and, perhaps more importantly, begin to establish a relationship between the buyer and supplier. Second, absent the ability of companies to conduct business development activities, government representatives and affiliated industry groups should be prepared to speak to the major actors about the capabilities of relevant companies in their geographic area of responsibility. Third, companies should ensure that their website has up-to-date, accurate, and detailed information about their products.

Our recommendations to companies are:

- Participate in industry forums and events as they take place. CanSec, WestDef, DefSec, and Industry Days hosted by tiered suppliers and governments provide good opportunities for companies to exchange information about needs and capabilities.
- Communicate clearly what your enterprise has to offer and how it adds value to the large company's supply chain.
- Maintain up to date, accurate and detailed information about products and services on the company website and on the Canadian Company Capabilities registry on Industry Canada's website.
- Register on the online supplier portals of the major platform and mission systems integrators and subsystems manufacturers. Companies use this information to collect information about potential supply chain partners.
- Monitor MERX Canadian Public Tenders Service (www.merx.com) for upcoming projects and bidding opportunities in Canada.

Our recommendations to governments are:

- Know the companies and their capabilities in the shipbuilding value chain in your geographic area of responsibility. Governments can create potential supplier lists by using the existing knowledge about the companies in their region, the Canadian Company Capabilities registry hosted by Industry Canada, and information provided in this report.
- Facilitate site visits to companies in the higher tiers of the production hierarchy. As with industry forums, the ability of buyers to meet potential suppliers provides the opportunity for a quick exchange of information about needs and capabilities among companies.
- Attend industry forums and events to develop contacts for companies, particularly SMEs, not able to attend.
- Communicate to companies how large firms meet suppliers.

7.1.2. Help SMEs overcome barriers to entry in the shipbuilding value chain

Findings

We found that SMEs face four kinds of barriers to enter the shipbuilding value chain.

- Information gaps:

  - Companies need information on who the Tier 1&2 suppliers are, effective ways to get into their supply chains, what regulations are relevant, and what government can do to help if they request assistance.
  - Easy access to information is lacking about companies in Nova Scotia and their capability to provide products and services for the shipbuilding sector.
  - Lack of information exists about the procurement practices of, and certifications required by, the major suppliers and systems integrators.
- Network gaps – SMEs lack the right contacts to bigger firms, which is exacerbated by the lack of resources needed to extend their network. We heard over and again the constraint on time and attention available in SMEs to participate in information sessions, join collaborative networks, and to expend time, personnel, and money on issues, topics, or technologies that are not of immediate value to the company.
- Certification gaps – SMEs do not have the right certifications needed to participate in this highly regulated chain.
- Coordination gaps – the transaction costs of organizing SMEs to become bigger players in the shipbuilding GVC are substantial.
  - Low levels of coordination and collaboration exist among SMEs in Nova Scotia to offer systems solutions to Tier 1 suppliers.
  - A package of companies that can do a piece of the vessels is more attractive to Tier 1 suppliers than single, small companies.

Recommendations

- Close information gaps: Since many of the companies in the ocean technology and shipbuilding sector are SMEs, governments should recognize and incorporate the resource and capacity constraints of SMEs in program design. Specifically,
  - Consolidate market relevant information in one location for easy access and promote its existence. One suggested approach is to develop a website with names of companies, products manufactured, services provided, size of firm, and sample list of customers for easy reference. The Industry Canada website already contains much of this information and can be used as a template to create a similar website for companies in Nova Scotia.
  - Continue to support supplier development and ISO sessions providing details on what certifications are needed to participate in the shipbuilding value chain.
  - Increase direct engagement of SMEs by scheduling visits at their business sites. Local partners in local economic development authorities and business associations can assist government in meeting with companies and providing good information to them.
  - Supplier development sessions sponsored by the province should include information on what government is doing to develop potential supplier lists, facilitate business-to-business meetings (B2B matchmaking), and disseminate information on how to become known by prime contractors and subcontractors.
- Close network gaps: Foster linkages between local suppliers and systems integrators (Tier 1 firms)

    - Develop and increase the frequency of meetings between integrators and SMEs.
- Close certification gaps: Evaluate small business assistance programs in province to identify needs and gaps in program offerings. In particular, consider conducting a capability assessment of SMEs in Nova Scotia, especially in rural areas and First Nation communities, and developing or enhancing capacity development assistance programs.
- Close coordination gaps: Foster linkages among Nova Scotia and Canadian firms to offer systems or sub-system solutions to Tier 1 firms.
    - A note of caution: Research finds that small businesses tend not to make strategic alliances among themselves and prefer to align with large businesses. The preference of SMEs to partner with large firms exists because large firms possess financial, tangible, and intangible resources that are a better complement for small firms than other small firms. In particular, small firms seek from large firms' access to financing, customers, and better IP protection. We heard some of these factors reflected in our interviews about SMEs in Atlantic Canada not working well together. Our perspective is that this may be a function of firm size rather than a cultural aspect of Atlantic Canada.

7.1.3. Inform value chain actors about the effect of public and private regulations on the value chain

Findings

- IRB is a policy with a major effect on the conduct of the supply chain for NSPS vessels, yet the policy has many sub-components that are not well or widely understood by industry.
- The Value Proposition and IRB are separate components of the NSPS procurement process.
- Controlled Goods Program is an important regulatory requirement companies may need to satisfy to participate in the value chain. Companies who are not Controlled Goods certified, but require it for a Request for Proposal, will be provided an opportunity to comply during the bidding process.
- Private regulations in the shipbuilding industry abound and significantly affect whether companies can participate in the supply chains of higher tier companies. Typical supplier standards are:
    - Ability to meet technical specifications
    - ISO 9001:2008 Quality Management
    - Controlled Goods Program / ITAR
    - Price competitiveness
    - Ability to help offset IRBs
    - Management capability
    - Patent experience
    - Capability Maturity Model Integration (CMMI)
    - ISO 14000 Environmental Management
- Buyers in the shipbuilding value chain rank suppliers on a number of factors, including:
    - Ability to meet product specifications
    - Ability to comply with security requirements, safety requirements and industry standards
    - Ability to meet delivery times

    - Ability to price product or service competitively
    - Ability to meet IRB requirements
    - Ability to meet direct rather than indirect IRB benefits.

Recommendations

- Provide information about IRB on a publicly available website and advertise existence of website
  - Clarify basic goal and need for policy
  - Clarify difference between direct and indirect offsets.
  - Clarify the role of Industry Canada
  - Clarify difference between IRB and Value Proposition
- Compile an easy reference source for the Controlled Goods program and ITARS. Place on website and communicate to companies about its existence.
- Compile an easy reference guide for common requirements placed on suppliers. Place on website and communicate to companies about its existence. Reflect in the guide findings about certifications and supplier assessments summarized above.

7.1.4. Improve communications about NSPS and relevant policies to companies and citizens

Findings

Confusion exists about the status of the NSPS Shipbuilding process, particularly:

- Time horizon and decision-making for different vessels
- Difference between production and in-service support contracts
- How access to the shipbuilding value chain is governed by tiered producers and national regulations
- Opportunities for new business

Recommendations

- Use existing organizations and established networks to provide information to small business, rural areas, and citizens about the status of the NSPS shipbuilding process and relevant policies to access the supply chain.
- Manage expectations of immediate economic impact by stating, and repeating, the long-term nature of the shipbuilding project.

Finding

Companies are uncertain which government agency and program to tap for information. Companies are uncertain about the roles of different levels of government in assisting companies, providing information, and their regulatory authority.

Recommendation

- Develop website clearly and authoritatively identifying the responsibility domain of different agencies involved in NSPS at the local, provincial, and federal level.

Finding

General confusion exists about the IRB policy.

Recommendation

- Clarify basic goal and need for policy
- Clarify difference between direct and indirect offsets
- Clarify the role of Industry Canada
- Clarify difference between IRB and Value Proposition
- Provide information on a publicly available website and advertise existence of website

7.2. Moving into higher value-added activities

Finding

Many of the best niches for high value activities occur at the junctures between different GVC stages. Specific examples include:

- the interface between design and component production (dampening of anthropomorphic noise, engine vibrations, acoustic technology and vessel design);
- the commercialization nexus between production and marketing of new end products

Recommendation

- Evaluate entrepreneurial potential, expansion of existing businesses, and supporting consortium opportunities in these areas.

Finding

Emerging technology opportunities in the shipbuilding sector include:

- fuel/energy efficiency (both technology and design)
- ballast water management systems
- automation
- robotics

- sensors
- arctic capable equipment
- smaller weapons systems
- secure communications systems
- combat systems integration
- electro-optics
- synthetic/simulated training

Recommendation

- Focus sector development strategies and programs on actors that participate, and are leaders in, these trends.
- Use province's innovation infrastructure to develop technology for sustaining and growing the shipbuilding industry.
    - Evaluate feasibility of SME consortium for technology development at HMRI
- Grow and nurture a pool of technology-based entrepreneurs
    - Encourage entrepreneurial training in science (oceanography) and engineering programs at the undergraduate and graduate level
    - Expand engineering program at Dalhousie University to offer specialization in systems engineering.

7.3. Regional value chain development activities

7.3.1. Connect with key players in the non-combat vessel value chains

Finding

Nova Scotia is not fully aware of the opportunity offered by the non-combat vessel value chains. Many of our interviews stated that the opportunity for Nova Scotia's SMEs is greater for the research vessels and icebreaker value chains because of the types of products they produce. Opportunities exist for Nova Scotia firms to plug into these chains, due to complementarities between local capabilities in acoustics and digital imaging technologies and the primary purpose (research activities) of the Seaspan ships.

Plugging in to the Seaspan supply chain will take extra effort, due to the distance and associated transactions costs. Sharing information coast-to-coast is costly, and transportation of sensitive equipment may pose challenges.

Recommendations

- Increase engagement with the governments of British Columbia and Vancouver
- Work to establish links to companies participating in the science vessel and icebreaker GVC
- Consider conducting multi-provincial trade missions to Western Canada in partnership with ACOA and WD.

7.3.2. Plan for the future

Finding

NSPS presents a tremendous opportunity for Nova Scotia and Atlantic Canada to develop a globally competitive shipbuilding sector in niche, high value areas.

Recommendation

Develop a plan for how to take advantage of the NSPS opportunity for long-term advantage. Especially important is the continued attention on building the *international* competitiveness of the shipbuilding and ocean technology sectors in Nova Scotia. To do so, we recommend the following:

- *Increase the quantity of high quality research with commercial relevance.* Indirect offsets may be one vehicle to increase the quantity of high quality research with commercial relevance. Organizing government, researchers, and the private sector in ways that make the province an attractive place to satisfy indirect IRB offsets should be strongly considered. Two suggestions we heard during interviews may be particularly helpful in this regard. The first suggestion was that the quantity of research with commercial relevance can be increased by focusing on the list of technologies on Industry Canada's "Enhanced Priority Technology List" (EPTL) developed by the Department of National Defence. The second suggestion is to develop a mechanism by which companies can approach universities or research consortia to explore areas of joint interest. The idea was that companies "go to universities and tell them exactly what they need" rather than expect university researchers to provide commercially relevant technology as a by-product of the academic discovery process. The Spring Board sessions we witnessed as part of the DefSec conference are one way to achieve this goal. Another way to achieve this goal is developing at HMRI a consortium of SMEs and academic researchers to develop commercially-relevant technology.
- *Grow and nurture a pool of technology-based entrepreneurs*. Entrepreneurial training in science and engineering programs at the undergraduate and graduate level support this goal, as do practitioner skills development, entrepreneurs in residence, and externships for graduate students and young faculty to work for a limited period of time at a relevant high-technology firm. The goal of these programs is to combine technical knowledge with entrepreneurial training to facilitate the development of new businesses.
- *Use the province's innovation infrastructure to sustain and grow the shipbuilding industry*. In many industrial sectors, the goal is achieved by infusing existing systems with new technology, particularly in materials science. Improving adoption of new technology in the shipbuilding sector will highlight the critical role of coordinating among different sectors and developing skills needed to fill gaps between nodes of the value chain.
- *Expand access and availability of investment capital to create and grow new companies*. Many federal Canadian programs provide some form of funding for R&D. ACOA, for example, has the Atlantic Innovation Fund; Industry Canada manages R&D related programs, as do Defence Research and Development Canada (DRDC), the National Research Council, Public Works and Government Services Canada through the Canadian Innovation and Commercialization Program

(CICP), and the Canada Revenue Agency through SRED (http://www.cra-arc.gc.ca/txcrdt/sred-rsde/menu-eng.html). We heard that companies are confused about which program is right for them, and are uncertain who in government can provide needed information. Evaluating how existing programs are advertised may be an initial step to expanding access and availability of investment capital to create and grow new companies.

Especially important is the continued attention on building the international competitiveness of the shipbuilding and ocean technology sectors in Nova Scotia. Organizing government, researchers, and the private sector in ways that make the province an attractive place to satisfy indirect IRB offsets should be strongly considered.

7.3.3. Broaden horizons

Based on our analysis of the NSPS Shipbuilding value chains, further evaluation is warranted in three areas: workforce, lessons learned from large government procurements, and improved coordination of the regional innovation system.

1. Workforce

Finding

Workforce issues are a persistent cause for uncertainty and concern in Nova Scotia's shipbuilding sector. One multinational captured this sentiment succinctly by recommending that Nova Scotia "develop a workforce development strategy and let people know what you're doing."

Recommendation

Conduct a local labor market analysis and workforce planning study.[13] Workforce planning studies typically have the following components:

- Local industry trends
- Technology and productivity trends in industry
- Sources of local product demand
- Population and labor force demographics
- Migration trends
- Occupational analysis
- Public education and training systems
- Firm-based training systems
- Role of labor market intermediaries in training
- Financing and coordination of training systems
- Workforce SWOT analysis
- Identification of skill/occupational gaps
- Identification of institutional gaps
- Recommendations for policy-makers and industry

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[13] Our understanding is that ACOA has sponsored a labor market study on the skilled trades and the major projects occurring across the Atlantic. The goal of the study is to help inform provincial and federal labor policy.

2. Lessons learned from recent government procurements relevant to NSPS

Finding

Models, best practices, and lessons learned from other countries are needed to illuminate capacity building and upgrading in Nova Scotia's shipbuilding sector.

Recommendation

Conduct a comparative study of large, recent, and relevant government procurements to identify models, best practices, and lessons learned in other regions.[14]

3. Coordinating the regional innovation system in shipbuilding and ocean technology

Finding

The development and coordination of the province's technology and innovation programs appear ad hoc.

Recommendation

Evaluate opportunities and gaps in existing programs to develop a coordinated technology-based economic development strategy in the shipbuilding and ocean technology sector. [15] The purpose of evaluating the regional innovation system for shipbuilding and ocean technology sector is to align actors and resources to:

- Increase the quantity of high quality research with commercial relevance
- Grow and nurture a pool of technology-based entrepreneurs
- Use province's innovation infrastructure to develop technology for sustaining and growing the shipbuilding industry
- Expand access and availability of investment capital to create and grow new companies

The objective is a coherent, rational process where actors in government, education, industry, and research are pulling together to achieve the same goals. NSPS offers a unique opportunity to evaluate the regional innovation system for the shipbuilding and ocean technology sectors and to develop a system that builds on the strengths already present in Nova Scotia.

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[14] In September, 2012, Public Works and Government Services Canada announced that it appointed a special advisor "to help improve the Canada's Defence Procurement process to better support the competitiveness of Canada's defence-related industries" (www.news.gc.ca). We understand that part of the research may investigate U.S. military procurements.

[15] The 2011 R&D Review Panel (www.rd-review.ca), sponsored by the Ministry of State for Science and Technology, investigated how to enhance federal programming in support of a more innovative economy. The review panel report provides information that may be relevant for the development of a regional innovation strategy outlined above.

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Appendix A- Firms & Supporting Organizations in the Nova Scotia Shipbuilding Value Chain

Company	Product or Service
ABB	Platform systems (propulsion)
ABCO Industries	Metal Fabrication - marine, alum. Boats RCN
Acklands Grainger	MRO industrial supplies; safety supplies
ADM SYSTEMS ENGINEERING	Industrial Engineering services;
Advanced Precision	Manufacture and assembly of precision components
Aecon Fabco	Industrial piping fabrication; ship repair & refit
AF Theriault & Son	Shipbuilding
Akoostix Inc.	Research software and solutions
Allendale Electronics Ltd	Semiconductor and circuit board manufacturing
Allswater Marine Consultants	Naval architecture & marine engineering (marine, offshore & naval); project management & survey
Alscott Air Systems	Marine and offshore HVAC
Aquatron Laboratory at Dalhousie University (HMRI)	Research on ballast water management systems
Atlantic Caterpillar	Marine Propulsion and Power Systems;
Atlantic Towing	Marine equipment; towing services
Atlantis Systems International	Training systems
Babcock Canada	Naval In-service Support & Integrated Logistics Support
BAE Systems	Engineering services; integration, data management
BlueDrop Performance Learning	Training& simulation: virtual reality/serious gaming
Bradeans	Tool and die, parts manufacturer
Breton ND Testing Inc.	Quality Assurance & Control, Hardness Testing and (PMI) Positive Material Identification
Bronswerk Marine	HVAC
Brookville Carriers Flatbed LP	Transportation
CAE Professional Services	Simulation and modeling technologies and integrated training solutions
Canadian Marine Consultants	Consulting to marine transportation
Canadian Maritime Engineering	Ship repair; fab/manufacture/machine
CarteNav	Situational awareness and training
Cherubini Group/Metal Works Limited	Metal Fabrication; Plate work, bridges, structural steel, ASME Pressure vessels
Composites Atlantic Limited	Structural and non-structural composites
Consolidated Fluid Power Ltd.	Marine & Offshore hydraulic training
Crimond Enterprises, Ltd.	Trawling nets
CTH Instruments Ltd.	Valves and calibrations
Deep Vision Inc.	Aerospace & Defence; autonomous systems
Detroit Diesel-Allison Canada, East (Wajax)	Diesel engines
DGI SUPPLY	Machine shop tools distributor
Dixon's Marine Group 2000 Inc.	Boatbuilding; repair & refit
Don Brenton's Fire Protection (DBCan)	Fire suppression and design integration

Company	Product or Service
DRDC-Atlantic	Conducts acoustics, marine materials and ship dynamics research
DRS Pivotal Power	High reliability static power conversion equipment
DSS Marine	Safety systems for marine industry
East Coast Hydraulics & Machinery	Hydraulic machinery
Eastpoint Engineering Ltd	Engineering services
Exact Machine Co. Ltd.	Machine shop
EYE Marine Consultants	Naval Architecture; Design and Engineering
Fieldco Services Inc	Offshore and Onshore Oil and Gas Management Consultancy; Marine and Defence Management Consultancy
Fleetway Inc. (JD Irving Group)	Ship design
G3 Galvanizing Limited	Hot dip galvanizing
General Dynamics Canada	Underwater and Acoustics; Software Support; Systems Integration; Civil Defence; Radio Systems; Command and Control
Geospectrum Technologies	Research instruments
GL Noble Denton Canada	Marine and Engineering Consulting; Technical Assurance
Global Maritime Ltd.	Vessel and rig design, engineering services
Grantec Engineering	Engineering design and analysis
Halifax Marine Research Institute	Pre-commercialization research
Hawboldt Industries	Deck equipment, LARS, propellers
Helly-Hansen Canada Ltd.	Cold weather and protective clothing
Hercules SLR	Cranes and Hydraulics
Horizon System Group	Ice management services
HSE Integrated Ltd.	Health Safety and Environment;
Hydraulic Systems Ltd. (Pennecon)	Hydraulics and deck machinery
IKB Technologies Ltd./Seistec	Research instruments
IMP Group Limited, Marine Division	Distributor of safety equipment, manufacturer of rigging for commercial fishing and aquaculture (cable assembly and fabrication)
Instrument Concepts	Research instruments
International Paint (AkzoNobel)	Paint and Coating Manufacturing
Irving Shipbuilding Inc. (JD Irving Group)	Halifax shipyard
Jasco Research	Noise control, research inst.
K&D Pratt Ltd.	Marine supplies
Keltic Marine Group	Boat and hovercraft design & build
Kongsberg Maritime Canada	Mission systems, deck equipment
L. Himmelman Elastomers Ltd.	Marine Industrial Manufacturing (Rubber and Urethane Products);
L3 Comms, Electronic Systems	Displays, repair and overhaul, logistics support
Lear Chemical Research Corporation	Ultra-thin coatings
Lengkeek Vessel Engineering	Naval architecture, engineering services
Lloyd's Register	Classification society
Lockheed Martin Canada	Mission systems
Lunenberg Ind. Foundry & Engineering	Propellers, shafts

Company	Product or Service
MacDonald Dettwiler & Associates (MDA Corporation)	Systems Integration, large data management/information systems; communications ISS
MacDonell Consulting Services	Port security, engineering services
MacGregor's Custom Machining Ltd.	Metal fabrication and machining; modular construction
MAN Diesel & Turbo Canada Ltd	Marine propulsion; diesel power plants
Marener Industries	Mechanical & hydraulic services; repair & equipment
Marid Industries Limited	Metal fabrication ferrous metals; Industrial and commercial construction (steel and equipment installation)
Martec Ltd	Naval architecture, engineering services, modeling & forecasting, software development
MetOcean Data Systems Ltd.	Research instruments; naval gun fire scoring
Micmac Fire Safety Source Ltd.	Fire & safety products
Mil-Aero Electronics	Electronics design, integration, (cables, harnesses)
MOOG Components Group	Research instruments
MTain Inc.	Logistics and reliability engineering assessment
Mulgrave Machine Works	Pressure vessel design and fabrication
Nautel Ltd	Navigation & communications; transmitters
Nicom Maritime	Computer systems integration; software development
Nodding Marine Limited	Marine repairs & fabrication; welding & machining
Nortek Scientific	Research instruments
Northrop Grumman/Sperry Marine	Marine Navigation Equipment Commercial and Military; Marine Radiocom and Satcom
ODIM (RR Naval Systems)	Research instruments
Offshore Technical Services Ltd.	Construction of Onshore/Offshore Mega Projects; Supply of project management and project controls team
Omnitech Inc.	Research instruments
Pesca Trawl	Trawling nets
Pro-Oceanus Systems Inc.	Ocean environmental instrumentation; ocean industrial instrumentation
Quality Machining Services Ltd.	Machining; fabrication
Quay Marine Associates Inc	Marine Surveys and Project Management;
Ragot CAD/CAM Services	CAM software reseller; CMM reseller
Rainbow Net & Rigging Limited	Trawling nets
Raytheon	Naval defence modeling; systems integration
RC Marine Electronics Ltd	Navigational & guidance instruments; acoustics, navigation & mapping
Remote Access Technologies	Industrial rope access services; inspection, maintenance & repairs
Romatec	Industrial Supplier, valves, automation, metering pumps;
Romor Atlantic, Ltd.	Research instruments
Rosborough Boats	Auxiliary vessels/RHIB
Saab	Radars
Safety Step.ca	Flooring safety
Samuel, Son & Co	Metals distributor
Satlantic Inc.	Research instruments

Company	Product or Service
Seimac	Marine communication products, handheld devices
Sheep Dog	Training& simulation: virtual reality/serious gaming
Siemens Canada	Engineering Services, emergency response services
SNC-Lavalin Defence Programs Inc.	Naval in-service support
Spar Marine	Wireless communications manufacturing
Sperry Marine (Northrop Grumman)	Integrated bridge systems/ Navigation
St. Francis Xavier	Environmental anti-fouling coatings research
Stevens Solutions & Design Inc.	Electronics, law enforcement/communications/video; electronics, defence/communications/video/cellular nodes
Survival Systems Training	Extreme weather survival training
Target Hydraulics & Machine Works Ltd.	Metal fabrication; machine shop
Team Space	Training& simulation: virtual reality/serious gaming
Techtronics Machine Works LTD	Machine Shop; navigation and mapping components manufacturing
TG Welding	Welding; steel fabrication
Thales Naval Services Canada	Surveillance, electronic warfare, engineering services
Trail Blazer Products Ltd.	Manufacturing; assembly
Ultra Electronics Maritime Systems	Mission systems, research instruments
Vemco Ltd. (Amirix Systems Inc.)	Research instruments
Wartsila Canada	Platform systems (propulsion/ballast mgt)
Welaptega	Research instruments
XEOS	Research instruments
Xero Point Green Technology	Hybrid marine propulsion systems
Yachtsmiths International Inc.	Boat building; metal fabrication

Source: CGGC Shipbuilding Database

Appendix B: Known components for the OFSV, organized by subsystem

Subsystem	Detail
Deck Equipment	Sweepline lifting winch (2)
	Trawl wire guide blocks (2)
	Mid water weight winch (2)
	Trawl winch (2)
	Guide for trawl winch (2)
	Plankton winch
	Scientific winch
	CTD winch
	General purpose winch
	Cod end winch
	Sonar winch
	Gilson winch
	Net drum
	Net drum guard
	Trawl net depressor
	Side A-frame
	Main crane
	Stern crane
	Gantry
	Outhaul boom
	Anchor
	Anchor windlass
	Trawl blocks
	Hydraulic system
	38-person lifeboat
	Life raft
	SAR boat
Laboratories and Scientific Equipment	Benches
	Science freezer
	Scientific Data Logger (SAIL)
	CTD
	Marine mammal observation station
	Fume hood
	Salinometer
	Sink
	Hold Downs
	Pingers
	Acoustic Doppler Current Profiler (ADCP)

Subsystem	Detail
Electrical System	Diesel generator (3)
	Main switchboard, 600V
	Active Front End (AFE) (2)
	Ship service switchboard, 600V
	Scientific switchboard, 240V
	Emergency switchboard, 600V
Mechanics	Propulsion motor
	Bow thruster
	Shaft
	Stern tube
	Propeller
	Flap rudder
	Fuel oil filter
	Engine box cooler
	Engine cooling pump
	Deckwash pump
	Sewage pump
	Other pump
Accommodations, etc.	Accommodation suites
	Chairs
	Accommodation doors
	Ventilation
	Windows
	Paint
Electronics (Navigation, communications, acoustics)	Acoustic equipment
	Probes
	Dynamic positioning system
	Gyroscope
	Global Positioning System (GPS)
	Auto-pilot
	Thruster interface
	Net monitor
	Plotter
	VHF communications system
	Automatic Identification System (AIS)
	Satellite communications system
	Intercom
	Radio Direction Finder (RDF)
Other Components	Pipe and fittings

Subsystem	Detail
	Interior joiner systems
	Steel Plate
	HVAC Systems
	Desalination system
	Pollution control system

Source: Best and Johnson 2012

About the Duke Center on Globalization, Governance and Competitiveness

The Center on Globalization, Governance & Competitiveness (CGGC), an affiliate of the Social Science Research Institute at Duke University, is built around the use of the Global Value Chain (GVC) methodology, developed by the Center's Director, Gary Gereffi. The Center uses GVC analysis to study the effects of globalization on various topics of interest including: industrial upgrading, international competitiveness, the environment, global health, engineering and entrepreneurship, and innovation in the global knowledge economy. CGGC has a long history of working in Canada, applying the GVC methodology to port development, the automotive industry, ocean technology, and shipbuilding for Canada's federal and provincial governments since 2006. More information about CGGC is available at http://www.cggc.duke.edu/.

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