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C I S M a R T

# Updated Canadian Asset Map and Assessment of Global Competitiveness in the Area of Maritime Autonomous Surface Ships (MASS)



**Submitted to:** National Research Council Canada  
**Submitted by:** Canadian Network for Innovative Shipbuilding,  
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The initial draft of the report was developed by Gary Dinn and Anthony Goode of M3 Sonar Inc. and Brian McShane who served as contractors of CISMART.

## Executive Summary

Maritime Autonomous Surface Ships (MASS) are poised to transform shipping through advanced automation and remote operation. This report provides a strategic overview of the emerging MASS ecosystem and Canada's position within it. The report's purpose is to identify Canada's capabilities and gaps in this domain, benchmark against international developments, and outline implications for policy and industry. Key findings indicate that MASS technologies have moved from concept to reality, driven by breakthroughs in digitalization, artificial intelligence (AI), and sensing that now enable vessels to operate with minimal human intervention. These innovations promise safer, more efficient and sustainable maritime operations by reducing human error, optimizing navigation, and lowering emissions. Globally, major economies and companies are investing heavily in MASS development, indicating a fast-growing sector as automation is adopted in commercial and naval fleets.

**Regulations:** Leading maritime nations are actively testing autonomous ships and updating/developing regulations. Europe and Asia have launched prominent pilot projects (e.g., Norway's autonomous fjord shipping, Japan's self-docking ferry, China's autonomous cargo routes) and "green corridors" to test uncrewed vessels, while the U.S. Navy aims for 30% of its fleet to be unmanned by 2045. As a global regulatory framework is taking shape, the International Maritime Organization (IMO) has completed its scoping exercise and defined four degrees of autonomy, laying the foundation for a non-mandatory IMO MASS Code expected in 2026, followed by a mandatory version in 2030, to be enforced from 2032. In parallel, countries are issuing interim guidelines to facilitate early deployments. For example, Norway and the UK agreed in 2024 to harmonize North Sea autonomous shipping standards, and the United States Coast Guard released policies to permit supervised MASS trials under existing law.

Regulatory developments in Canada have been cautious but progressing: Transport Canada introduced interim rules (a "Tier I" MASS policy) requiring case-by-case risk assessments for unmanned vessels to meet current safety standards. These efforts, domestically and abroad, aim to ensure laws keep pace with technology as higher degrees of ship autonomy are tested.

**Sector trends:** Technologically, MASS capabilities are advancing rapidly. Ships equipped with extensive sensor networks (radar, LiDAR, optical/infrared cameras) and AI-driven navigation systems have demonstrated the ability to detect obstacles, make navigation decisions, and even execute complex maneuvers like autonomous docking. Early deployments still keep humans "in the loop" remotely, but trials of increasing autonomy (Levels 2–3) are underway on vessels ranging from small workboats to coastal cargo ships. Cybersecurity has become a key focus to protect these connected, software-dependent vessels from hacking.

Strategic drivers for MASS adoption include safety, security, and sustainability: navies and coast guards see autonomy as a force multiplier for surveillance and patrol (allowing persistent presence in hazardous

or remote regions like the Arctic), and industry views automation as a path to greener shipping (reducing fuel use and emissions through optimized operations). Governments are beginning to incorporate MASS into national strategies for ocean protection and innovation, recognizing that autonomous and remotely-operated vessels can serve the public (e.g. environmental monitoring, search and rescue) more effectively.

Canada possesses significant capabilities relevant to MASS, yet has only started to explore their integration. The nation's strengths include a robust marine technology sector (exemplified by companies developing autonomous vessel platforms, sensors, and AI software), strong expertise in AI/robotics and communications, and specialized testing hubs (e.g. the Launch facility in Marine Institute and the COVE facility in Halifax) for ocean innovation. Canadian firms have contributed to MASS projects (for instance, through partnerships with Sea Machines and others on autonomous control systems), and Canada's Navy and Coast Guard are evaluating uncrewed vessels for Arctic surveillance and coast guard duties. However, Canada's current approach remains *cautious* - no full-scale autonomous commercial ships are in operation yet, and policy-makers are proceeding via limited pilot projects and forums (e.g. the Canadian Forum for MASS) rather than a comprehensive program. International comparisons indicate that Canada is lagging behind leading peers in the deployment of MASS. Several allied navies and industries have progressed more rapidly, placing Canada at risk of becoming dependent on foreign technologies unless it accelerates its domestic initiatives.

At the same time, the relatively slow rollout of fully autonomous shipping worldwide provides Canada a window to develop a cohesive strategy before MASS becomes mainstream. Overall, this report concludes that MASS represents a transformative shift in maritime transport and security. It emphasizes that with proactive leadership, Canada can leverage its technological and maritime strengths to capitalize on this emerging trend, thereby enhancing its competitiveness, safeguarding its vast waters, and advancing sustainability. This strategic approach will better position Canada in the global maritime sector rather than risk falling behind.

To seize the opportunities presented by MASS, build on Canada's existing strengths, and address key identified gaps, a set of prioritized, actionable recommendations is proposed for government, industry, academia, and regulators. These measures aim to foster a cohesive Canadian MASS ecosystem, spanning policy, technology, skills, and partnerships, and to position Canada as a global leader in maritime autonomy.

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# 1. Introduction

Maritime Autonomous Surface Ships (MASS) are increasingly being tested and deployed in limited roles, driven by the promise of improved safety, efficiency, and cost savings. Early commercial implementations focus on crew reduction and navigation support for routes that are predictable and repetitive. Many projects target operations where automation can reduce human risk and fatigue. For example, several autonomous ferries and short-haul cargo vessels are operating in fixed-route, low-traffic environments close to shore. Stakeholders report that current autonomous ships are best suited for limited, controlled operations, such as inland waterways or coastal routes at lower speeds, where a clear business case (e.g., labor cost reduction or increased safety) justifies their use<sup>1</sup>. In practice, all current MASS deployments still involve human controllers: either crews on board or remote operators ready to intervene. According to the International Maritime Organization (IMO), even the most advanced autonomous trials today maintain a human-in-the-loop for oversight and emergency control. This reflects the cautious approach of industry and regulators, i.e., using autonomy to assist or replace crew in specific functions, but not (yet) removing human control entirely.

As a notable example, the Yara Birkeland, an electric container ship, commenced commercial operations in the spring of 2022, navigating an 11-nautical-mile route between Herøya and Brevik in Norway. Initially, the vessel operated with a small crew onboard. As of March 2023, it completed its first fully autonomous voyage under human supervision. However, due to regulatory requirements, a crew of three remains on board for safety monitoring. Plans are in place to reduce the crew size to two, with the ultimate goal of transitioning to fully unmanned voyages. Such projects highlight how the first wave of MASS emphasizes remote monitoring and decision support rather than total autonomy. This gradual approach allows testing of autonomous capabilities in real commercial settings (e.g., port-to-port short voyages, harbour tug assistance, survey drones) without compromising safety or violating current manning regulations.

## 1.1 Levels of Autonomy

MASS is defined by the IMO as “a ship which, to a varying degree, can operate independently of human interaction.” The IMO, in its scoping exercise, defined the degree of autonomy for MASS as follows<sup>2</sup>:

- **Degree 1** - ship with automated processes and decision support. Seafarers are on board to operate and control shipboard systems and functions. Some operations may be automated and, at times, unsupervised, but with seafarers on board ready to take control.
- **Degree 2** - a remotely controlled ship with seafarers on board. The ship is controlled and operated from another location. Seafarers are available on board to take control and operate the shipboard systems and functions.
- **Degree 3** - remotely controlled ship without seafarers on board. The ship is controlled and operated from another location. There are no seafarers on board.

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<sup>1</sup> gao.gov

<sup>2</sup> IMO MASS Scoping Exercise: MSC.1/Circ.1638, 3 June 2021

- **Degree 4** - fully autonomous ship. The operating system of the ship is able to make decisions and determine actions by itself.

In practical terms, Degrees 1 and 2 describe advanced but conventional operations (crewed ships with automation or remote support) and are already technically feasible today. Degree 3 (uncrewed but remotely operated vessels) is being tested in restricted contexts, but wider use awaits changes in regulations and proof of reliability. Degree 4 remains aspirational. No large commercial ship currently operates fully autonomously for extended periods, and the IMO has emphasized that a human must be able to control or intervene in all MASS deployments at present.

A ship comprises many embedded systems and could be said to comprise a “system of systems,” to communicate the complexity involved. As automation increases, support for the technologies required to integrate these systems will require more substantial shore-based support in both personnel and equipment. To achieve this, there is a technical requirement to define and agree on a common set of definitions that describe MASS automation technologies and how the user interacts with them.

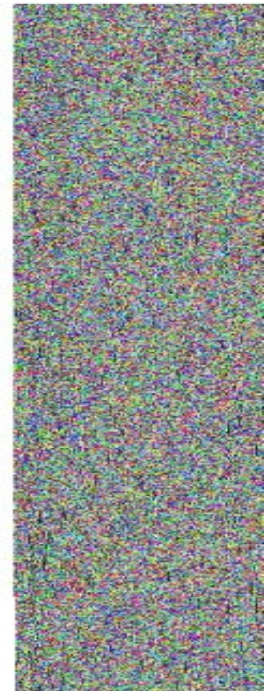
The IMO has typically engaged technical organizations, such as the International Electrotechnical Commission (IEC) and/or the International Standards Organization (ISO), to create and publish detailed technical standards for the technologies that would comprise MASS implementation.

Beyond the IMO’s definitions, other international standards bodies have developed frameworks to characterize levels of autonomy. For example, the ISO has issued terminology to distinguish between *automated* and *autonomous* functions in ship systems. In ISO’s vocabulary (ISO/TS 23860:2022), “automated” refers to processes or equipment that can function without human control under defined conditions, whereas “autonomous” indicates the system can make decisions and take actions by itself, under specific conditions, without human assistance. This helps ensure consistent use of terms like “autonomous ship” across the industry.

Classification societies have also introduced their own categorizations to guide vessel design and certification. For example, Lloyd’s Register (LR) defines six Autonomy Levels (AL 1 to AL 6) (see the figure below). At the lowest level of autonomy (AL 1), the ship possesses minimal autonomous capabilities, primarily manual control with onboard decision support. At the highest level (AL 6), the vessel operates fully autonomously, with no crew onboard and no human intervention required throughout the voyage. LR’s framework (along with similar ones by DNV, ABS, and others) is used to specify and class vessels with incremental autonomous features. For instance, a ship might be built to AL 4, meaning it can operate for long periods without crew but still has remote supervision, versus AL 6, which implies total autonomy and the ability to handle all situations independently.

These industry standards complement the IMO’s categorical degrees by offering more detailed design and testing criteria. However, the autonomy levels defined by these standards do not align perfectly with the IMO “degrees,” which highlights the inherent complexity of implementing the MASS concept in practice. As a result, the current active work being carried out across the world’s fleet is largely confined to IMO Degree 1 and Degree 2 implementations.

In essence, the IMO outlines the autonomy scenario under which a MASS operates, while ISO standards and classification societies provide the framework for consistently describing and achieving those capabilities in practice.



A key conclusion is that the progression toward higher degrees of autonomy will likely take longer to implement than current technological capabilities might suggest. Note that this presents an opportunity for Canada, as it provides sufficient time to develop and execute a strategic approach despite the limited progress in adopting MASS technology.

## 1.2 MASS Potential Applications, Risks and Challenges

In recent years, rapid technological advancements in MASS have led international maritime agencies, such as the IMO and the International Organization of Marine Aids to Navigation (IALA), to focus on the implications of MASS for their members and the broader maritime community. In 2023, IALA held a workshop to assess MASS and its potential global impact<sup>3</sup>. The workshop considered four scenarios for the application of MASS and their likelihood of occurrence over the next ten to fifteen years:

- a. Many crewed ships with automated functions in machinery, navigation, and communications (IMO Degree 1): This scenario is becoming increasingly likely as shipowners and operators recognize the benefits of automation and the technology matures. As more functions are automated, ships with extensive automation could become candidates for remote control from shore-based operations centers. The Yara Birkeland, an automated ship controlled from ashore (to be discussed later), is a prime example of this emerging trend.
- b. Few crewless autonomous ships (IMO Degrees 3-4): This scenario envisions a limited number of crewless autonomous ships, primarily for specific applications such as surveillance, hydrographic data collection, and hazardous operations (e.g., firefighting). Short sea shipping routes could see more of these ships, as the routes are suitable for fully autonomous vessels. However, regulatory and safety concerns will need to be addressed early in the transition. It is expected that few passenger or deep-sea cargo ships will meet the criteria for IMO Degrees 3 and 4.

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<sup>3</sup> IALA- Report on workshop on “Future of Maritime Autonomous Surface Ships (MASS)” -Future Scenarios regarding development and evolution of MASS: 2024

- c. More crewed ships with automated functions (IMO Degrees 1-2): This scenario is highly likely over the next ten to twenty years, as shipowners increasingly order new vessels with higher levels of automation. Building highly automated ships is easier than retrofitting existing vessels. These ships can be remotely controlled, but initially, they will have full or reduced crews onboard to maintain systems and assume control when necessary. Lloyd’s Register is already working with several shipbuilders and shipping companies to develop advanced commercial vessels with fully autonomous capabilities.
- d. Some crewless autonomous ships (IMO Degrees 3-4): It is expected that the number of crewless autonomous ships will increase significantly over the next ten to twenty years as the technology matures and operators become more comfortable with the associated challenges and risks. The increase will likely be confined to passenger and RO-RO ferries, survey ships, vessels engaged in hazardous operations, and naval fleets. According to IALA, while MASS technology will continue to advance in the mid-term, it is unlikely to be applied to large passenger and deep-sea cargo ships for at least twenty-five years<sup>4</sup>.

### 1.2.1 Applications

There are several potential applications for MASS-equipped vessels, including:

- a. Short-sea commercial vessels: Several countries are beginning to integrate MASS technology into short-sea shipping routes and internal waterways, such as the Great Lakes, Norwegian fjords, and various Asian regions. By operating with reduced crews or fully unmanned vessels, significant reductions in personnel costs can be achieved, helping address the widespread skills shortages in the maritime industry. When coupled with electric or hybrid propulsion systems, these vessels can also reduce environmental impacts in coastal and inland waterways.
- b. Smaller vessels, whether with reduced crews or unmanned, are highly suited for automation and autonomous operations, making them ideal for providing persistent and cost-effective surveillance in coastal regions. The same level of automation is beneficial for hydrographic surveys, search and rescue missions, environmental response, and interdiction of illegal activities.
- c. Mission-specific workboats: Routine maintenance tasks, such as servicing offshore wind turbines, pilot delivery, and pickup, could be carried out much more efficiently by purpose-built autonomous vessels, as these tasks are repetitive and predictable. Similarly, harbour lighters used for moving landfills or refueling ships alongside harbors would also benefit from increased automation.
- d. Ferries: As demonstrated in Sweden and other countries, unmanned ferries can be both cost-effective and improve service quality for passengers and vehicles. Short routes, in particular, are well-suited for electric or hybrid-powered autonomous ferries, offering predictable, efficient service similar to automated train systems at airports and on commuter rail lines. For example, the ferry connecting Toronto Island Airport to the mainland, which operates every 15 minutes, is an ideal candidate for autonomous operation, as are many daily harbor ferry routes worldwide.

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<sup>4</sup> <https://maritimecyprus.com/wp-content/uploads/2024/01/The-Future-of-Mass-2024c.pdf>

- e. Naval vessels: Navies worldwide are increasingly designing, building, and retrofitting vessels to incorporate varying levels of automation and autonomy. While most of these platforms are currently smaller, larger navies, such as those of the United States, France, and Germany, are now developing larger, long-endurance, transoceanic vessels. Notably, the U.S. Navy has contracted L3Harris to design a Large Unmanned Surface Vessel (LUSV) as part of its ongoing transition. According to the latest U.S. Navy Force Structure Assessment, between 119 and 146 Unmanned Surface Vessels (USVs) are projected to be in service by 2045, with seven expected to be operational by the end of FY2025<sup>5</sup>. This modernization effort is being guided by a Systems Engineering Framework, which is structured around six key lines of effort: reliable hull, mechanical, and electrical (HME) systems; automated communications; integrated combat systems; common control systems; sensory perception and autonomy; and platform and payload prototyping<sup>6</sup>. In addition, the U.S. Department of the Navy’s Science and Technology Board recently published a report titled “Path Forward on Unmanned Systems,” which provides recommendations for the immediate funding and deployment of a future hybrid fleet consisting of both manned and unmanned vessels.

### 1.2.2 Risks and Challenges

While momentum for adopting MASS technologies continues to grow, several significant risks and challenges remain, limiting their widespread adoption across the commercial maritime sector, government agencies (including navies), and the academic community. These challenges include the following<sup>7</sup>:

- a. Regulatory challenges. There is a pressing need for the global maritime regulatory framework to evolve to accommodate autonomous vessels. This includes developing clear standards for safety, security, and liability, as well as modernizing existing maritime laws. While the IMO and major classification societies are actively working to address these issues, progress remains slow, constrained by the traditionally conservative nature of the maritime sector across both commercial and defence fields.

Some progress is being made through bilateral and regional agreements, particularly in Europe, where countries have enabled cross-border demonstrations of autonomous ships. As the technology matures, port and coastal states will play a critical role in updating their regulations to support the broader adoption of MASS.

Canada currently manages MASS-related activities through individual permitting processes rather than a unified regulatory framework. As autonomous shipping gains traction globally, Canada will need to align with evolving international standards to ensure consistent and safe operations in its ports and coastal waters. Proactively addressing these regulatory needs will be essential for fostering domestic innovation and positioning Canada as a key player in the global autonomous maritime sector.

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<sup>5</sup> Report to Congress on the Annual Long- Range Plan for Construction of Naval Vessels for Fiscal Year 2025. March 2024, p.4 and pp. 11-12.

<sup>6</sup> <https://www.cto.mil/sea/se/>

<sup>7</sup> “The Future of Shipping: Autonomous and Unmanned Marine Vehicles”. Marine Link, Jan 21, 2025.

<https://www.marinelink.com/articles/maritime/the-future-of-shipping-autonomous-and-unmanned-marine-vehicles->

- b. Cybersecurity risks. Given their heavy reliance on digital control systems for machinery monitoring, propulsion, and automated navigation, autonomous vessels are particularly vulnerable to cyber threats. A successful cyberattack could compromise the safe and reliable operation of an unmanned ship, potentially leading to loss of control, disruption of operations, or malicious use of the vessel to damage port infrastructure or cause environmental harm. The consequences of such incidents would be highly disruptive and cannot be underestimated.

A breach in the data centers or remote control infrastructure of MASS can severely compromise vessel safety by enabling attackers to override navigation, disrupt fleet communications, manipulate operational data, or cause physical harm, such as collisions or environmental damage. It also risks widespread fleet disruption, data theft, regulatory violations, and erosion of trust in autonomous systems, with potentially serious commercial, environmental, and national security consequences.

In light of the growing frequency and sophistication of cyberattacks targeting land-based infrastructure, government systems, and commercial networks, it is imperative that robust cybersecurity measures are embedded in the initial design and manufacturing of shipboard systems. While retrofitting cybersecurity features is possible, it is often more costly and less effective than incorporating protections from the outset.

MASS cybersecurity capabilities must be continuously upgraded through secure-by-design system architecture, routine software patching, and the integration of advanced threat detection tools. Critical systems should be isolated to prevent unauthorized access, and security updates must be deployed remotely and promptly to address vulnerabilities. AI-based anomaly detection should be implemented to monitor for irregular behaviour, allowing early threat identification and automated defensive responses.

National governments and international regulatory bodies must play a proactive role in raising awareness among shipowners and operators about cyber risks. In parallel, they should develop and enforce regulations to mandate the adoption of cybersecurity best practices and countermeasures across the maritime industry. Ensuring a secure digital foundation is essential to the safe and resilient deployment of MASS on a global scale.

Cybersecurity enhancements must align with evolving international standards, including IMO guidelines and classification society requirements. Operators should conduct regular penetration testing, leverage digital twins for cyber risk simulation, and maintain human-in-the-loop oversight to ensure safe intervention when needed. This layered, proactive approach is essential to keeping MASS secure and resilient as autonomy and connectivity increase.

### 1.3 Core MASS Technologies, Maintainability and Operational Implications

MASS technologies can be broadly categorized into four interdependent system types:

- a. Sensing systems: These systems gather data from both the vessel and its external environment, incorporating a range of sensors such as optical and infrared cameras, radar, LiDAR, sonar, GPS, and inertial measurement units (IMUs). Together, these sensors deliver real-time information on the vessel's position, speed, heading, attitude, and operational status, along with data on nearby obstacles, traffic, weather, and sea conditions.

- b. **Communication systems:** These systems facilitate data exchange between the vessel and external entities, such as other ships, shore-based control centers, and satellite networks. Technologies such as radios, satellite links, cellular networks, Wi-Fi, and optical communication enable this exchange. Communication systems are crucial for situational awareness, remote control, navigation, coordination, collision avoidance, and integration with Search and Rescue (SAR) operations.
- c. **Decision-making systems:** This category includes the onboard processing systems that interpret sensor and communication inputs and generate commands for the vessel. It encompasses computers, software algorithms, artificial intelligence (AI), and machine learning (ML). These systems enable autonomous route planning, mission execution, and adaptive responses.
- d. **Actuation systems:** These systems physically carry out the decisions made by the control systems. They include propulsion and maneuvering components such as motors, propellers, rudders, thrusters, valves, and pumps. Actuation systems enable the vessel to navigate, stop, steer, adjust buoyancy, and perform mission-specific tasks.

While the reliability of individual components within MASS has significantly improved over the past two decades, the overall complexity and interdependence of these systems have also grown due to increased digital integration. This complexity demands high levels of integration reliability, cybersecurity, and adaptability.

As automation increases, maintaining system integrity will require more specialized training for engineering and navigation personnel. In practice, this often leads to a greater reliance on shore-based support for diagnostics and system management, especially as shipowners consider reducing crew sizes. A smaller crew may result in routine and non-critical maintenance being deferred until the vessel is alongside, potentially increasing turnaround times and associated costs.

Even ships designed to meet IMO Degrees 3 and 4 autonomy, and equipped with substantial redundancy, may still require emergency maintenance during operations. A recent example occurred during the U.S. Navy's deployment of a squadron of four uncrewed surface vessels across the Pacific for major exercises. Each vessel was accompanied by a small crew for maintenance and operational oversight, underscoring the current limitations of fully autonomous maintenance and the critical role of onboard or support personnel in addressing unanticipated technical issues.

In summary, the adoption of MASS introduces advanced technologies that significantly enhance operational capabilities, but also necessitate a new level of maintenance planning, technical expertise, and support infrastructure to ensure safety, reliability, and mission success.

Note that remote control systems, monitoring centers, and data infrastructure must be recognized as integral components of the MASS ecosystem and subjected to regulatory oversight. These elements play a critical role in the safe and effective operation of autonomous vessels, especially at higher levels of autonomy where human intervention is minimal or remote. Including these systems within the regulatory framework ensures that the broader socio-technical system is addressed, encompassing not just the vessel itself but also the supporting infrastructure that enables autonomous operations.

If these components are not explicitly regulated, clear mechanisms must still be established to define the roles, responsibilities, and accountability of shore-based operators and facilities. Regulations should

mandate certification of remote operation centers, enforce cybersecurity and data integrity standards, and establish clear chains of command and liability in the event of incidents. This approach is essential to prevent oversight gaps, ensure operational continuity, and maintain trust in the safety and reliability of MASS technologies.

#### 1.4 Public Perception and Acceptance

As with any transformative technology, public perception and acceptance are critical to the widespread adoption of MASS. Transparency in deployment and a demonstrated track record of safety and reliability will be essential to gaining the trust of stakeholders, including regulators, shipowners, maritime professionals, and the general public.

The views of regulatory authorities and vessel operators, in particular, strongly influence public sentiment. In this context, the safety performance of early MASS adopters will be a decisive factor. A single high-profile incident involving loss of life or significant environmental damage could lead to negative perceptions for years, severely hindering public and regulatory confidence in autonomous maritime operations.

A useful parallel can be drawn from the nuclear energy sector. Despite its overall strong safety record, a few catastrophic events, such as Chernobyl, Fukushima, and Three Mile Island, have had a lasting impact on public confidence and societal acceptance. As a result, nuclear power remains controversial in many jurisdictions, complicating its adoption even as a clean energy alternative to fossil fuels.

For MASS, a similar pattern could emerge. While the technology holds promise for safer, more efficient maritime operations, it will require sustained, incident-free performance in early deployments, alongside proactive communication from industry and regulators, to maintain public trust. Engaging stakeholders early and establishing clear risk management protocols will be crucial in building confidence and fostering broader acceptance of autonomous maritime technologies.

## 2. International MASS Initiatives and Regulatory Developments

Maritime Autonomous Surface Ships (MASS) are rapidly emerging as a transformative force in the global maritime industry. Leading regions, including the United States, Europe, and Asia, are at the forefront of advancing MASS technologies, real-world demonstration projects, and regulatory frameworks. These efforts span both commercial and defence sectors and encompass the development of technical standards, cybersecurity strategies, and risk mitigation protocols. Operational pilots, or real-world trials, are being carried out to validate MASS technologies under practical conditions, enabling regulators and industry stakeholders to assess their performance, safety, and integration with existing maritime systems. The rising interest in maritime autonomy highlights its potential to enhance safety, improve operational efficiency, and reduce crew requirements across a broad range of maritime activities. The following sections provide an overview of recent and ongoing MASS initiatives in the U.S., Europe, and Asia, with a particular focus on regulatory progress, cybersecurity challenges, and defence-related applications.

### 2.1 The United States

The United States is actively advancing the development and deployment of MASS to strengthen the effectiveness of maritime operations. Key initiatives, including those led by the U.S. Navy and outlined in the U.S. Coast Guard's 2023 Unmanned Systems Strategic Plan<sup>8</sup>, are leveraging autonomous technologies to enhance maritime domain awareness, optimize resource allocation, and address critical mission areas such as search and rescue, environmental response, and the interdiction of illegal activities.

Pilot programs and controlled testing are being undertaken to assess the integration of MASS into existing operational frameworks, with an emphasis on maintaining safety and aligning with international regulatory standards. These technologies are expected to enhance operational efficiency, extend the reach and resilience of maritime personnel, and reinforce U.S. leadership in the global maritime domain.

In parallel, the Defence Advanced Research Projects Agency (DARPA) is pursuing the No Manning Required Ship (NOMARS) program, which aims to develop fully autonomous, crewless vessels. The following sections highlight collaborative testing efforts, enabling technologies, and leading U.S. industry stakeholders involved in the development and deployment of MASS.

#### 2.1.1 Marine Autonomy Research Site

The Marine Autonomy Research Site (MARS)<sup>9</sup>, established in August 2018 at Michigan Technological University (Michigan Tech)'s Great Lakes Research Center (GLRC), is recognized as the world's first freshwater testbed dedicated to autonomous surface and subsurface vehicles and related technologies. This 30-mile radius testbed encompasses diverse environments, including Lake Superior's coastline and inland waterways, providing a controlled and varied setting for rigorous testing and development.

- **Diverse Testing Environments:** MARS offers access to urban and industrial settings, natural lakes, bays, rivers, and deepwater sea conditions without the complications of salt, tides, or

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<sup>8</sup> <https://www.dco.uscg.mil/Portals/9/DCO%20Documents/2023%20Unmanned%20Systems%20Strategic%20Plan.pdf>

<sup>9</sup> <https://smartshipscoalition.org/maritime-autonomy-research-site-mars/>

marine mammals. This variety allows for comprehensive testing of autonomous systems in different freshwater scenarios.

- **Advanced Research Platforms:** The GLRC has developed an autonomous Yamaha WaveRunner, integrating an autopilot system for unmanned operation while retaining manual control capabilities. This platform supports research in areas such as high-resolution bathymetric surveying and habitat mapping.
- **Collaborative Initiatives:** MARS serves as the home base for the Smart Ships Coalition<sup>10</sup>, a network of scientists, policymakers, resource managers, and industry leaders focused on advancing autonomous marine technologies and establishing guidelines for their use on the Great Lakes.
- **Industry Partnerships:** As a PlanetM testing facility partner<sup>11</sup>, the GLRC provides resources for companies worldwide to test and deploy connected and automated vehicle technologies in freshwater ecosystems, fostering innovation in maritime autonomy.

Through MARS, Michigan Tech is at the forefront of marine autonomy research, offering advanced facilities and expertise to foster the development and deployment of intelligent maritime systems. For instance, on September 9, 2024, the research center launched a pioneering mission of an 8-meter Autonomous Surface Vessel (ASV) owned by marine robotics company Ocean Infinity. This mission aimed to evaluate the vessel's capabilities in mapping Lake Superior, identifying maintenance issues with underwater harbour structures, and locating archaeological sites of interest.

Note that Transport Canada participates in the Smart Ships Coalition of the Great Lakes–St. Lawrence Seaway, a collaborative initiative supported by the Great Lakes Research Center.

### 2.1.2 SeaRobotics Corporation

Founded in 1999 and based in Florida, SeaRobotics Corporation<sup>12</sup> has been a leader in the development of ASVs for over 25 years. As of 2024, the company has delivered nearly 70 ASVs, with core expertise spanning marine survey applications, such as seafloor mapping and environmental monitoring, and defence and security operations, including coastal surveillance and tactical missions.

#### Key ASV Platforms

SeaRobotics offers a range of ASVs tailored to different operational needs:

- **Surveyor Class** – Compact, portable ASVs designed for use in coastal and inland waters.
- **Utility Class** – Mid-sized, multipurpose ASVs capable of supporting interchangeable payloads for diverse mission profiles.
- **Endurance Class** – Larger ASVs built for extended-duration missions, featuring hybrid diesel-electric propulsion and advanced navigation and collision avoidance systems.

Notable platforms include the SR-Surveyor M1.8, launched in 2019, which delivers synchronized, high-resolution data acquisition in a compact design. Another flagship model, the SR-Endurance 8.0, supports missions of up to 11 days and can deploy additional assets such as uncrewed surface vehicles (USVs) and remotely operated vehicles (ROVs). In 2022, the Marine Institute of Memorial University

<sup>10</sup> <https://smartshipscoalition.org/>

<sup>11</sup> <https://www.michiganfoundations.org/news/planetm-announces-pilots-address-mobility-challenges>

<sup>12</sup> <https://advancedoceansystems.com/>

acquired an Endurance-class ASV for operations at its marine technology test facility, The Launch, in Holyrood, Newfoundland and Labrador.

### Design Philosophy

SeaRobotics maintains a collaborative design approach, working closely with clients to tailor each platform to its intended missions and environmental conditions. Their design principles emphasize:

- Maximizing platform versatility and modularity
- Integrating advanced hardware and software systems
- Optimizing payload-to-platform ratios for varied operational environments

This client-centric strategy allows SeaRobotics to support both off-the-shelf deployments and highly customized mission solutions.

### Market Outlook and Future Applications

The global ASV market is projected to become a multibillion-dollar industry by 2030<sup>13</sup>, driven by increased demand from defence, offshore energy, marine infrastructure, and environmental sectors. As ASV use expands, future applications are expected to include:

- Naval operations and surveillance
- Offshore wind and oil platform monitoring
- Long-duration environmental surveys
- Search and rescue (SAR)
- Multi-ASV coordinated “swarm” deployments

Growth in this space is being supported by continuous advancements in obstacle detection, automated payload handling, and real-time data analytics.

### Innovation Focus

SeaRobotics is investing heavily in next-generation autonomy and uncrewed system capabilities, with a focus on:

- Autonomous Deployment Systems – Allowing ASVs to independently manage onboard sensors and auxiliary assets.
- Swarm Operations – Developing coordinated control systems enabling multiple ASVs to operate under centralized or distributed command, supporting scalable, over-the-horizon operations.
- Defence and Security Integration – Enhancing capabilities for coastal surveillance, tactical operations, and search and rescue missions, where unmanned platforms can perform high-risk tasks safely and cost-effectively.

Through these innovations, SeaRobotics aims to further enable safe, efficient, and scalable uncrewed maritime operations across both public and private sectors.

### **2.1.3 Sea Machines Robotics**

Sea Machines Robotics, headquartered in Boston, Massachusetts, is a leading developer of autonomous command and control systems for the maritime industry. Their technologies enhance the safety,

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<sup>13</sup> <https://www.grandviewresearch.com/industry-analysis/unmanned-surface-vehicle-market-report>

efficiency, and performance of various vessels, including workboats, government and defence vessels, shipping, and passenger vessels.

### Workboats

Sea Machines offers the SM300 autonomous command and control system, enabling workboats to operate with greater autonomy and precision. This system allows for remote and autonomous operations, reducing the need for onboard crew and increasing operational efficiency. For example, in May 2021, Foss Maritime selected the SM300 system for its tugboat, Rachael Allen, making it the first U.S.-flagged harbour tug to incorporate autonomous systems into commercial operations<sup>14</sup>.

### Government and Defence

In collaboration with the U.S. Department of Defence's Defence Innovation Unit, Sea Machines is developing autonomous replenishment vessels. These vessels are designed to support military operations by providing autonomous, self-propelled platforms capable of landing and replenishing military aircraft. The project includes the integration of the SM300 system into existing commercial barges, enhancing logistical capabilities for defence missions.

### Shipping

Sea Machines' technologies are also applied in the shipping industry to improve operational situational awareness. Their systems utilize advanced perception and computer vision to assist in navigation and obstacle avoidance, contributing to safer and more efficient maritime transport. Notably, in October 2021, Sea Machines completed 'The Machine Odyssey,' the world's first long-distance journey of a commercial vessel using autonomous and remote-control technology. The tugboat, Nellie Bly, travelled more than 1,000 nautical miles, starting and ending in Hamburg, Germany, after sailing around Denmark. During the 15-day trip, the vessel was operated by Sea Machines' SM300 system, which handled tasks like navigation and avoiding other ships. While a crew was onboard for safety, licensed officers in Boston, over 3,000 miles away, monitored and guided the journey remotely. The mission demonstrated how this kind of technology could be used for future long-distance shipping.

### Passenger Vessels

For passenger vessels, Sea Machines' autonomous systems are designed to enhance operational reliability and safety by reducing the risk of human fatigue and distraction. By automating routine navigation tasks, such as course keeping, collision avoidance, and situational awareness, the technology supports more consistent performance and frees up crew members to focus on passenger service, emergency readiness, and other mission-critical duties. This not only improves overall vessel efficiency but also contributes to a safer and more comfortable experience for passengers.

Sea Machines is recognized as a leader in the integration of autonomous technologies across multiple maritime sectors, playing a key role in advancing innovation and shaping the future of intelligent and efficient ocean operations.

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<sup>14</sup> <https://sea-machines.com/foss-advances-the-industry-with-first-commercially-funded-autonomous-harbor-tug/>

### 2.1.4 US Navy Funded Developments

Over the past several years, the United States Navy (USN) has initiated extensive programs to develop large and medium-sized unmanned vessels, with Congress authorizing various study contracts awarded to major defence contractors<sup>15</sup>. Notably, in September 2020, the Navy awarded contracts totalling approximately \$42 million to six companies, Austal USA, Huntington Ingalls Industries (HII), Fincantieri Marinette Marine, Bollinger Shipyards, Lockheed Martin, and Gibbs & Cox, to conduct studies on the Large Unmanned Surface Vessel (LUSV) program.

These studies serve as a foundation for the USN's plans to integrate multiple LUSVs and Medium Unmanned Surface Vessels (MUSVs) into the fleet over the next decade as part of its broader expansion strategy. The involvement of these companies, many of which have Canadian subsidiaries, highlights potential collaboration opportunities should the Royal Canadian Navy (RCN) define its own requirements for MASS.

In parallel, the Navy has embarked on the development of Extra-Large Unmanned Undersea Vehicles (XLUUVs). In February 2019, Boeing was awarded a \$43 million contract to build four Orca XLUUVs, with the total contract value later reaching \$274.4 million for five units. The Orca, based on Boeing's Echo Voyager, is designed for extended missions, capable of autonomous operation for several months, and features a modular payload bay to accommodate a variety of mission requirements.

Collectively, these initiatives aim to advance technologies that mitigate operational risks associated with unmanned surface and undersea vessels.

#### U.S. Navy Task Group Operation

In October 2023, a U.S. Navy task group comprising four unmanned surface vessels (USVs), Seahawk, Sea Hunter, Ranger, and Mariner, successfully completed a historic deployment across the Pacific Ocean, arriving in Sydney Harbor on October 24. This mission, part of Integrated Battle Problem (IBP) 23.2, marked significant advancements in naval autonomy and operational integration<sup>16</sup>.

Note that Seahawk and Sea Hunter are trimaran platforms designed specifically for autonomous operations, reflecting the Navy's commitment to integrating advanced unmanned systems. Ranger and Mariner, originally fast supply vessels, have been retrofitted with autonomous capabilities. These conversions provided valuable insights into adapting existing platforms for unmanned operations<sup>17</sup>.

Key achievements and milestones<sup>18</sup> are outlined below:

- **First cohesive USV task group operation:** This deployment represented the inaugural instance of these USVs operating collectively as a unified task group, demonstrating enhanced coordination and capability.
- **Extended operational range:** The USVs traversed critical maritime boundaries, including crossing the International Date Line and the Equator, and conducted port visits in Japan, Guam,

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<sup>15</sup> Congressional Research Service report R45757, "Navy Large Unmanned Surface and Undersea Vehicles: Background and Issues for Congress," updated as of December 19, 2024

<sup>16</sup> <https://news.usni.org/2024/01/16/navy-wraps-first-unmanned-surface-deployment-to-westpac>

<sup>17</sup> <https://www.navalnews.com/event-news/indo-pacific-2023/2023/11/experimental-usn-unmanned-surface-vessel-division-visits-australia/>

<sup>18</sup> <https://seapowermagazine.org/u-s-navy-deployment-puts-leidos-autonomy-on-display/>

the Marshall Islands, Papua New Guinea, and Australia. This extended their operational reach beyond previous limits, showcasing their endurance and reliability.

- Technological demonstration: Equipped with advanced autonomy technology developed by Leidos, the vessels operated in complex maritime environments, providing valuable data on autonomous operations and integration with manned units.

Key technological and operational insights are summarized as follows:

- Integration with manned combatants: The deployment validated that combining autonomous vessels with manned ships enhances maritime domain awareness and accelerates decision-making processes, contributing to more effective naval operations.
- Performance in challenging conditions: The USVs demonstrated high reliability, successfully navigating the demanding conditions of the Western Pacific, thereby affirming their operational readiness in diverse environments.

## 2.2 Europe

Europe has positioned itself as a global leader in the development and implementation of MASS, advancing both regulatory frameworks and technological innovation. The region has supported numerous pilot projects, research consortia, and commercial trials, often funded through the European Union (EU)'s Horizon programs. Countries such as Norway, Finland, France, and the United Kingdom have demonstrated sustained investments in autonomous maritime systems for both commercial and defence applications. Concurrently, the European Union is developing regulatory mechanisms to balance innovation, safety, and ethical use of AI in maritime autonomy. This section outlines key developments in regulation, major pilot projects, and national efforts across Europe.

### 2.2.1 Regulatory Frameworks

The EU is actively developing comprehensive regulations to integrate MASS into existing maritime laws, focusing on safety, liability, and environmental standards. The European Maritime Safety Agency (EMSA) plays a pivotal role in this process, conducting studies and proposing guidelines for MASS operations. Additionally, the EU Artificial Intelligence (AI) Act, effective from August 2024, introduces a regulatory framework for AI, emphasizing safety, transparency, and ethical use, which will significantly shape the development and deployment of autonomous ships through a careful balance between regulatory compliance and technological innovation. A concise review of the EU AI Act on MASS was given by Lee et al. (2024)<sup>19</sup>. It focuses on ethical AI use, safety concerns, and regulatory challenges, including

- Technological maturity and regulation: The EU AI Act requires compliance with specific safety, data protection, and risk management measures for AI systems used in autonomous ships. The ethical use of AI in MASS aims to ensure that maritime autonomy aligns with fundamental rights and societal values. To uphold core ethical principles, including human oversight, transparency, accountability, non-discrimination, and data protection, MASS systems must incorporate human-in-the-loop controls, clearly defined responsibility frameworks, rigorous algorithm audits, and robust

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<sup>19</sup> Lee, YG., Lee, CH, Jeon, YH and Bae, JH, 2024, Transformative Impact of the EU AI Act on Maritime Autonomous Surface Ships, *Laws*, 13(5):61

cybersecurity measures, while actively safeguarding against bias and prohibiting invasive practices such as indiscriminate biometric surveillance.

- **Risk-based regulation:** The EU AI Act classifies AI risks into four categories: unacceptable, high, limited, and minimal. Under the AI Act’s risk-based framework, autonomous navigation and control systems are expected to be classified as “high-risk” AI, comparable to safety components in other transport technologies. High-risk AI systems used on ships will, therefore, face strict requirements: they must undergo conformity assessments by accredited bodies, adhere to rigorous risk management and testing standards, ensure human oversight capabilities, and meet data quality and transparency criteria.
- **Challenges and recommendations:** The precautionary principles of the EU AI Act may slow the pace of innovation and commercialization of autonomous ships. Shipbuilders and shipping companies are encouraged to adopt voluntary codes of conduct, enhance data governance, and collaborate with classification societies to align regulations.
- **Implications for stakeholders:** The EU AI Act’s global reach will affect shipbuilders, software developers, and operators, especially those outside the EU. Compliance with the Act is critical for accessing the European market, positioning the legislation as a global benchmark for AI regulation.
- **Future directions:** Collaboration between regulatory bodies, innovators, and international organizations like the IMO is necessary to balance innovation and regulation. There is a need for ethical guidelines, transparency, and stakeholder education to support the safe and responsible deployment of AI in maritime industries.

These developments underscore the EU's commitment to fostering sustainable advancements in the maritime sector through ethical AI practices, robust safety measures, and proactive collaboration among stakeholders. The EU’s regulatory approach is being developed hand-in-hand with industry players, academia, and member state experts. Pilot projects funded by the EU serve as living laboratories for regulation.

## 2.2.2 EU Pilot Projects and Initiatives

### AUTOSHIP

Europe has been proactive in promoting multimodal transport solutions to foster sustainable business practices, alleviate road congestion, and reduce pollution. A pivotal initiative in this regard is the Motorways of the Sea (MoS) concept, introduced in 2001. This initiative aims to establish a new intermodal, maritime-based logistics chain across Europe, targeting a shift of 30% of road freight over 300 km to multimodal solutions by 2030, and over 50% by 2050<sup>20</sup>. However, current capacities have not yet met these ambitious targets, necessitating further enhancements. Coastal short-sea shipping and inland waterways often face stiff competition from road transport in various European regions, leading to a decline in their market share relative to road transport.

To enhance the competitiveness of maritime transport, the AUTOSHIP project was launched under the European Union’s Horizon 2020 research and innovation program<sup>21</sup>. Running from June 2019 to November 2023, this initiative brought together 15 European partners, including leading industry

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<sup>20</sup> [https://ec.europa.eu/commission/presscorner/detail/en/ip\\_11\\_372](https://ec.europa.eu/commission/presscorner/detail/en/ip_11_372)

<sup>21</sup> <https://www.autoship-project.eu/wp-content/uploads/2023/03/Roadmap-for-Autonomous-ship-adoption-and-development.pdf>

players and research institutions, to develop, integrate, and demonstrate the next generation of autonomous shipping technologies. The project focused on advancing both established and cutting-edge technologies to increase the efficiency and attractiveness of short-sea shipping and inland waterway transport. As part of its real-world demonstrations, AUTOSHIP equipped two vessels, the Eidsvaag Pioner, a coastal cargo ship operating in Norway, and the Zulu 04, an inland waterway barge in Belgium, with autonomous navigation, situational awareness, and remote-control systems.

Through successful trials involving autonomous sailing, docking, and shore-based remote operations, AUTOSHIP showcased the potential of unmanned maritime systems. These achievements demonstrated Europe's leadership in high-tech, specialized shipbuilding and support a more sustainable and competitive maritime transport sector.

Note that the two vessels represent the first in a series designed to showcase key enabling technologies for autonomous operations, including remote-controlled navigation, automated port operations, and integrated communications systems. The following table provides more details of the two vessels and unmanned operations<sup>22</sup>:



<b>Operational focus</b>	Transit, docking & undocking, lock navigation, continuous operation	Transit, docking & undocking, cargo operation, fish farm interaction, weather window
<b>Autonomy level</b>	4. Constrained Autonomous & Continuously Unmanned	3. Constrained autonomous & Periodically unmanned bridge - high degree of automatic operations
<b>Area of operation</b>	Inland Waterways	Open Sea
<b>Rules &amp; regulations</b>	National Authorities and local governing bodies	Flag state, Classification Societies, IMO
<b>Shore operation</b>	Logistical and transport planning, monitoring, exception handling	Route planning, monitoring, remote controlled operations, exception handling, decision support
<b>Infrastructure</b>	RIS (River Information System), VTS, Lock interaction	Local / Coastal VTS
<b>Connectivity</b>	Near land possible use of mobile networks and shorter range communication	Shorter range communication where available, otherwise satellite communications

Autonomous ships, equipped with advanced systems capable of independent decision-making, offer significant potential for fuel efficiency and crew reduction. The AUTOSHIP project successfully demonstrated these capabilities on two prototype vessels, marking key milestones toward zero-emission, autonomous shipping. Through comprehensive digital integration and successful trials in both short-sea and inland waterway operations, AUTOSHIP has laid a strong foundation for a more sustainable maritime future.

Building on these achievements, the next phase will focus on refining autonomous technologies and expanding their adoption across the maritime industry. To support this progression, new EU-funded projects have been launched to further develop and scale the innovations pioneered by AUTOSHIP.

### SEAMLESS

The SEAMLESS project (Safe, Efficient and Autonomous: Multimodal Library of European Shortsea and Inland Solutions) is an EU-funded initiative focused on advancing autonomous shipping

<sup>22</sup> <https://www.autoship-project.eu/demo-use-case/>

technologies, including remote control systems. Building on objectives similar to those of the AUTOSHIP project, SEAMLESS is scheduled to run from January 2023 to December 2026<sup>23</sup>.

The project's primary goal is to develop and adapt essential technological components to establish a fully automated, economically viable, and resilient waterborne freight feeder service for short-sea shipping and inland waterway transport. By integrating autonomous systems, SEAMLESS aims to shift freight transport from road networks to waterways, thereby enhancing the performance of the trans-European transport network.

Key objectives of SEAMLESS include:

- Developing and integrating autonomous navigation, cargo handling, and energy management technologies to ensure safe, efficient, and environmentally friendly operations.
- Conducting full-scale demonstrations of the autonomous feeder services in real-world scenarios to validate technological advancements and operational feasibility.
- Evaluating sustainability and developing innovative business models to support the widespread adoption of autonomous shipping solutions.
- Identifying regulatory gaps and providing recommendations for policymakers to facilitate the smooth and safe deployment of fully automated services.

Through these efforts, SEAMLESS aims to contribute significantly to the evolution of autonomous shipping, promoting a more sustainable and efficient maritime industry.

### ReNEW

The ReNEW project (Resilience-centric Smart, Green, Networked EU Inland Waterways) is an EU-funded initiative focused on enhancing the resilience and efficiency of inland water transport through digitization and innovation<sup>24</sup>. A central feature of the project is the ZULU X-Barge, an autonomous, zero-emission vessel developed to demonstrate the transformative potential of digital technologies in modernizing inland waterway transport.

The ReNEW consortium brings together 24 partners from 11 EU countries, each contributing to the transition of inland waterway transport into a smarter, greener, more sustainable, and climate-resilient sector.

The ZULU X-Barge marks a significant step forward in autonomous shipping, aligning with the EU's broader objectives of reducing emissions and improving the efficiency of freight transport networks across Europe.

### AVATAR

The AVATAR project (Autonomous Vessels, cost-effective Transshipment, waste Return) is an EU co-funded initiative under the North Sea Region Programme 2014 - 2020, running from May 2020 to June 2023. It focused on developing urban, highly autonomous, and zero-emission water-bound cargo transport solutions for last-mile distribution within metropolitan areas, aiming to utilize existing waterways to reduce courier traffic and emissions. The project consortium comprises seven partners from three countries, Belgium, Germany, and the Netherlands, including three universities, three SMEs, and one cluster organization<sup>25</sup>.

<sup>23</sup> <https://smartmaritimenetwork.com/2023/03/13/seamless-project-to-develop-autonomous-inland-shipping-in-eu/>

<sup>24</sup> <https://cordis.europa.eu/project/id/101069682/reporting>

<sup>25</sup> <https://www.tudelft.nl/en/me/about/departments/maritime-and-transport-technology/research/transport-engineering-and-logistics/theme-3-real-time-coordination-for-operational-logistics/avatar>

AVATAR addressed the underutilization of inland waterways in the North Sea Region, particularly in urban settings, presenting opportunities for technological innovations. The project aimed to deploy zero-emission automated vessels to facilitate hourly traffic between Urban Consolidation Centers located outside cities and inner-city hubs, focusing on the distribution of palletized goods and waste return. Key objectives of the AVATAR project included developing prototypes of automated to autonomous ship units, creating remote monitoring and control concepts, formulating use cases and business models for urban contexts, analyzing political and legal frameworks for deploying autonomous ship units in participating regions, and conducting pilot tests to assess performance and feasibility.

The project successfully developed the 1-ton Maverick vessel and a 25-ton highly automated, zero-emission vessel. Both have undergone extensive testing through pilot demonstrations in the partner regions. For instance, on November 9, 2022, a fully automated demonstration showcased autonomous, emission-free waterway vessels, highlighting advancements in long-range remote control and AI-directed collision-avoidance technology.

### 2.2.3 European Nations' Efforts

#### 2.2.3.1 Norway

##### Commercial Initiatives

Yara International and Kongsberg Group launched Yara Birkeland<sup>26</sup>, the world's first autonomous, zero-emission container feeder (120 TEU capacity), which began a two-year testing period in 2021. By 2023 it had completed initial voyages and was nearing certification for fully unmanned operations.

Another milestone is ASKO Maritime's autonomous electric freight ferries "Marit" and "Therese," introduced in 2022. These 67-meter battery-powered vessels carry truck trailers across the Oslofjord; they operate initially with small crews and will transition to remote control from Massterly's onshore center once certified<sup>27</sup>. Norway's maritime industry is also pursuing autonomous coastal shipping for logistics, for example, furniture maker Ekornes partnered with DB Schenker and Naval Dynamics to develop an autonomous electric container vessel for short-sea routes. In addition, Kongsberg and partners delivered "Reach Remote 1", a 24-meter unmanned offshore support vessel, in 2025, to perform subsea surveys. It was developed with Reach Subsea ASA, Massterly, and Trosvik Maritime, and underwent sea trials with DNV and the Norwegian Maritime Authority<sup>28</sup>. These public-private projects underscore Norway's leadership in commercial MASS deployment.

##### Regulatory Efforts

Norway has established a regulatory framework that actively facilitates autonomous ship trials. The Norwegian Maritime Authority (NMA) and the Norwegian Coastal Administration have designated specific test areas, such as the Trondheim Fjord, for conducting trials of unmanned vessels. In 2016, the

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<sup>26</sup> [https://www.change-climate.com/Transport\\_Land\\_Sea\\_Sustainable/Autonomous\\_Battery\\_Electric\\_Ships\\_Feeders\\_Ferries/Yara\\_Birkeland\\_Autonomous\\_Battery\\_Electric\\_Feeder\\_Container\\_Ship.htm](https://www.change-climate.com/Transport_Land_Sea_Sustainable/Autonomous_Battery_Electric_Ships_Feeders_Ferries/Yara_Birkeland_Autonomous_Battery_Electric_Feeder_Container_Ship.htm)

<sup>27</sup> <https://www.maritime-executive.com/article/electric-autonomous-ro-ro-freight-ferries-begin-service-in-norway#:~:text=Norway's%20Oslo%20Fjord,venture%20between%20Wilhelmsen%20and%20Kongsberg>

<sup>28</sup> <https://www.workboat.com/kongsberg-delivers-first-reach-remote-usv#:~:text=Kongsberg%20Maritime%20has%20announced%20the,and%20the%20Norwegian%20Maritime%20Authority>

Trondheim Fjord became the world's first officially designated test site for autonomous ships, providing a controlled environment for testing and developing autonomous maritime technologies<sup>29</sup>.

Since then, Norway has expanded its support for autonomous shipping by establishing additional test areas, including those in Storfjord and Horten<sup>30</sup>. By providing these designated test areas, Norway enables companies and research institutions to conduct trials of unmanned vessels, fostering innovation and development in autonomous shipping technologies.

Norwegian authorities collaborate closely with the country's maritime industry to adapt safety requirements and issue time-limited permits for experimental autonomous operations, ensuring these vessels maintain safety standards equivalent to crewed ships. Regulations are applied on a case-by-case basis using existing laws, with exemptions granted as necessary. The NMA utilizes IMO guidelines to assess novel systems. For instance, the Yara Birkeland initially operated with a minimal crew on board, despite being remotely controlled from shore. As safety was demonstrated through successful tests, the NMA permitted a gradual reduction in crew size<sup>31</sup>.

In May 2024, Norway joined the United Kingdom, Belgium, Denmark, and the Netherlands in signing a Memorandum of Understanding (MoU) to harmonize standards and facilitate cross-border MASS operations in the North Sea. This agreement aims to establish common technical standards and solutions for autonomous ships operating beyond national waters, pending the development of global regulations. The MoU is based on existing guidelines from the IMO and the European Union<sup>32</sup>.

Norway's proactive approach, including active participation in the IMO's efforts to develop non-binding rules for autonomous cargo ships expected to be finalized by 2025, demonstrates its commitment to maintaining its status as a leading maritime nation in the autonomous era.

### 2.2.3.2 Sweden

#### Commercial Initiatives

Sweden's maritime industry is actively researching autonomous and smart ship technologies, though large-scale deployments are fewer than in neighbouring countries like Norway or Finland. Swedish companies have contributed to advancements in remote bridge operations and sensor systems for MASS. For instance, Saab has developed the Autonomous Ocean Core, a vessel-agnostic control system designed to autonomously manage various types of craft, enhancing mission capabilities and providing baseline autonomy, including vessel control, to platforms on or below the ocean surface<sup>33</sup>. Saab has also been transferring its autonomous systems expertise from defence to civilian applications. The Autonomous Ocean Core can be integrated into existing vessels, enabling them to operate autonomously or be remotely controlled, which could allow Swedish workboats or ferries to perform tasks like surveying or short-route ferrying with reduced crew requirements.

There have been pilot projects in Swedish waters, such as trials of automated navigation on Lake Mälaren, often conducted in academic settings. The One Sea alliance, a Finnish-led autonomous

<sup>29</sup> <https://www.sdir.no/en/news/worlds-first-test-area-for-autonomous-ships-opened/>

<sup>30</sup> <https://safety4sea.com/cm-autonomous-ships-test-areas-and-research-centers-making-headlines/>

<sup>31</sup> <https://www.gao.gov/assets/gao-24-107059.pdf>

<sup>32</sup> <https://reachsubsea.no/new-agreement-ensures-international-cooperation-in-the-operation-of-autonomous-ships/>

<sup>33</sup> <https://www.designdevelopmenttoday.com/home/news/22925517/saab-brings-autonomous-capability-to-naval-vessels>

maritime ecosystem that includes Swedish stakeholders, has facilitated access to test areas in the Baltic Sea for such trials<sup>34</sup>.

While no Swedish commercial ship currently operates autonomously in daily service, significant research and development efforts, supported by Swedish universities and the maritime administration, position Sweden to implement MASS solutions in the near future. For example, the Swedish policy lab for maritime autonomous surface ships has explored various use cases to develop practical policies, indicating a proactive approach to integrating autonomous technologies into the maritime sector<sup>35</sup>.

### Regulatory Efforts

Sweden's maritime authorities are actively aligning national regulations with emerging EU and IMO frameworks for MASS. The Swedish Transport Agency has participated in the EU's regulatory scoping exercises and contributed to the development of the 2021 EU Operational Guidelines for MASS trials.

Domestically, Sweden permits experimental operations of autonomous or remote-controlled vessels on a case-by-case basis through exemptions. The Swedish Transport Agency is responsible for producing regulations and ensuring compliance across all modes of transport, including shipping. Before granting trial permissions in Swedish waters, authorities require a safety case demonstrating equivalence to crewed operations.

Sweden also engages in Nordic cooperation on MASS, exchanging best practices with Norway, Finland, and Denmark, thereby leveraging the Nordic maritime technology cluster's experience. While Sweden has not yet enacted dedicated MASS legislation, the government has indicated support for updating rules to address issues such as compliance with the International Regulations for Preventing Collisions at Sea (COLREGs) for autonomous vessels and defining the responsibilities of remote operators. Currently, any autonomous vessel operating in Sweden must obtain an experimental permit and adhere to specific conditions, which may include having a standby crew or remote supervisor.

### 2.2.3.3 France

France has been actively advancing autonomous maritime operations through several notable initiatives:

#### SeaOwl's "ROSS" Initiative

In 2020, SeaOwl, a French marine services firm, launched the Remotely Operated Service at Sea (ROSS) project<sup>36</sup>. As part of this initiative, SeaOwl retrofitted the 80-meter-long supply vessel VN Rebel for remote operation. In a landmark demonstration off Toulon, a SeaOwl captain in Paris remotely commanded the vessel, marking France's first application of an IMO MASS trial resolution on a sizable ship. This trial was conducted under authorization from French authorities, with Bureau Veritas (BV), collaborating on compliance and class rules.

#### Naval Group's Contributions

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<sup>34</sup> <https://www.ship-technology.com/features/featureone-sea-the-global-future-for-autonomous-marine-transport-5920992/>

<sup>35</sup> <https://www.diva-portal.org/smash/get/diva2%3A1803727/FULLTEXT01.pdf>

<sup>36</sup> <https://maritime-executive.com/article/seaowl-plans-unmanned-fleet-for-offshore-inspection-services>

Beyond SeaOwl, companies like Naval Group have been transferring autonomous technologies to civilian applications. For example, Naval Group's subsidiary, Sirehna, has provided autonomous navigation software for trials of remote tug operations in French ports<sup>37</sup>.

### EU-Funded MOSES Project

France has also participated in the EU-funded MOSES project<sup>38</sup>, which concluded at the end of 2023. This project aimed to enhance short sea shipping by developing innovations such as autonomous ship maneuvering and berthing systems, and a feeder vessel equipped with a robotic container-handling system. French ports and firms contributed to developing an autonomous berth-to-berth navigation system for short-sea feeders, aiming to improve the operational capacity of small ports<sup>39</sup>.

### CMA CGM's Research Initiatives

In addition, French shipping companies like CMA CGM are researching smart ship systems, including intelligent autopilots and automated engine rooms, to move toward semi-autonomous operations in the future.

While no French commercial ship operates fully autonomously in daily service yet, these pilot programs and the collaborative efforts of organizations like Bureau Veritas are laying the groundwork for future advancements in autonomous maritime operations.

### Regulatory Efforts

France has proactively updated its legal framework to accommodate autonomous vessels, taking several significant steps:

- a. Legal Definitions and Framework
  - 2016 amendment to the Transport Code: France amended its Transport Code to define an "uncrewed ship" legally, marking an early move to recognize autonomous vessels within its legislative framework.
  - Law of 24 December 2019: This law empowered the French government to issue regulations facilitating autonomous ship navigation and to address related safety, liability, and insurance matters.
- b. Ordinance and Decree Establishing Experimental Regime
  - Ordinance No. 2021-1330 of 13 October 2021: In accordance with the 2019 law, this ordinance established a specific experimental regime for fully autonomous or remotely controlled vessels. It allows such vessels to operate in French territorial waters for up to two years under strict conditions, effectively creating a controlled environment for MASS innovation.
  - Legal definitions introduced<sup>40</sup>:
    - Autonomous vessel: Defined as a vessel operated remotely or by its own operating systems, whether or not there are seafarers on board.
    - Maritime drone: Defined as a floating surface or underwater craft operated remotely or by its own operating systems, without personnel, passengers, or freight on board, and whose technical characteristics, particularly limits of size, power, and speed, are defined by regulation, with a gross tonnage of less than 100.

<sup>37</sup> <https://www.sirehna.com/autonomous-and-remote-control-vessel-kit/>

<sup>38</sup> [https://moses-h2020.eu/wp-content/uploads/2022/03/MOSES\\_Project-Overview-presentation\\_new.pdf](https://moses-h2020.eu/wp-content/uploads/2022/03/MOSES_Project-Overview-presentation_new.pdf)

<sup>39</sup> <https://www.fundacion.valenciaport.com/en/news-events/2024/03/moses-project-develops-autonomous-feeder/>

<sup>40</sup> <https://www.hfw.com/insights/la-boussole-french-shipping-bulletin-feb-2022/>

- Technical distinctions: The decree sets technical limits (e.g., size, speed, tonnage) to distinguish "maritime drones" (small craft under 20 knots and under 100 gross tons), which can be tested more readily.
  - Clarification of legal responsibility: The decree confirms that the "master" of an autonomous ship is the person who commands it, even from a remote center, thereby clarifying legal responsibility.
- c. Standards and Guidelines
- Bureau Veritas involvement: The French classification society, Bureau Veritas, has released guidelines for autonomous shipping and has collaborated with the French Flag to ensure the application of IMO's MASS Interim Guidelines in French trials.
  - EU initiatives: French representatives contributed to the EU MASS trial guidelines in 2021, aligning national efforts with broader European initiatives.

### Defence Applications

France is actively investing in unmanned naval systems, recognizing their critical role in future naval operations. The French Navy (Marine Nationale), in collaboration with the United Kingdom, has developed the Maritime Mine Countermeasures (MMCM) program, delivering autonomous mine-hunting systems. In December 2024, Thales delivered the first serial production unmanned surface vehicle (USV) equipped with towed sonar to the French Navy as part of this Franco-British initiative<sup>41</sup>.

Under France's SLAM-F program (Système de Lutte Anti-Mines Futur or Future Mine Warfare System), the Navy is set to receive six USVs in 2025. These will be deployed in system-of-systems configurations, each comprising two USVs, alongside autonomous underwater vehicles (AUVs), to enhance mine countermeasure capabilities while minimizing risks to personnel<sup>42</sup>.

Beyond mine warfare, Naval Group, France's leading naval shipbuilder, unveiled the Seaquest autonomous surface vessel at Euronaval 2024. This USV is designed for surveillance and anti-submarine warfare roles, reflecting France's commitment to integrating unmanned systems into various naval operations.

The French Navy has been actively testing a range of unmanned assets, including surface drones for surveillance missions in regions like the Gulf of Guinea and the Mediterranean, aiming to counter piracy and smuggling activities. France's 2030 Naval Technology plan emphasizes the integration of drones across all domains to operate alongside crewed warships. Notably, the newest French frigates and the future aircraft carrier are being designed to control swarms of aerial and surface drones, showcasing a strategic shift towards autonomous capabilities.

French defence companies such as Thales, Naval Group, and Exail (formerly ECA Group) are collectively advancing a suite of unmanned systems, ranging from USVs to AUVs and unmanned aerial vehicles (UAVs), for integrated naval use. These developments position France to field one of Europe's most robust sets of naval USVs, particularly in mine countermeasures, a capability shared with Belgium and the Netherlands, and potentially expanding to armed unmanned patrol boats for force protection. This dual focus on mine warfare and power projection support illustrates how France is integrating autonomy into its naval doctrine.

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<sup>41</sup> [https://www.thalesgroup.com/en/worldwide/defence-and-security/press\\_release/world-first-thales-delivers-first-autonomous-drone](https://www.thalesgroup.com/en/worldwide/defence-and-security/press_release/world-first-thales-delivers-first-autonomous-drone)

<sup>42</sup> <https://militaryembedded.com/unmanned/sensors/autonomous-mine-countermeasure-drone-system-delivered-to-french-navy-by-thales>

Naval Group and its subsidiary Sirehna are at the forefront of French efforts in MASS. The Seaquest S is a 9-meter tactical USV designed for intelligence, surveillance, and reconnaissance (ISR), hydrography, and armed patrol missions. It can be launched from larger ships and features full sensor integration. In addition, a 50-meter Medium Unmanned Surface Vessel (MUSV) is under development, offering transoceanic endurance. Current operations are remotely supervised, but future vessels are being designed for higher levels of autonomy, aligning with IMO Degree 4 autonomy standards.

#### 2.2.3.4 Finland

Finland has been a pioneer in maritime automation through its strong technology companies. Wärtsilä, a Finnish marine systems firm, has developed autonomous navigation solutions and in 2018 showcased an autonomous ferry trial with Finferries (the ferry “Falco” executed auto-docking and collision avoidance under remote supervision). Building on this, Finnish stakeholders launched the One Sea ecosystem, an industry alliance mentioned earlier (including Wärtsilä, ABB, Cargotec, and others), with the goal of enabling autonomous shipping by 2025 in the Baltic. A dedicated test area, Jaakonmeri off Finland’s west coast, was established in 2017 for MASS trials. This has hosted experiments such as remote-controlled harbour tug maneuvers and sensor testing for autonomous vessels.

Finnish companies also participate in EU projects, for example, AUTOSHIP involved Finnish partners and demonstrated autonomous barge operation. Meanwhile, Wärtsilä converted one of its vessels, AHTI, into a floating lab to test autonomous navigation in real conditions<sup>43</sup>. In 2022–2023, Finferries and partners continued trials on short-route ferries using automated crossing systems, aiming to eventually deploy an autonomous electric ferry in the archipelago service. Finland’s focus is on integrating autonomy with green shipping, as seen by its projects that combine electric propulsion with autonomous control for sustainable, efficient short-sea shipping.

#### Regulatory Efforts

Finland has adopted a progressive and controlled approach to MASS, facilitating innovation while ensuring safety:

- **Jaakonmeri test area**  
In 2017, Finland inaugurated the Jaakonmeri test area, the world's first open maritime test zone for autonomous shipping projects. Located off the west coast near Eurajoki, this area is accessible to companies, research institutions, and other entities worldwide wishing to test autonomous maritime traffic, vessels, or related technologies. The test area is managed by DIMECC Ltd., which oversees its operations and ensures compliance with established guidelines<sup>44</sup>.
- **Regulatory framework**  
The Finnish Transport and Communications Agency (Traficom) issues time-limited trial permits for MASS operations, contingent upon comprehensive risk assessments and mitigation plans. Temporary regulations have been enacted to accommodate experimental activities, allowing for crew reductions or omissions within the test area under specific conditions. This framework ensures that autonomous vessel trials are conducted safely and responsibly<sup>45</sup>.
- **International collaboration**  
As an active member of the EU, Finland contributed to the development of the EU Operational Guidelines for Safe, Secure, and Sustainable Trials of MASS in 2021 and is working to incorporate these guidelines into national practices. Finnish policymakers advocate for revising international

<sup>43</sup> <https://www.wartsila.com/ancs/ahti/Getting-AHTI-ready-for-upgrade>

<sup>44</sup> <https://www.aalto.fi/en/news/launching-autonomous-vessels-in-our-waters>

<sup>45</sup> <https://safety4sea.com/finland-amends-law-to-promote-automation-in-maritime>

regulations, such as the International Regulations for Preventing Collisions at Sea (COLREGs) and the International Convention for the Safety of Life at Sea (SOLAS), to explicitly address autonomous ships. In the interim, remote operators are treated analogously to crew members for legal purposes.

- **Nordic cooperation**  
Finland participates in Nordic cooperation on autonomy, sharing data and best practices with neighbouring countries like Norway and Sweden. This collaboration leverages the collective experience of the Nordic maritime technology cluster to advance autonomous shipping initiatives across the region.
- **Safety coordination**  
The Finnish Navy and Border Guard coordinate with civilian agencies to ensure that autonomous vessel tests in Finnish waters do not compromise safety, particularly in busy seaways like the Gulf of Finland. This inter-agency collaboration underscores Finland's commitment to maintaining maritime safety while fostering innovation.

Overall, Finland's regulatory stance is forward-thinking, facilitating real-world trials to inform the development of permanent rules. By aligning with EU-wide standards, Finland aims to ensure the feasibility of cross-border MASS operations in the future.

### 2.2.3.5 Denmark

Denmark, renowned for its robust maritime industry, has adopted a collaborative and incremental approach toward the integration of autonomous shipping technologies.

#### Industry Initiatives and Pilot Projects

Danish maritime firms, including industry leaders such as Maersk and DFDS (Det Forenede Dampskibs-Selskab, i.e., The United Steamship Company), have invested in automating port operations and optimizing voyages, laying the groundwork for the future adoption of MASS. While fully autonomous Danish merchant vessels are not yet operational, several pilot projects have demonstrated significant advancements:

- **Automated ferry berthing:** In 2020, DFDS, in collaboration with partners, tested an automated ferry berthing system, enhancing docking efficiency and safety.
- **Autonomous workboats:** The Port of Copenhagen experimented with small autonomous workboats for harbour monitoring, showcasing potential applications in port management.
- **Remote navigation trials:** Sea Machines Robotics, a U.S.-based startup with Danish founders, conducted remote navigation trials in 2017 using a Svitzer tug in Copenhagen, successfully demonstrating autonomous transit and docking capabilities.
- **Autonomous harbour bus:** In December 2022, a collaboration involving the Technical University of Denmark (DTU) resulted in Denmark's first autonomous harbour bus prototype, the GreenHopper, which operates in the Port of Aalborg.

Building on early EU projects like MUNIN (Maritime Unmanned Navigation through Intelligence in Networks)<sup>46</sup>, which envisioned unmanned bulk carriers and included participation from Danish academia, Denmark's maritime industry is preparing for the gradual implementation of autonomous technologies in vessels such as short-sea cargo ships and survey vessels. Danish shipping companies

<sup>46</sup> <https://www.cml.fraunhofer.de/en/research-projects/munin.html>

are also observing Norway's advancements; for instance, DFDS has considered deploying autonomous feeder vessels to connect Nordic ports in the future. The current commercial focus is on incremental automation, such as automated onboard systems and remote engine monitoring—as progressive steps toward full autonomy, often achieved through partnerships with international technology developers.

### Regulatory Efforts

The Danish Maritime Authority (DMA) has proactively addressed the regulatory challenges associated with autonomous shipping:

- **Regulatory analysis:** Recognizing that existing maritime regulations assume manned vessels, the DMA commissioned analyses to identify regulatory barriers. In 2017, it recommended a unified approach through the IMO for regulating autonomous ships<sup>47</sup>.
- **Flexible testing regime:** To foster innovation ahead of formal legislation, Denmark established a flexible test regime. The DMA permits experimental autonomous operations under specific waivers, provided that safety is demonstrably maintained. It has published guidelines for testing maritime technologies, inviting companies to apply for trials in Danish waters. The DMA designates test areas and sets conditions, such as requiring a standby crew or implementing special traffic measures<sup>48</sup>.
- **Safety standards:** The DMA emphasizes that autonomous trials must be "at least as safe" as conventional shipping. Denmark supports the IMO's interim guidelines and the EU's trial guidelines, ensuring that national exemptions align with international principles.
- **International collaboration:** Danish authorities coordinate with other agencies, including ports and the Coast Guard, to manage autonomous vessel tests effectively. In September 2023, Denmark signed a MoU with the United Kingdom and Belgium to enhance collaboration on digital technologies and autonomous systems aboard ships, aiming to share knowledge and harmonize technical standards with neighbouring countries.

### 2.2.3.6 Germany

Germany has adopted a research-driven and incremental approach to autonomous shipping, focusing on high-tech niches and inland navigation. German universities and research institutes, notably the Fraunhofer Center for Maritime Logistics and Services (CML) in Hamburg, have been at the forefront of pioneering projects such as MUNIN, which aimed to develop and verify concepts for autonomous ships<sup>49</sup>.

### Key Initiatives and Projects:

- **CAPTn initiative in Kiel:** The Clean Autonomous Public Transportation Network (CAPTN) in Kiel has been developing the research vessel MV Wavelab, Germany's largest autonomous shipping research catamaran. Launched in 2022, Wavelab is undergoing semi-autonomous and autonomous navigation tests in the Kiel Fjord, utilizing digital twin technology and 5G communications, with contributions from local firms like Anschütz<sup>50</sup>.
- **Inland waterway trials:** The German Aerospace Center (DLR) is constructing a digital test field for automated and autonomous inland navigation on the Spree-Oder Waterway. This initiative

<sup>47</sup> <https://www.ship-technology.com/news/denmark-recommends-global-regulation-autonomous-ships/>

<sup>48</sup> <https://www.dma.dk/growth-and-framework-conditions/maritime-digitalization/guidelines-for-testing-maritime-technologies/>

<sup>49</sup> <https://www.cml.fraunhofer.de/en/research-projects/>

<sup>50</sup> <https://www.rivieramm.com/news-content-hub/news-content-hub/autonomous-vessel-set-to-be-demonstrated-in-2024-78986>

- aims to address challenges such as unreliable satellite data reception in built-up areas by integrating satellite navigation with other sensors installed on ships and on land<sup>51</sup>.
- Industry contributions: German marine electronics companies, including Raytheon Anschütz, are advancing autonomous navigation technologies. For instance, Anschütz has been involved in the development of the MV Wavelab, contributing to the progress of autonomous navigation systems<sup>52</sup>.

#### Regulatory Developments:

Germany is methodically examining its legal framework to accommodate autonomous ships while maintaining its stringent safety culture. The Federal Ministry of Transport initiated a comprehensive regulatory review following IMO's scoping exercise on MASS. Germany contributed to crafting the EU Operational Guidelines for MASS trials in 2021 and has largely adopted them for national use. Currently, German law mandates that a ship's captain be on board; therefore, unmanned operations require case-by-case exemptions. To facilitate testing, Germany has established dedicated test fields, such as the Elbe Maritime Innovation Region (eMIR) in the North Sea and a test stretch on the Spree-Oder Waterway. These areas are utilized by organizations like DLR and industry partners to trial autonomous navigation under controlled conditions.

The German flag state authority, BG Verkehr, has issued guidance that MASS proposals must demonstrate equivalent safety standards, such as ensuring lookout capabilities via cameras and that remote operators possess qualifications akin to onboard crew. In September 2023, Germany concluded a government study identifying necessary legal changes, including clarifying the definition of "Schiffsführer" (master) in the context of unmanned vessels. While primary legislation updates are anticipated, Germany aims to align with eventual IMO regulations.

Although Germany did not sign the May 2024 North Sea MoU on autonomous ships, it continues to collaborate closely with signatory nations through the European Maritime Safety Agency (EMSA) and the Bonn Agreement for maritime safety. Germany's decision not to sign the MoU was likely based on a methodical, step-by-step strategy for adopting MASS. German authorities have emphasized the importance of first developing robust domestic legislation and aligning with emerging international regulations before committing to such agreements<sup>53</sup>.

In summary, Germany's regulatory efforts are characterized by a methodical, research-backed approach: enabling pilot projects under strict oversight now and systematically planning legislative amendments to swiftly permit autonomous shipping in regular service once technology and international law mature.

#### 2.2.3.7 The Netherlands

The Netherlands is at the forefront of developing and regulating MASS, combining cutting-edge projects with proactive policy. Below are key initiatives and a summary of Dutch leadership in MASS technology and governance.

#### Innovative Autonomous Vessel Projects in the Netherlands:

<sup>51</sup> <https://www.dlr.de/en/media/publications/magazines/all-digital-magazines/dlrmagazine-174/full-steam-ahead-for-autonomous-shipping>

<sup>52</sup> <https://massworld.news/anschutz-prepares-for-autonomy-tests-with-mv-wavelab/>

<sup>53</sup> [https://www.bmv.de/SharedDocs/EN/publications/strategy-for-autonomous-driving.pdf?\\_\\_blob=publicationFile#:~:text=Maritime%20Organization%20,not%20subject%20to%20IMO%20guidance](https://www.bmv.de/SharedDocs/EN/publications/strategy-for-autonomous-driving.pdf?__blob=publicationFile#:~:text=Maritime%20Organization%20,not%20subject%20to%20IMO%20guidance)

- Fugro’s Blue Essence USVs: Dutch survey company Fugro operates a fleet of Blue Essence uncrewed surface vessels (USVs) that are redefining offshore inspections. In April 2023, Fugro achieved a world first by completing a fully remote subsea inspection of an offshore wind farm using a 12-meter Blue Essence USV equipped with an eROV (electric ROV)<sup>54</sup>. The operation at the Aberdeen offshore wind centre was controlled from Fugro’s remote operations centre onshore and included structural inspections of turbines and a seabed survey. Notably, Blue Essence is also the first USV to receive Maritime and Coastguard Agency approval for fully remote surveying in UK waters. These USVs can operate for two weeks at sea without refuelling and cut emissions by 95% compared to conventional vessels, showcasing safer and greener offshore operations.
- SEA-KIT collaboration and approvals: Many of Fugro’s USVs were co-developed with SEA-KIT International, a UK pioneer in uncrewed vessels. Fugro’s Blue Essence design is based on SEA-KIT’s 12m USV platform, and the partnership has achieved several milestones. Together they delivered the first commercially available USV+ROV combination for offshore inspection and secured operating approvals from authorities in Europe, the Middle East, and Australia for these remote-controlled vessels. By late 2023, Fugro moved to fully acquire SEA-KIT, underscoring the Dutch commitment to scaling autonomous maritime technology. This partnership’s accomplishments, including the North Sea wind-farm inspection noted above, demonstrate the Netherlands’ ability to integrate and deploy cutting-edge autonomous vessels under real-world regulatory oversight.
- Damen’s autonomous tug development: Damen Shipyards, the Netherlands’ leading shipbuilder, has been actively exploring autonomous workboats. In 2019, Damen provided a Stan Tug 1004 to Boston-based Sea Machines, which was retrofitted with an SM300 autonomy system as a demo vessel<sup>55</sup>.
- Autonomous canal boats – Roboat and AVATAR: The Netherlands is also pioneering autonomous vessels for urban waterways. The Roboat project, a joint effort of MIT and AMS Institute in Amsterdam, built self-driving electric boats to navigate the city’s canals. By 2022, full-scale Roboat prototypes (approximately 4 meters long) were undergoing tests in Amsterdam, transporting passengers or 3,000+ pounds of cargo and even autonomously docking to collect waste<sup>56</sup>

#### Progressive Regulation and Policy Frameworks:

The Netherlands has been proactively updating its laws to accommodate autonomous and remotely operated ships. As early as 2018, the Ministry of Infrastructure introduced a Policy Regulation for Experiments in Autonomous Sailing on inland waterways. Effective 1 October 2018, this policy created a legal basis for companies to conduct trials with highly automated vessels under strict safety plans. It allows temporary exemptions from crew requirements so that prototypes can be tested on designated routes, with oversight by Rijkswaterstaat and the ILT (Inspectie Leefomgeving en Transport)<sup>57</sup> regulator. A similar policy was adopted in 2019 for trials in Dutch territorial seas. These experimental frameworks have enabled dozens of pilot projects in the years since, greatly accelerating innovation while maintaining control over navigational safety.

<sup>54</sup> <https://www.fugro.com/news/business-news/2023/fugro-blue-essence-completes-worlds-first-fully-remote-offshore-wind-rov-inspection#>

<sup>55</sup> <https://www.damen.com/services/damen-trading/news/an-autonomous-damen-tug#>

<sup>56</sup> <https://www.theautopian.com/autonomous-robotic-boats-are-being-tested-in-amsterdam-and-are-clever-as-hell/>

<sup>57</sup> <https://www.ilent.nl>

Building on the experimental rules, Dutch authorities moved in late 2021 to develop permanent technical standards for unmanned vessels. In consultation with the maritime sector, a draft “Technisch Kader Varende Drones” (Technical Framework for Sailing Drones) was formulated, targeting uncrewed vessels up to 20 meters. This framework specifies design and equipment requirements to ensure that small USVs can achieve safety levels equivalent to manned ships, for example, robust collision avoidance, fail-safes, and reliable remote-control links. The goal is to streamline the process of granting exemptions for compliant USVs and ultimately to incorporate these standards into law.

Indeed, an advisory assessment document based on the “Varende Drones” requirements has already been published to guide regulators in approving unmanned vessel operations. Full legislation to formally allow unmanned vessels under 20m on Dutch inland waters is expected by early 2025, paving the way for commercial deployments. At the same time, the Netherlands is revising core maritime laws like the Shipping Traffic Act (Scheepvaartverkeerswet) and crew qualification rules to accommodate remote operators.

Current law still assumes a human skipper on board, which is incompatible with true unmanned ships. The ILT and Ministry have acknowledged this and are working to amend regulations so that a certified remote operator in a shore control center can legally fulfill the role of an onboard watchkeeper. While these amendments are complex and ongoing, the Netherlands has mitigated delay by using interim solutions, e.g., case-by-case exemption permits as noted above. By doing so, Dutch regulators ensure that industry advancements (like long-range USV operations) are not held back by outdated rules, while permanent laws catch up.

A clear example is crewing regulations: a future framework may allow vessels under a certain size or in certain areas to operate with zero crew, provided a licensed remote captain is monitoring multiple ships from the shore. Dutch regulators through ILT are also key contributors at the IMO, Rhine Commission (CCR), and European forums scoping out uniform MASS codes.

The Netherlands’ balanced approach, encouraging experimentation under oversight, setting interim rules, and pushing for global standards, illustrates how to responsibly unlock the benefits of autonomous shipping.

### 2.2.3.8 United Kingdom

The UK’s long-term maritime strategy, Maritime 2050<sup>58</sup>, positions autonomy as a key growth area. The government aims for the UK to be “world-leading” in smart shipping, pledging to develop a domestic regulatory framework for autonomous vessels and to champion international regulations. Maritime 2050 and its Technology & Innovation route map set ambitious targets, for example, capturing a 10% share of the \$150 billion global MASS market by 2030<sup>59</sup>. The strategy commits to funding flagship autonomy projects and creating innovation hubs, ensuring the UK remains a vibrant R&D base for “technologically advanced and autonomous vessels”. Industry guidance is also evolving; Maritime UK’s Code of Practice for MASS (Version 5) underlines the UK’s intent to lead in safe autonomous operations, with officials affirming that “through our Maritime 2050 strategy, the UK is determined to leverage our position as the most innovative, competitive and sustainable maritime centre by the

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<sup>58</sup> [https://assets.publishing.service.gov.uk/media/5e6a248786650c7272f4c59d/Maritime\\_2050\\_Report.pdf](https://assets.publishing.service.gov.uk/media/5e6a248786650c7272f4c59d/Maritime_2050_Report.pdf)

<sup>59</sup> <https://www.haynesboone.com/news/publications/uk-sets-out-the-future-regulation-of-autonomous-vessels>

middle of this century”<sup>60</sup>. This top-level support provides clear direction for both commercial innovators and the Royal Navy, fostering a dual-use approach to autonomous technology development.

### Test Zones and Innovation Hubs

The UK has established dedicated test zones to accelerate MASS development. Smart Sound Plymouth in southwest England is the nation’s premier proving ground for marine autonomy, offering over 1,000 km<sup>2</sup> of instrumented, de-conflicted waters for trials<sup>61</sup>. The area is equipped with a private 4G/5G network, interconnected control centers, and a mix of surface, subsurface, and aerial drone platforms, creating an ideal real-world environment for testing unmanned vessels and sensors. The site’s “Future Autonomous at Sea Technologies (FAST)” cluster exemplifies civil-military collaboration, bringing together industry, academia, and government in a triple-helix model to advance autonomy<sup>62</sup>. Projects like the Maritime Autonomy Assurance Testbed (MAAT), led by Lloyd’s Register and the National Physical Laboratory, are developing the world’s first certification frameworks for autonomous ships at Smart Sound<sup>63</sup>. A new fully autonomous research vessel (“Oceanus”) is also being developed as a test platform, capable of global ocean navigation while serving as a MASS testbed for industry trials<sup>64</sup>.

### Naval Autonomous Programs

The Royal Navy is actively testing unmanned surface vessels as part of its “NavyX” innovation program. In late 2024, the Navy achieved a first in UK waters by remotely operating a Pacific 24 RIB from the experimental ship XV Patrick Blackett, navigating the busy Solent without crew<sup>65</sup>. During these trials, the 7.8 m RIB (dubbed “Autonomous Pacific 24” or APAC) operated in both pre-programmed autonomous mode and real-time remote control, successfully avoiding traffic in Portsmouth Harbour. Building on this success, the Royal Navy is expanding tests to larger and more specialized uncrewed vessels. In early 2025, it began trials of a new autonomous anti-submarine warfare (ASW) USV, a 7.5 m vessel capable of high speeds and equipped with a simulated weapon on its bow. These trials (conducted in the waters off Portsmouth) are evaluating the USV’s remote/autonomous operation in various scenarios, with Navy engineers on standby in a support craft. This initiative highlights the Navy’s commitment to integrating uncrewed surface platforms for missions such as force protection, patrol, and anti-submarine warfare (ASW), drawing on lessons learned from the commercial sector. Notably, the Navy’s new offshore support vessel, RFA Proteus, is expected to serve as a mothership for unmanned systems, part of a broader strategy to align civilian, developed autonomous technologies with naval requirements in a dual-use approach.

### Industry Leadership (SEA-KIT & Robosys)

British companies are at the forefront of MASS technology. SEA-KIT International, a small UK shipbuilder, gained international recognition when its 12 m USV Maxlimer completed award-winning long-endurance missions, demonstrating over 10,000 nautical miles range. Building on that success, SEA-KIT is producing larger platforms: in 2022 it secured a contract with geo-data firm Fugro to build an 18 m SEA-KIT XL USV at its Essex facility<sup>66</sup>. This next-generation vessel boasts a 7-ton payload

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<sup>60</sup> <https://www.maritimeuk.org/media-centre/news/news-maritime-uk-launches-version-5-its-industry-code-practice-maritime-autonomous-ship-systems/>

<sup>61</sup> <https://www.smartsoundplymouth.co.uk/#:~:text=,Interconnected%20remote%20operation%20centres>

<sup>62</sup> <https://pml.ac.uk/sciencetopics/autonomy-technology-and-digitisation/>

<sup>63</sup> <https://www.lr.org/en/knowledge/press-room/press-listing/press-release/2022/mas-technology-moving-fast-but-regulatory-and-assurance-concerns-remain/>

<sup>64</sup> <https://divemagazine.com/scuba-diving-news/meet-oceanus-the-worlds-first-long-range-autonomous-research-vessel>

<sup>65</sup> <https://www.royalnavy.mod.uk/news/2024/november/25/20241125-xv-patrick-blackett-trials-apac#>

<sup>66</sup> <https://insideunmannedsystems.com/sea-kit-and-fugro-ink-contract-for-next-generation-18m-usv/#:~:text=World%20leading%20Geo,facility%20on%20the%20Essex%20coast>

capacity and robust seakeeping, enabling tasks like towing sonar arrays or deploying robots for offshore energy surveys. The design focuses on extended endurance and heavy-weather operation, pushing the boundaries of uncrewed capability for both commercial and security missions.

Another key player is Robosys Automation, a UK-based developer of platform-agnostic maritime autonomy software. Robosys's flagship Voyager AI system can be installed on virtually any motorized vessel (from 2 m RHIBs to 320 m ships), instantly enabling remote and autonomous operations. The AI pilots the vessel under International Regulations for Preventing Collisions at Sea (COLREGs), with features like advanced sensor fusion, collision avoidance and dynamic route optimization to achieve IMO Degree 4 autonomy when needed. Critically, the Voyager AI is fully agnostic, integrating with third-party steering, propulsion, and engine control systems of new or existing vessels. This flexibility has proven valuable for both civil and military users: the software can upgrade crewed ships to operate in "lean-crewed" or unmanned modes at the push of a button, which improves safety and lowers operating costs in applications from hydrographic surveying to naval patrols.

The UK's maritime sector places strong emphasis on dual-use innovation. For example, Robosys's autonomous solutions are being demonstrated in collaboration with both the Royal Navy and the Maritime & Coastguard Agency, showcasing how a single autonomy toolkit can meet the needs of commercial shipping and Ministry of Defence (MOD) operations alike. In essence, through companies like SEA-KIT (hardware) and Robosys (software and AI), the UK is building a robust and integrated MASS ecosystem that spans both industry and defence.

#### Regulation and International Alignment:

The UK is aligning its laws and standards to accommodate autonomous vessels, while working with global partners. Until now, MASS operations under the UK flag have relied on ad-hoc exemptions or equivalencies to legacy regulations (e.g. load line, watchkeeping), granted by the Maritime and Coastguard Agency on a voyage-by-voyage basis. Recognizing the inefficiency of this approach, the Department for Transport held a major consultation on maritime autonomy. In late 2023, the government announced plans to amend core maritime legislation (such as the Merchant Shipping Act 1995 and Harbours Act 1964) to explicitly legalize and govern MASS, regardless of size. This proactive regulatory overhaul will replace case-by-case waivers with a clear framework for uncrewed vessel certification, operations, and liability in UK waters.

Notably, the UK chose not to simply wait for the IMO to finalize MASS conventions (which are not expected in mandatory form until 2030 with a 2-year transition to be enforced in 2032<sup>67</sup>). Instead, it will implement domestic laws sooner, while actively contributing to IMO discussions to ensure international rules eventually align with the UK's high standards.

The Maritime and Coastguard Agency has also run the Maritime Autonomy Regulation Lab (MARLab) project in partnership with industry, as a sandbox to inform these rule changes.

## 2.3 Asia

Asia has emerged as a hub for MASS development, with several countries actively pursuing advancements in this transformative technology. Leading nations like Japan, China, and South Korea are investing heavily in autonomous vessel research, testing, and deployment to strengthen their maritime industries.

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<sup>67</sup> <https://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx/>

### 2.3.1 China

Significant advancements have been observed in China’s development, construction, and testing of MASS. These efforts are part of a broader initiative to enhance maritime capabilities through automation and intelligent systems. The Office of the U.S. Trade Representative, in a January 2025 Report<sup>68</sup>, indicated that “...in high-technology ships, China initially set a target of 20 percent of global market share by 2011, but now aims to achieve 50 percent global market share by 2025. For maritime engineering equipment, China initially targeted 10 percent of global market share by 2011 and now seeks 40 percent market share by 2025.” These marine equipment sectors increasingly encompass technology and vessels comprising MASS autonomy and technology.

#### Regulatory Initiatives

In line with its “Made in China 2025” initiative, China is developing regulations to support the deployment of Level 4 autonomous vessels by 2025, aiming to lead in maritime innovation.

The China Classification Society (CCS) introduced the world’s first “Intelligent Ship Rules” in 2015, with subsequent updates in 2020 and 2022. These rules establish standards for the design, construction, and operation of intelligent ships, encompassing aspects such as automated navigation, integrated platform management, and comprehensive health management systems.

In 2018, CCS released the “Guidelines for Autonomous Cargo Ships,” providing a framework for the development and classification of autonomous cargo vessels. These guidelines address various levels of autonomy, from partial to full automation, and outline requirements for safety, communication, and control systems.

Starting in 2019, China initiated efforts to incorporate autonomous navigation into its national legislation. This move reflects the country’s recognition of the importance of establishing a legal framework to govern the operation of autonomous vessels, ensuring safety and compliance with international maritime standards.

#### Development and Construction

China’s commitment to MASS is exemplified by the construction of the Wanshan Marine Test Field in Zhuhai, Guangdong Province. Initiated in 2018, this facility spans approximately 770 square kilometres and serves as a primary base for research into autonomous ship technologies, including obstacle avoidance and autonomous navigation systems. In June 2022, China’s first 200-ton-class unmanned surface vessel conducted its inaugural autonomous sea trial in Zhoushan, Zhejiang Province. This milestone indicates progress in the development of large-scale autonomous vessels capable of complex maritime operations.

The JARI Unmanned Surface Vehicle developed by the China Shipbuilding Industry Corporation is a 15-meter vessel equipped for various combat roles, including anti-ship, anti-submarine, and air defense missions. It features advanced systems such as phased array radar and vertical launching systems, enabling it to operate autonomously or under remote control.

Launched in 2022, Zhuhai Cloud is an oceanographic research vessel designed for uncrewed operations and serves as a mother ship for various unmanned vehicles. Dubbed the world’s first “drone mothership,” it underscores China’s commitment to integrating autonomous technologies into maritime research and operations.

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<sup>68</sup> <https://ustr.gov/issue-areas/enforcement/section-301-investigations/section-301-china-targeting-maritime-logistics-and-shipbuilding-sectors-dominance>

## Testing and Trials

The Wanshan Marine Test Field has facilitated various trials and enabled the testing of technologies such as autonomous steering and obstacle avoidance. These trials are essential for validating the performance and safety of MASS in real-world maritime environments.

## Research

A recent scientometric study<sup>69</sup> by the National Research Council Canada covering a total of 94 countries identified a total of more than 6,000 publications in the MASS-relevant scientific literature since 2018 and found that China is by far the dominant player in the domain, responsible for over 50% of all scientific publications identified. The USA was noted as a distant second with a 9.1% share, followed by Norway with a 6.9% share. Canada was ranked 13th with 117 publications and a 1.9% share.

China's advancements in MASS research, development, construction, and testing demonstrate a significant commitment to integrating autonomous technologies into maritime operations. Like European countries, such as Norway, Finland, and the United Kingdom, each of which has established test areas and launched trials, China has also developed advanced testing facilities and successfully conducted trials of large unmanned vessels, underscoring its rising prominence in the field.

### 2.3.2 South Korea

South Korea is placing significant emphasis on smart shipping solutions, driven by its strong shipbuilding industry and a forward-looking approach to maritime innovation. Hyundai Heavy Industries (HHI) is at the forefront, developing advanced autonomous platforms that integrate navigation, collision avoidance, and remote monitoring systems. HHI's pioneering efforts include the construction of autonomous vessels equipped with their proprietary Hyundai Intelligent Navigation Assistant System (HiNAS), which utilizes AI and big data to optimize routes and enhance safety<sup>70</sup>.

Additionally, South Korea is actively fostering partnerships between its shipbuilding giants and technology firms to accelerate the creation of smart shipyards. These facilities leverage automation, robotics, and digital twins to streamline vessel production, reduce costs, and enhance precision. For instance, Samsung Heavy Industries has implemented AI-driven welding robots and virtual reality training systems to improve productivity and safety in shipyard operations.

The South Korean government has also played a significant role in advancing MASS technologies through investing in initiatives and supporting collaborations between industry leaders and academic institutions. This ecosystem is further bolstered by South Korea's focus on sustainability, with efforts to integrate eco-friendly propulsion systems and green technologies into autonomous ships.

South Korea has launched the Korea Autonomous Surface Ship (KASS) Project<sup>71</sup>, a collaborative initiative involving research institutes, commercial enterprises, and regulatory bodies. This project aims to develop core technologies for autonomous ships and establish a foundation for their commercialization. The KASS Project, running from 2020 through 2025, focuses on key areas such as intelligent navigation systems, engine automation, performance demonstration, and standardization. It also includes phased demonstrations to validate these technologies, with plans to test them on vessels like the 1,800 TEU container ship, POS Singapore.

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<sup>69</sup> Culhane, M., Scientometric Study on Maritime Autonomous Surface Ships (MASS), NRC Project No: S698763, June 2024

<sup>70</sup> <https://www.rivieramm.com/news-content-hub/news-content-hub/hyundais-hinas-20-awarded-aip-by-kr-amp-liscr-74831>

<sup>71</sup> <https://wwwcdn.imo.org/localresources/en/About/Events/Documents/2024%20IMO-ROK%20MASS%20Symposium%20presentations/1-3.%20The%20sea-trials%20for%20the%20demonstration%20of%20autonomous%20ship%20technologies%20developed%20by%20KASS%20-%20Geuntae%20Yim%20%28KRISO%29.pdf>

South Korea published the Act on Promoting the Development and Commercialization of Autonomous Ships (Act No. 19909) on January 2, 2024. This legislation aims to foster technological advancements, safe operations, and progress towards a maritime logistics system tailored to autonomous vessels. This was set to automatically become law on January 2, 2025.

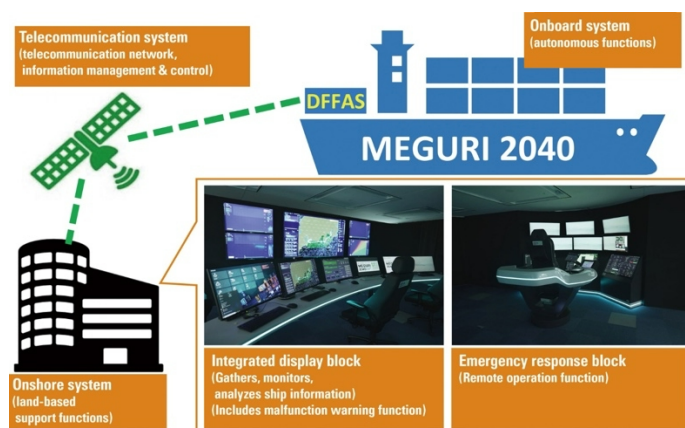
These advancements position South Korea well to affect smart shipping and autonomous maritime solutions with innovation that is impacting global standards in shipbuilding and maritime operations.

### 2.3.3 Japan

As a major marine nation, both in the commercial and naval sectors, Japan has launched several legislative initiatives to modernize its marine regulatory regime. Japan's Ministry of Land, Infrastructure, Transport and Tourism (MLIT) has introduced the "i-Shipping" initiative, aiming to revolutionize productivity within the maritime industry. This strategy focuses on developing integrated systems, advanced data analytics, and artificial intelligence to enhance navigational safety and operational efficiency. Through the application of advanced MASS technologies, Japan positions itself at the forefront of global competition in automated and autonomous shipping.

In the coastal shipping sector, Japan faces significant challenges due to an aging workforce. Currently, over 50% of the workforce is aged over 50, and approximately 30% are over 60. This demographic shift poses a threat to the nation's supply chain, as coastal shipping is responsible for about 40% of domestic logistics and approximately 80% of the transportation of basic industrial materials. If unaddressed, this issue could impact Japan's current high standard of living<sup>72</sup>.

Given this challenge, the Nippon Foundation has launched the MEGURI2040 Fully Autonomous Ship Program to realize a world underpinned by fully autonomous ships. In response, the Designing the Future of Full Autonomous Ship (DFFAS) project that comprises 30 leading Japanese companies from diverse sectors such as meteorology, telecommunications, IT and some thinktanks whose aim is to develop autonomous on-board communications, integrated navigation, and onshore control systems<sup>73</sup>. The basic functions developed by DFFAS are illustrated in the diagram below<sup>74</sup>:



In March 2022, the project successfully demonstrated a fully autonomous voyage through Japanese inland waters from Tokyo to the Port of Tsumatsusaka, a round-trip voyage through some of the most congested waters in the world using the DFFAS system to safely maneuver the ship. Most of the

<sup>72</sup> [https://www.spf.org/opri/en/newsletter/527\\_3.html](https://www.spf.org/opri/en/newsletter/527_3.html)

<sup>73</sup> “Designing the Future of Full Autonomous Ship (DFFAS) Project Grand Design Drawn by Diverse Experts”, Abstract, Satoru Kuwahara, DFFAS Project Leader, Japan Marine Science Inc. Sasakawa Peace Foundation. Tokyo, 22 Jul 2022.

<sup>74</sup> [https://www.spf.org/opri/en/newsletter/527\\_3.html](https://www.spf.org/opri/en/newsletter/527_3.html)

voyage was completed under full autonomy in the most challenging conditions. The voyage showcased advancements in land-based support functions, integrated display systems, and emergency response mechanisms. Although the system worked as intended, there were still some challenges that need to be addressed in future tests including the stability of internet-based communications and trackability of control functions. Given that the voyage took place in congested regions, the applicability of the successful results to oceanic voyages is limited due to environmental conditions and the limited access to satellite-based communications systems.

#### 2.3.4 Singapore

Singapore is situated on perhaps the busiest waterway in the world, the Singapore Straits with over 1,000 ships transiting daily. The Republic of Singapore Navy (RSN) is tasked with maintaining surveillance, control, and defence of the Straits and recently has acquired four domestically developed USV's to enhance their existing Littoral Mission Vessels (LMV). The USV's are 16.9m long, with a beam of 5.2m and shallow draft for navigating the shoals in the Straits and are operated by a crew of two in a shore-based Remote Monitoring and Operations Centre (RMO) over a mission duration of several days<sup>75</sup>.

The USV's were designed and developed in collaboration with the "Defence Science & Technology Agency (DSTA) and DSO National Laboratories, the new USV harnesses the latest technologies to enable autonomous operations in congested maritime environments. The USVs are equipped with autonomous navigation systems, which include a Collision Detection and Collision Avoidance (CDCA) algorithm that enables the vessel to navigate through the heavy traffic in the Singapore Strait and cope with the constantly changing environmental conditions at sea<sup>76</sup>". The CDCA autonomous navigation system integrates the USV's perception and navigation sensors in a rules-based system. It combines collision detection equipment used for typical maritime navigation (such as navigation charts, Maritime Automatic Identification System and Differential Global Positioning System) with an algorithm designed for the RSN's operations. This ensures that the USV assesses and responds to maritime traffic situations in a predictable manner in accordance with the COLREGS in the same way as a manned vessel. Even though this system is designed for a military vessel, it is also applicable to commercial vessels that need to operate autonomously in congested passages.

#### 2.3.5 Australia

Australia is planning and advancing the application of MASS activity to strengthen its maritime capabilities and support its extensive coastline and economic zones. Through initiatives like the Australian Autonomous Vessel Forum and collaborations with research institutions and industry stakeholders, the country is developing frameworks for the safe and effective deployment of autonomous vessels. Key focus areas include enhancing maritime domain awareness, supporting defence and border protection, and advancing sustainable practices in commercial shipping. Australia's approach emphasizes rigorous testing in diverse environments, including the Great Barrier Reef and remote waters, to ensure compliance with safety and environmental standards while at the same time fostering innovation in autonomous maritime technologies.

##### Regulatory Developments:

Australia is actively developing regulatory frameworks to accommodate the integration of MASS into its maritime operations. The Australian Maritime Safety Authority (AMSA) currently regulates

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<sup>75</sup> [https://www.mindef.gov.sg/news-and-events/latest-releases/04feb25\\_fs](https://www.mindef.gov.sg/news-and-events/latest-releases/04feb25_fs)

<sup>76</sup> Ibid.

remotely operated and autonomous vessels under the same framework as conventional vessels, encompassing survey standards and crewing requirements. Recognizing the unique challenges posed by autonomous technologies, AMSA is collaborating with stakeholders to establish appropriate regulations that ensure safety and operational efficiency.

For small unmanned autonomous vessels under 12 meters operating in specific waters, AMSA has issued guidance outlining the process for obtaining specific exemptions from standard certification requirements. This approach provides flexibility while maintaining safety standards.

In the defence sector, the Australian Naval Classification (ANC) Authority has introduced Division 5 of the ANC Rules, which applies to surface or sub-surface remotely operated uncrewed and autonomous naval vessels. These rules specify mandatory requirements for the design, construction, and operation of such vessels, ensuring they meet defined safety and performance standards.

In addition, the Australian Code of Practice for the Design, Construction, Survey, and Operation of Autonomous and Remotely Operated Vessels has been released to provide best practice standards tailored for these vessels operating in Australia. This code offers comprehensive guidelines to ensure the safe and effective deployment of autonomous maritime technologies<sup>77</sup>.

#### Royal Australian Navy: Austal Australia

Building upon their successful collaboration during the Patrol Boat Autonomy Trial (PBAT)<sup>78</sup> for the Royal Australian Navy, Austal Australia and Greenroom Robotics have formalized a Strategic Partnership Agreement (SPA). This agreement enables both companies to further develop watercraft-based products, services, and technologies aimed at reducing crew requirements, enhancing safety, and facilitating remote and autonomous vessel operations<sup>79</sup>

During the PBAT, the decommissioned Armidale-class patrol boat, Sentinel, was equipped with Greenroom Robotics' Advanced Maritime Autonomy (GAMA) software, which integrated seamlessly with Austal's MARINELINK platform management system. This integration allowed for reliable and safe autonomous operation of the 57-meter vessel, including successful collision avoidance exercises off the Western Australian coast.

The SPA reflects Austal and Greenroom Robotics' commitment to advancing remote and autonomous technologies, aligning with AUKUS Pillar 2 objectives to develop advanced military capabilities. Both companies are poised to pursue opportunities that may contribute to future naval vessel programs within the AUKUS alliance.

## 2.4 Other Nations

According to Holman Fenwick Willan's (HFW) latest update, several other nations are working on MASS vessels including UAE, which is developing a USV for remote inspection, hydrographical and geophysical survey operations that entered service in 2024<sup>80</sup>. A Belgian company Anglo Belgian Shipping is working with Zulu Associates to develop a 200TEU short-sea container ship concept, which has received approval in principle (AiP) from Lloyd's Register, will be fully electrical and powered by modular energy containers provided by established energy storage companies using batteries and/or hydrogen-based power systems. In addition to zero-emission electrical propulsion, the

<sup>77</sup> <https://tasdcrc.com.au/code-of-practice-autonomous-vessels/>

<sup>78</sup> <https://www.austal.com/news/austal-australia-completes-sea-trials-royal-australian-navys-patrol-boat-autonomy-trial>

<sup>79</sup> <https://markets.businessinsider.com/news/stocks/austal-australia-and-greenroom-robotics-establish-a-strategic-partnership-agreement-following-successful-patrol-boat-autonomy-trial-1033780898>

<sup>80</sup> <https://www.hfw.com/insights/autonomous-vessels-the-momentum-is-building/>

ship will be equipped with auxiliary wind propulsion, and the feasibility of wave propulsion is being investigated<sup>81</sup>.

## 2.5 Implications for Canada

European nations and industries have made major strides in developing and deploying autonomous vessel technology. Across both commercial and naval sectors, Europe is pioneering real-world use of MASS. Several EU member states have launched sea-going autonomous or remotely-operated vessels that are already in service, demonstrating Europe's leadership in this field. For example, the UK's Sea-KIT program has produced uncrewed surface vessels (USVs) like the 12-meter SEA-KIT Maxlimer, which in 2019 became the first unmanned vessel to complete a commercial cargo crossing of the English Channel. In Norway, the groundbreaking Yara Birkeland, a 120 TEU container ship, was launched as the world's first fully electric and zero-emission autonomous cargo vessel. The Yara Birkeland began commercial operations in 2022 and is undergoing a two-year transition to achieve fully autonomous sailing. Such projects underscore that Europe is at the global forefront of MASS development. European industry and governments have every intention to continue progressing up the autonomy scale toward Level 4, full autonomy, in the near future.

Europe's momentum in MASS is driven by clear operational and strategic motivations. A key goal is to reduce the costs of ship operations and fleet development by automating functions traditionally requiring onboard crew. Autonomous and remotely-operated ships promise savings on crew expenses and improved safety by minimizing human error, which is a leading cause of marine incidents. European projects also link autonomy with sustainability goals: for instance, the Yara Birkeland is not only autonomous but also fully electric, intended to cut emissions and improve efficiency in short-sea shipping. In addition, Europe faces a shortage of mariners in some sectors and sees autonomy as a way to maintain maritime throughput while relieving workforce pressures. These factors, combined with the EU's twin objectives of digitalization and decarbonization, mean that European governments and companies are investing heavily in progressively more advanced MASS capabilities.

Driven largely by EU member states, the IMO is actively working to develop regulations governing fully autonomous ships, with the aim of adopting a mandatory MASS Code by 2030. However, progress at the IMO is inherently gradual, as new regulations require consensus among a diverse set of member states. This slow pace has prompted many national regulatory bodies to implement their own interim frameworks - several of which have been summarized earlier in this report. The resulting regulatory fragmentation has led to a patchwork of national rules, which can increase complexity and compliance costs for commercial shipowners operating across jurisdictions.

Nonetheless, the EU's quasi-federal structure, combined with the technical leadership demonstrated by its member states, offers valuable insights. Their coordinated regulatory efforts and collaborative approaches to MASS deployment provide important lessons for Canada's institutions and companies engaged in the development and implementation of autonomous shipping technologies. These lessons can be summarized as follows:

- Government leadership is critical. Senior officials at both the federal and provincial levels must demonstrate clear leadership in supporting the development of MASS technologies. In addition, organizations such as CISMaRT, the Ocean Supercluster (OSC), the Centre for Ocean Ventures

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<sup>81</sup> <https://rina.org.uk/industry-news/zulu-associates-aims-for-uncrewed-zero-emission-shipping-by-2026/>

and Entrepreneurship (COVE), industry associations, academic institutions, and related bodies all have important roles to play in advancing practical applications of MASS.

- The academic, industry and government collaboration is a key.
- Long-term commitment and funding are essential. Drawing on European experience, such as the AUTOSHIP program, Canadian MASS initiatives must be designed as multi-year projects with substantial, sustained funding. Adequate financial buffers should be built in to account for potential cost overruns and ensure continuity through to completion.
- Project objectives must be clearly defined and focused. Success depends on establishing realistic, clearly articulated goals that are limited in scope and aimed at achieving specific, measurable outcomes.
- Leverage existing and Canadian technologies. Where appropriate, projects should incorporate proven technologies already available on the market, and prioritize the use of Canadian-developed solutions when feasible. Avoiding unnecessary development of custom-built technologies in the early stage can help ensure success. A core objective should be the effective integration of existing systems, such as autonomous navigation and collision avoidance, into a suitable hull platform to safely interact with conventional, crewed vessels.
- Experienced leadership is a prerequisite. Project leadership must include individuals with substantial naval architecture and system integration experience and recognized operational competencies.
- Initial development should focus on controlled, local environments. Early testing and deployment should take place in designated local areas where defined geographic boundaries and tailored regulatory frameworks allow for safe and effective trials. Canada's existing testing facilities for MASS include the Launch Marine Autonomous Systems Testbed<sup>82</sup> in Newfoundland and Labrador; the Port Innovation, Engagement, and Research (PIER) living lab at the Port of Halifax<sup>83</sup>; the Centre for Ocean Ventures and Entrepreneurship (COVE), a high-tech innovation hub in Halifax Harbour<sup>84</sup>; and the Centre for Ocean Applied Sustainable Technologies (COAST) in British Columbia<sup>85</sup>. In addition, Canada's vast ocean territory encompasses a full range of marine environments from sheltered estuaries to some of the world's harshest northern conditions, making it exceptionally well-suited for developing and testing MASS capable of withstanding diverse and demanding operational scenarios.
- Canada's MASS approach should prioritize domestic requirements while leveraging and building on existing national capabilities. With vast coastlines, remote Arctic regions, and complex maritime environments, Canada has unique operational needs that autonomous systems can help address, such as enhancing maritime domain awareness, improving search and rescue capabilities, and supporting environmental monitoring in hard-to-reach areas. By focusing on these domestic challenges, Canada can stimulate targeted innovation within its robust marine technology ecosystem.
- Canada should address the regulatory gaps and uncertainties through modernizing regulations or new statutory provisions. Canada's regulators will have to strike a balance between not getting ahead of IMO (to maintain international consistency) and not lagging so far that domestic projects stagnate for lack of a clear framework.

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<sup>82</sup> <https://www.thelaunch.mi.mun.ca>

<sup>83</sup> <https://www.thepierhfx.com>

<sup>84</sup> <https://coveocean.com/news/canadas-ocean-supercluster-announces-3-8m-ai-powered-vessel-automation-toolkit-project/#:~:text=The%20project%20aims%20to%20deliver,ghost%20gear%20in%20deep%20water>

<sup>85</sup> <https://canadacoast.ca>

- Canada has the potential to become a leader in developing dual-use technologies by fostering collaboration between civil and military sectors.

## 3. Worldwide Readiness of Enabling Technologies

The current state and readiness level of technologies enabling MASS varies considerably depending on their maturity, adoption, and integration capabilities. This ranges from fully operational to 10 years out, and an overview of these technologies is provided below, including radars, cameras, LiDAR, Electronic Chart Display and Information System (ECDIS), engine control system, Bridge Alert Management (BAM), Virtual Data Room (VDR), artificial intelligence, Internet of Thing (IoT), cyber security risk solutions and others, encompassing all autonomous navigation system-related technologies as well as emerging quantum navigation approaches.

### 3.1 Radar systems

Radar comprises one of the most important safety and navigation tools on any marine vessel, always providing crucial situational awareness, but especially in reduced visibility. Today’s radar systems offer enhanced displays and post-processing to improve situational awareness in critical situations.

#### 3.1.1 Current State

Marine radar, which has been available since early WWII, is very mature and widely used in a variety of situations at sea including navigation. Integration of radar with other sensors has been a characteristic of military command and control systems for some decades and is being introduced into the commercial sectors. Post-processing for enhanced image resolution is commercially available and includes both spatial and temporal data products. One example is Rutter Inc., which provides wave period tracking to indicate “quiet” periods to aid sensitive operations at sea, as well as detection of oil sheen on seawater to indicate evidence of a recent oil release/spill. Object detection and man-overboard detection have been some of the long-standing search and rescue enhancements that Rutter supplies through radar processing. This is based on discrimination between incoherent wave clutter and sporadic but repetitive coherent targets. Rutter has supplied radar processing systems to international buyers for MASS vessel implementations.

#### 3.1.2 Enhancements

- AI and machine learning algorithms are being employed to improve ship detection in complex maritime environments, such as the Anchor-Free-based Multi-Scale Feature Fusion Network (AFMSFFNet)<sup>86</sup>.
- Multi-scale object detection models: enhanced convolutional neural networks, such as VarifocalNet, are improving object detection under harsh maritime conditions by capturing features at multiple scales<sup>87</sup>.
- Advanced radar processing software solutions like Cambridge Pixel’s SPx Tracking Server and SPx Fusion Server<sup>88</sup>. Rutter product offerings fall under this category<sup>89</sup>.
- Synthetic aperture radar (SAR) image processing: techniques such as the Ship Detection Network based on Global Context and Multi-Scale Feature Enhancement (FGNet)<sup>90</sup> utilize SAR images to detect ships with high accuracy, even in complex environments. SAR radars have been employed in

<sup>86</sup> Zhang, Yanlong, et al. “AFMSFFNet: An Anchor-Free-Based Feature Fusion Model for Ship Detection.” *Remote Sensing*, vol. 16, no. 18, 2024, p. 3465, <https://doi.org/10.3390/rs16183465>

<sup>87</sup> [https://openaccess.thecvf.com/content/CVPR2021/papers/Zhang\\_VarifocalNet\\_An\\_IoU-Aware\\_Dense\\_Object\\_Detector\\_CVPR\\_2021\\_paper.pdf](https://openaccess.thecvf.com/content/CVPR2021/papers/Zhang_VarifocalNet_An_IoU-Aware_Dense_Object_Detector_CVPR_2021_paper.pdf)

<sup>88</sup> <https://cambridgepixel.com/products/>

<sup>89</sup> <https://rutter.ca/sts/>

<sup>90</sup> BFEA: A SAR Ship Detection Model Based on Attention Mechanism and Multiscale Feature Fusion, *IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing*

advanced military aircraft for decades, but the technology can now be found on advanced naval ships in the USA and other.

- Adaptive attention mechanisms: networks like the Adaptive Multi-Hierarchical Attention Network (AMANet) incorporate attention modules to learn multi-scale features and adaptively aggregate relevant features from various layers. This approach improves the detection of small and coastal ships in cluttered environments.
- Optical and SAR image fusion: combining optical and SAR imagery enhances ship detection and recognition by leveraging the strengths of both sensor types.

### 3.1.3 Technology Readiness Level of Radar

The technical readiness level is high for conventional radars when overseen by a skilled operator, and medium for autonomous systems requiring high levels of integration and data fusion. This can be aided by high-bandwidth data sharing with operations centre personnel (by satellite internet). The key to using data from advanced autonomous radar systems is a high level of integration with other systems such as ECDIS.

## 3.2 Electronic Chart Display and Information System (ECDIS)

The IMO mandates the use of ECDIS for passenger ships over 500 gross tonnes operating in certain areas, codifying the move away from conventional paper charts<sup>91</sup>. ECDIS enhances technical maritime navigation and advances safety protocols at sea. Applying ECDIS in a manner that maximizes its benefits in MASS applications will provide additional benefits in enhancing operational safety and efficiency.

### 3.2.1 Overview of the Current State of the Art in ECDIS<sup>92</sup>

ECDIS systems play a key role as data aggregator technology on board modern vessels, allowing a single workstation to provide a full suite of navigation-related data to be presented to bridge personnel at the click of a button. ECDIS therefore represents a nexus of critical information necessary for MASS operation.

A ship ECDIS comprises a navigational aid with display and software for both vector and raster (scanned) digital charts, as well as the vessel's complimentary data. Units are available tailored for a variety of vessel types, such as cargo ships, passenger ships and military vessels. The ECDIS can display digital navigational data such as C-Map or CM93 cartography and provide concise decision-making support. Weather modules, radar imagery, water depth, speed, ice conditions and other data can be displayed, and the ECDIS can be connected to other systems such as alarms, cargo management, engine parameters, fuel, stores management, and other control/data functions.

In practice, the ECDIS takes the form of a console with a central large screen, with some models equipped with two or three screens for simultaneous display of different data at appropriate stations. System control comprises a combination of pushbuttons, a keyboard, joystick, switches, and a mouse/trackball.

Essential for aboard modern commercial vessels, especially ships sailing the high seas or in dangerous areas, the ECDIS is mandatory on certain vessels, as defined by international conventions and classification organizations.

<sup>91</sup> <https://www.imo.org/en/OurWork/Safety/Pages/ElectronicCharts.aspx>

<sup>92</sup> <https://www.boats.com/on-the-water/riding-the-wave-of-innovation-advances-in-the-marine-industry-in-2023/>

Key features of ECDIS include:

Integration with Advanced Technologies:

- Incorporation of artificial intelligence (AI) for predictive route optimization and hazard detection.
- Enhanced connectivity with the Internet of Things (IoT) for real-time data sharing and system integration.
- Adoption of augmented reality (AR) to overlay navigational data onto real-world views, improving situational awareness.

User-Centric Design:

- Development of intuitive user interfaces with touch-screen capabilities and customizable displays.
- Focus on reducing cognitive load for navigators through streamlined information presentation.

Enhanced Safety Features:

- Real-time hazard detection and automatic alert systems.
- Integration with automatic identification systems (AIS) for improved vessel tracking and collision avoidance.

Compliance with International Standards:

- Adherence to IMO regulations and International Hydrographic Organization (IHO) standards, including the transition to the S-100 Universal Hydrographic Data Model.

### 3.2.2 Leading ECDIS Manufacturers' Products<sup>93</sup>

Leading ECDIS manufacturers include the following:

OSI Maritime Systems Ltd (Canada):

- **ECPINS Warship:** Canada's leading ECDIS manufacturer supplies over 20 navies around the world with a system for naval vessels that enhances situational awareness and improves navigational safety and enables military navigators to navigate in the most challenging conditions and conduct mission-critical work with success.
- **ECPINS Submarine:** This system enables submarines to enhance situational awareness and improve navigational safety and allows submarine navigators to navigate in the most challenging conditions and conduct mission-critical work with success.

Furuno (Japan):

- **FMD-3100:** A compact ECDIS featuring a 24-inch-wide LCD, designed for seamless integration into existing bridge systems.

Raytheon Anschütz (USA):

- **Synapsis ECDIS:** Offers a scalable solution with advanced route planning and monitoring features, suitable for various vessel types. Virtual Marine from St. John's has partnered with Raytheon Anschütz to provide simulation scenarios including navigation in ice.

JRC (Japan Radio Co.):

- **JAN-9201/7201:** ECDIS models that provide dynamic information on other ships, supporting safe navigation with safety functions including the generation of warnings when necessary.

Kongsberg Maritime (Norway):

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<sup>93</sup> <https://www.nauticexpo.com/boat-manufacturer/ship-ecdis-20034.html>

- K-Bridge ECDIS: A fully compliant and easy-to-operate system designed for both new builds and retrofit installations, assisting in safe navigation.

#### Kelvin Hughes (U.K.):

- Integrated ECDIS: Features an integrated display incorporating market-leading software functionality, updated with new time-saving features.

#### PC Maritime (U.K.):

- Navmaster ECDIS: A well-established system designed to deliver clear functionality and ease of use in a familiar MS Windows environment.

#### Sperry Marine (USA):

- VisionMaster FT: Provides flexibility in modes, including Radar Overlay, ECDIS, Conning Info Display, and Central Alarm Management, from standalone ECDIS to a multi-node networked system.

#### TOKIO KEIKI (Japan):

- EC-8100 / EC-8600: ECDIS with Track Control System, offering 26-inch displays and advanced navigation features.

### 3.2.3 Technology Readiness Level of ECDIS

Manufacturers shown here represent some of the leading companies providing ECDIS technology and have demonstrated a willingness to continually enhance their products to meet evolving maritime safety standards and the operational needs of modern vessels. It is a safe assumption that they will continue to do so in the manner required to support MASS applications. At present ECDIS technology readiness is high for MASS usage when overseen by a skilled operator; and medium for autonomous systems requiring higher levels of integration. The progression to better service for MASS applications will be aided by high-bandwidth data sharing through remote operations centres with manufacturers as well as a high level of integration with other systems such as radar and acoustic sensors. It should be noted that data fusion is a key aspect of ECDIS, and researchers must be aware of proprietary technology ownership concerns when one manufacturer controls all data fusion.

## 3.3 Cameras (Optical and Thermal)

### 3.3.1 Current State

Advanced camera systems with AI-based image recognition are being developed for object detection and navigation. Recent significant advancements in these camera systems include AI-based image recognition for maritime use, primarily focused on enhancing object detection and navigation, with a focus on addressing challenges posed by varying weather conditions, lighting changes, and complex image backgrounds. Canada has many companies active in enhanced optical and camera systems, including Teledyne DALSA, L3Harris Wescam, Raytheon ELCAM, Telops, Photon etc., Novacam, Current Scientific, and Cantronic Systems.

### 3.3.2 Enhancements

#### Wescam Maritime Intelligence, Surveillance and Reconnaissance (ISR)

L3 Harris's latest WESCAM MX-Series is a new generation of forward-looking infrared and electro-optical sensor systems that offer advanced asymmetrical threat identification technologies that can be integrated into comprehensive Command, Control, Communication and Computers ISR (C4ISR) combat management systems. These new systems feature wireless delivery of contact information, both

friendly and opposing forces, that enable 21<sup>st</sup> century threats to be detected, verified, and neutralized. WESCAM's new product line can be configured for both land and ship-based maritime domain awareness and can be installed in both manned and unmanned vessels. The MX series of EO/IR sensors range in size from the MX-10 that offers surveillance, vessel threat detection, covert operations, and naval remote weapon stations in a small package ideally suited for small vessels and autonomous ships to the MX-15 suitable for installation in larger vessels, both manned and unmanned. The latest MX systems combine all the product enhancements listed below, in a Canadian designed and manufactured system that is sold around the world.

### Improved Object Recognition

AI algorithms, particularly deep learning models, are now capable of accurately identifying various objects at sea, including ships, buoys, debris, and even marine life. This has been achieved through training on vast datasets of maritime images and videos, enabling the system to differentiate between different types of vessels, distinguish between small and large objects, and estimate distance and speed. The Orca AI Seapod<sup>94</sup> is an example of this (see link below), shown detecting a maritime vessel approaching a ship fitted with this technology.



Orca AI Seapod

### Enhanced Situational Awareness

By integrating object detection with other sensor data, such as radar and AIS, the AI-based camera system can provide a more comprehensive view of the vessel's surroundings. This means of providing enhanced situational awareness can help manage collision avoidance risk and assist navigation in congested waters, where monitoring of maritime traffic is crucial. The Wärtsilä AI camera system<sup>95</sup> below provides enhanced situational awareness.

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<sup>94</sup> <https://www.orca-ai.io/seapod/>

<sup>95</sup> <https://www.wartsila.com/media/news/25-04-2022-wartsila-takes-situational-awareness-to-a-new-level-with-launch-of-its-s-p-e-c-s-camera-system-3290938>



Wartsila AI Camera System

### Improved Adverse Weather Performance

Where traditional camera systems struggle in challenging weather conditions like fog, rain, and darkness, AI-powered systems have the potential to utilize image enhancement techniques, noise reduction, and thermal imaging to enhance visibility and object detection even in adverse weather. This can mean the difference in maintaining safe navigation in these conditions. A FLIR AI camera system image is shown under foggy conditions to optimize maritime shipping operations<sup>96</sup>.



FLIR AI Image

- Real-time monitoring and alerts: AI-based systems can process images and videos in real time, providing immediate alerts to the crew about potential hazards or critical events. This can enable proactive decision-making and timely responses to avoid accidents and improve safety. It should be noted, however, that current bridge systems can generate numerous alerts to the crew, and

<sup>96</sup> <https://www.flir.ca/discover/rd-science/can-thermal-imaging-see-through-fog-and-rain/>

information overload has been a topic of discussion at technical committees for more than 25 years. Hence AI-based systems need to manage information well to achieve this objective.

- Integration with autonomous systems: Advancements in AI-based camera systems certainly appear crucial for the development of autonomous ships. These systems essentially act as the "eyes" of the autonomous vessel, enhancing its ability to perceive the surroundings, and should lead to more informed decisions, and increased safety of navigation without human intervention. Integration in complex systems is a challenge for system designers, with much work still to be done to ensure seamless integration in unmanned vessels but the systems are rapidly improving. From a Canadian perspective, coming to the market later than Europe offers certain advantages in that our designers will be able to avoid many of the problems faced by early entrants into the market, which should result in a much more advanced USV.

### 3.3.3 Specific Technology Examples

#### Orca AI

As mentioned above, it uses AI-powered cameras to provide enhanced situational awareness, even in challenging situations like fog and low-light/dark conditions. It was used on the world's first autonomous commercial voyage in congested waters. In early 2022, Orca AI's advanced navigation system was instrumental in completing the world's first autonomous commercial ship voyage through congested waters. As discussed in the Asia section of the report, the trial was conducted by the cargo ship Suzaku, a 749-gross-ton vessel selected by the DFFAS consortium. During the 40-hour voyage, Suzaku operated under full autonomy for 99% of the time, successfully performing 107 collision avoidance maneuvers on the outbound journey alone. The program director suggested that the system avoided a total of 400 to 500 ships. This achievement marks a significant milestone in autonomous shipping, demonstrating the potential for AI-driven systems to enhance maritime safety and operational efficiency in complex and busy waterways.

The Orca AI system received the world's first Product Design Assessment (PDA) certification for an AI-based navigation safety platform from the American Bureau of Shipping (ABS) in February 2022. This certification validates Orca AI's platform, which enhances situational awareness by automatically detecting, prioritizing, and alerting crews to maritime targets in real time. The system integrates computer vision sensors, thermal and low-light cameras, and AI-powered algorithms to provide comprehensive monitoring and support for vessel navigation. The platform is already in use by leading industry players, including Maran Tankers, TMS Gas, Enesel, Wärtsilä, and NYK, who rely on the system to enhance safety and operational efficiency.

ABS's PDA certification assesses materials, components, products, or systems for specific uses in compliance with ABS Rules, Guides, and national or international standards. This certification marks a significant milestone in the maritime industry, recognizing the potential of AI-based solutions to improve navigation safety and operational performance.

#### ShipIn Systems

The ShipIn platform<sup>97</sup> utilizes AI-powered CCTV cameras to monitor various activities on board, including safety, security, and cargo handling. The fleet management technology provides real-time alerts and analytics to improve operational efficiency and prevent incidents.

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<sup>97</sup> <https://shipin.ai/how-shipin-works/>



ShipIn Systems Platform

ShipIn Systems has recently announced investment in its visual fleet management platform, through a series of funding, for a total investment of \$24 million.

### JRCS

The Infoceanus command system<sup>98</sup> uses AI-based object recognition to assist in watchkeeping, reducing the workload on sailors and improving safety. It can detect objects that are undetectable by other nautical instruments. This is a command maritime navigation support system designed to enhance safety and reduce the workload on ship crews. It uses computer vision technology to provide real-time object detection and situational awareness as well as cameras and AI algorithms to detect and identify objects at sea, including other vessels (both AIS-equipped and non-AIS), buoys, debris, and even small objects that may be difficult to spot with traditional methods.

By processing images in real-time and integrating with existing navigation instruments, the Infoceanus command provides a comprehensive view of the vessel's surroundings, aiding in collision avoidance and navigation in congested waters. It acts as an extra set of eyes for the local or remote crew, reducing the mental burden of constant visual monitoring and allowing them to focus on other critical tasks. The AI algorithms are designed to work effectively even in challenging weather conditions like fog, rain, and darkness, enhancing safety in all situations. It should be kept in mind that these technologies are currently only utilized for MASS Degree 1 and 2 applications, but they have potential for use in MASS Degree 3 and 4 applications since they can reduce the risk of collision and marine accidents, improve navigation in adverse conditions thus lessening crew workload and fatigue and enhancing overall situational awareness.

These advancements in AI-based camera systems are revolutionizing maritime shipping by improving safety, efficiency, and autonomy. As technology continues to evolve, we can expect even more sophisticated solutions that will further transform the industry. It is anticipated that the challenges of safely operating MASS Degree 3 and 4 vessels will require this and many additional technologies that can improve safety and situational awareness.

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<sup>98</sup> <https://www.jrcs.co.jp/en/news/article/20230727/>

### 3.3.4 Technology Readiness Level of Camera Systems

Technological readiness for optical and thermal camera systems, particularly for those integrated into high-level systems that provide enhanced situational awareness for MASS applications is medium.

More research and development are required to ensure that these integrated systems can provide the necessary reliability and accuracy required for Degree 3 and 4 systems. With AI software more readily available and much-increased processing power, these performance enhancements could provide impetus for shipping companies and navies to begin to develop Degree 3 and 4 fully autonomous ocean-going ships. But even though processing capability is advancing apace with overall technology and software development, it is subject to the limitations of the physical processes involved.

Canadian researchers should focus their future efforts on improvements in adverse weather conditions and utilize improved real-time processing to provide the required improvements.

### 3.4 Navigation Improvements including Quantum Navigation

USVs currently rely heavily on Global Positioning System (GPS) signals to provide the precise navigation data essential for safe operations, particularly in proximity to other vessels, shorelines, or confined waterways. However, GPS signals are inherently vulnerable to jamming and interference due to their extremely low signal strength at the Earth's surface (approximately  $10^{-16}$  watts), making them susceptible even to relatively weak jamming devices. To address this vulnerability, companies such as Leidos are developing resilient navigation solutions designed to maintain positioning accuracy across land, sea, and air platforms, particularly in contested or combat environments where GPS reliability cannot be guaranteed. The Leidos-Applied Positioning Navigation and Timing (APNT)<sup>99</sup>, was the system used in the USN deployment of 4 USVs in 2023/24 to provide reliable situation awareness.

Inertial Navigation Systems (INS) that provide reliable position data that cannot be jammed have been in use for some decades, particularly in submarines that require accurate positions at all times to update the navigation systems in their onboard ballistic missiles. However, they are expensive to acquire and require significant maintenance effort to maintain accuracy and functionality. Recently, manufacturers such as Honeywell have combined GPS and INS capabilities in hybrid systems that could be used in USVs.

#### 3.4.1 Current State

New navigation applications in quantum technology are emerging that can detect any attempt at tampering, including GPS spoofing or denial of service through interference. These quantum inertial measurement units hold the potential to provide reliable positioning for MASS applications but require further development. The Perimeter Institute of Theoretical Physics in Waterloo, Ontario is well-versed in the theory and could help Canadian companies advance in applications of this emerging technology. Some alternate navigation technology that is resistant to interference will be required for MASS Degrees 3 and 4 to roll out safely. Many bets are being made that this is the one that will succeed.

#### 3.4.2 Developments and Trials Underway

Boeing, in collaboration with AOSense<sup>100</sup>, has successfully conducted a four-hour flight test using a quantum inertial measurement unit (IMU) navigating without GPS. This six-axis quantum IMU

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<sup>99</sup> <https://www.leidos.com/interactives/assured-positioning-navigation-timing/index.html>.

<sup>100</sup> <https://aosense.com/research-and-development/inertial-sensors/>

employed atom interferometry to detect rotation and acceleration with exceptional precision, to provide reliable navigation in GPS-denied environments.

AOSence, Infleqtion<sup>101</sup>, Q-CNTL<sup>102</sup>, Sandia Labs<sup>103</sup>, BAE Systems<sup>104</sup>, and QinetiQ<sup>105</sup> are some of the groups experimenting with this emerging quantum navigation technology.

In November 2024, Aquark Technologies<sup>106</sup>, a UK quantum technology company, achieved a significant milestone in the development of quantum sensing for military applications. Partnering with the Royal Navy's Office of the Chief of Technology Officer (OCTO), Aquark successfully conducted sea trials of its cold atom technology aboard HMS Pursuer.

The trials demonstrated the robustness of Aquark's miniature cold atom systems, which utilize a unique "super molasses" laser-cooling method that eliminates the need for a magnetic field, resulting in smaller, lighter, and more cost-effective sensors. Throughout the tests, conducted under various realistic operating conditions and maneuvers at different locations on the vessel, cold atoms were consistently captured. While the trials identified areas for further engineering, particularly in magnetic shielding, they validated the technology's potential for applications such as covert monitoring and precise positioning, navigation, and timing (PNT), especially in GPS-denied environments.

This successful demonstration follows Aquark's previous achievement of flying the first cold atom device on a drone and reinforces the company's progress towards deploying practical quantum systems. The Royal Navy aims to accelerate the development of such technologies, recognizing their importance for maintaining operational advantage in challenging environments. This work is supported by €5 million in seed funding led by the NATO Innovation Fund and other investors, including MBDA (Matra BAe Dynamics Alenia) and the UK Innovation and Science Seed Fund (UKI2S). Note that Aquark Technologies is a spin-out of the University of Southampton.

### 3.4.3 Technology Readiness Level of Quantum Navigation

Quantum navigation readiness for MASS application is currently low to medium; and is reliant on further development and commercialization of the technology for ease of practical application. With aviation applications providing the main driving force behind technological advances, a relatively short timeline of 10 years is anticipated for commercial marine adoption.

With Canada's recognized expertise in studying Quantum Mechanics with three universities offering graduate programs (Waterloo, Calgary and Polytechnique Montréal) and the Canadian Quantum Research Centre and the Institute for Quantum Computing, Canada is well placed to study the applications of Quantum Mechanics to navigation systems. To do so would require a well-funded and focused research program to produce meaningful results in the short term. Such a program could be focused on marine applications using the progress achieved to date in aeronautical applications, with the potential for spin-offs into MASS appropriate markets, given the correct ecosystem conditions.

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<sup>101</sup> <https://www.businesswire.com/news/home/20240513725547/en/Un-Jammable-Quantum-Tech-Takes-Flight-to-Boost-UK%E2%80%99s-Resilience-Against-Hostile-Actors>

<sup>102</sup> <https://www.zhinst.com/americas/en/company/our-story>

<sup>103</sup> <https://www.sandia.gov/quantum/>

<sup>104</sup> <https://www.baesystems.com/en-uk/feature/flying-with-the-fifth-state-of-matter-quantum-sensing-takes-a-leap-forward>

<sup>105</sup> <https://www.qinetiq.com/en/news/quantum-tech-takes-flight-to-boost-uks-resilience>

<sup>106</sup> <https://www.aquarktechnologies.com/aquark-and-royal-navy-test-quantum-sensing-at-sea>

## 4 Canadian Technologies and Systems with Application to MASS

### 4.1 Current Status

Canadian innovators are developing uncrewed surface vessels and associated technologies to perform ocean missions safely and efficiently.

#### 4.1.1 Autonomous Uncrewed Surface Vessel (USV) Platforms

Several Canadian companies are designing and building autonomous or remotely-operated surface vessels for civil and defence applications. Open Ocean Robotics (Victoria, BC) produces solar-powered USVs (e.g. the Data Xplorer) that can operate for extended durations to collect real-time ocean data for environmental monitoring<sup>107</sup>. This SME has received federal support to scale up production of its autonomous boats, which are used to monitor marine environments more safely and affordably.

Shift Coastal Technologies (Victoria, BC) has developed the OceanSled® series of rugged autonomous vessels, including the OceanSled Ranger, a shallow-water, multi-mission autonomous surface vessel (ASV) delivered in 2024 as the Canadian Coast Guard’s first autonomous surface platform<sup>108</sup>. The Coast Guard’s adoption of this system, following a two-year pilot collaboration with Shift Coastal, highlights Canada’s domestic capabilities in uncrewed surface vessel (USV) design, modular sensor integration, and remote operations for applications such as nearshore search and rescue and environmental response.

In Atlantic Canada, LeeWay Marine (Nova Scotia) is retrofitting high-speed research boats for autonomy. Its 22 m LeeWay Striker, capable of 55 knots, has been outfitted with digital control systems and remote monitoring, positioning it as an “autonomous-capable” hydrographic survey vessel<sup>109</sup>. The growing trend of designing or converting vessels for optional unmanned operation is enabling the development of a diverse range of Canadian uncrewed surface vessel platforms, spanning from small, rugged skiffs to larger ocean-going craft.

#### 4.1.2 Autonomy Software and AI for Navigation and Control

Canada’s MASS ecosystem includes significant development of vessel autonomy software, spanning autonomous navigation, perception, and command-and-control. Marine Thinking (Halifax, NS) leads an Ocean Supercluster project to create an AI-powered vessel automation toolkit for retrofitting existing boats with autopilot and smart navigation capabilities<sup>110</sup>. This toolkit applies artificial intelligence for route planning (e.g., optimizing fishing routes) and detecting hazards like “ghost gear” to enhance safety and efficiency in operations.

Several Canadian startups are emerging as specialists in marine artificial intelligence and computer vision technologies. For example, through DND’s IDEaS program, multiple firms were funded to build lookout-assist systems that use machine learning and sensors to detect small vessels or obstacles among waves. Companies such as Nuvoola, Visual Defence, and Metaspectral have prototyped smart camera and radar fusion solutions to reliably spot debris, other craft, or persons in the water. On the research

<sup>107</sup> <https://oceannews.com/news/science-technology/open-ocean-robotics-will-upgrade-usv-production-with-new-pacifican-funding/>

<sup>108</sup> <https://maritime-executive.com/corporate/the-canadian-coast-guard-s-delivery-of-its-first-autonomous-surface-vessel>

<sup>109</sup> <https://resourceinfocus.com/2021/11/what-lies-beneath/>

<sup>110</sup> <https://coveocean.com/news/canadas-ocean-supercluster-announces-3-8m-ai-powered-vessel-automation-toolkit-project/>

front, groups are advancing core autonomy algorithms. The National Research Council Canada - Ocean, Coastal and River Engineering (OCRE), working with Memorial University, is applying reinforcement learning and bio-inspired swarm intelligence to coordinate fleets of autonomous vessels<sup>111</sup>. Their recent project explores how a “swarm” of self-driving uncrewed boats could cooperate to clear sea-ice channels behind an icebreaker, persistently keeping shipping lanes open.

Collectively, these advancements in AI-driven navigation, path planning, and control logic serve as the core intelligence of MASS, enabling vessels to comply with COLREGs, avoid collisions, and make operational decisions with minimal human intervention.

#### 4.1.3 Sensor and Situational Awareness Technologies

A strong domestic sensor industry supports MASS development in Canada, adapting high-performance ocean sensors for autonomous use. Kraken Robotics (Newfoundland and Labrador) provides advanced sonar systems such as high-resolution Synthetic Aperture Sonar (SAR) and launch/recovery equipment that can be integrated into USVs for mine countermeasures and seabed mapping<sup>112</sup>. The use of Kraken Robotics’ SAS system and autonomous launch-and-recovery winch aboard the high-speed LeeWay Striker vessel illustrated the potential of unmanned platforms to conduct rapid hydrographic surveys and mine-hunting missions. In the area of environmental monitoring, JASCO Applied Sciences (Halifax, NS) has adapted its Passive Acoustic Monitoring (PAM) systems for integration with uncrewed surface vehicles. In a 2021 trial, JASCO, in partnership with Open Ocean Robotics, equipped a Data Xplorer USV with a towed hydrophone array and JASCO’s OceanObserver software and high-resolution camera to autonomously detect whale calls in real time<sup>113</sup>. The USV streamed acoustic detections and camera feeds to shore analysts, successfully demonstrating all-Canadian technology for marine mammal monitoring.

Canadian firms are also leaders in radar and optical sensors that enhance situational awareness for autonomous navigation. Rutter Inc. (St. John’s, NL) produces the Sigma S6 radar processing suite, which can be carried on MASS platforms to automatically detect small objects, ice, oil slicks, and wave patterns using enhanced radar analytics<sup>114</sup>.

High-performance electro-optical and infrared (EO/IR) camera systems, such as those produced by L3Harris WESCAM (Ontario), are frequently integrated into uncrewed surface vessels to provide human-like visual perception at sea. These sensors, along with Automatic Identification System (AIS) receivers and GNSS/INS navigation units (including Canadian-made GPS systems from Hexagon | NovAtel), feed into the vessel’s AI-powered perception stack. Through ongoing research and development, Canada is actively adapting its established ocean sensor technologies for use in autonomous systems, helping ensure that MASS possess the situational awareness required to operate safely in complex and dynamic marine environments.

#### 4.1.4 Systems Integration and Platform Management

Effective MASS deployment requires integrating diverse subsystems, hulls, power systems, sensors, and software, into a reliable platform. Canadian organizations play key roles in systems integration and

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<sup>111</sup> <https://nrc.canada.ca/en/stories/autonomous-fleet-ice-management-reinforcement-learning#>

<sup>112</sup> <https://www.globenewswire.com/news-release/2019/04/03/1795982/0/en/LeeWay-Marine-Completes-Successful-Trials-of-Kraken-s-SeaScout-System.html>

<sup>113</sup> <https://www.jasco.com/press-releases/2022/jasco-applied-sciences-and-open-ocean-robotics-demonstrate-novel-all-canadian-marine-mammal-monitoring-service-via-usv>

<sup>114</sup> <https://quemaritime.com/Product/Oil-Spill-Detection-Radar>

developing platform management systems for USVs. For instance, Shift Coastal’s Coastal Intelligence Management System (CiMS) is a unified command-and-control software that links their USVs with sensors and cloud services, allowing operators to monitor missions and sensor data in real time via a user-friendly interface<sup>115</sup>. The CiMS platform fuses inputs from surface and subsea cameras, radar, and other sensors to enhance the operator’s situational awareness during autonomous operations.

Larger defence contractors in Canada are also contributing to integration. Kraken Robotics, beyond providing sensors, acted as the prime integrator for the Royal Canadian Navy (RCN)’s new Remote Mine-hunting and Disposal System. Under a \$57.9 M contract, Kraken is delivering a suite of autonomous underwater vehicles and mine neutralization robots, packaged with a transportable command center for deployment from RCN vessels<sup>116</sup>.

In the private sector, LeeWay Marine serves as an integrator by outfitting its vessels with cutting-edge autonomy and monitoring systems. It partners with technology providers and modifies vessels to host autonomous kits, as seen in collaborations where a small USV was networked with underwater drones and an aerial UAV to jointly survey mine-like objects in trials<sup>117</sup>.

Furthermore, Canadian naval architectural firms, such as Vard Marine, are beginning to incorporate autonomous-ready designs into small craft and workboats, ensuring new vessels have the modularity to add remote operation, redundant control systems, and autonomous navigation suites. This system-level approach, melding hull design, electrical systems (often hybrid or electric propulsion for quiet, efficient running), sensor integration, and fail-safe controls, is a Canadian asset, supported by decades of experience in shipbuilding and ocean engineering. Robert Allen Limited, well-known for tugboat design, has been working on a ‘Line Transfer System’ (LTS) to pass the towline from an uncrewed tug to a ship since 2020.

#### 4.1.5 Testing and Demonstration Infrastructure

Canada has established several venues and programs to test MASS technologies in real-world conditions. A notable hub is the Centre for Ocean Ventures & Entrepreneurship (COVE) in Halifax, which provides access to a sheltered harbour test range and a community of ocean tech companies. Firms like LeeWay Marine collaborate with startups and the Nova Scotia Community College to continuously test and refine new marine autonomous systems in the field<sup>118</sup>. COVE’s facilities (piers, a marine terminal, and instrumented test sites) enable trials of USVs’ navigation systems, sensors, and communications in a safe environment before wider deployment. In Newfoundland and Labrador, Marine Institute’s Holyrood Marine Base, the Launch, offers a deep-water protected bay for testing autonomous platforms in harsh Atlantic conditions.

On the Pacific coast, the Centre for Ocean Applied Sustainable Technologies (COAST) offers programs, services, spaces and partnerships that directly meet ocean entrepreneurs' needs, and empower BC's world-class ocean and marine innovation ecosystem to thrive<sup>119</sup>. Trials are often conducted in the waters around Vancouver Island: for example, Open Ocean Robotics and JASCO carried out their joint USV demo near Victoria to showcase long-range acoustic monitoring. Defence

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<sup>115</sup> <https://shiftcoastal.com>

<sup>116</sup> <https://www.krakenrobotics.com/kraken-awarded-50-million-navy-contract-for-royal-canadian-navy-minehunting-program>

<sup>117</sup> <https://www.canada.ca/en/defence-research-development/news/articles/exercise-unmanned-warrior-an-international-exercise-using-autonomous-tech-to-detect-underwater-mines.html>

<sup>118</sup> <https://leewaymarine.ca/services/ocean-technology-testing-research>

<sup>119</sup> <https://canadacoast.ca/>

R&D Canada (DRDC) also facilitates demonstration exercises to validate MASS in operational scenarios. DRDC has participated in international exercises (like Unmanned Warrior) where Canadian-built surface and subsurface vehicles were networked together to hunt mines, testing interoperability with allied systems.

Through the Innovative Solutions Canada program and Ocean Supercluster projects, the government has funded numerous pilot projects that require field trials, such as the Canadian Coast Guard's evaluation of Shift Coastal's ASV in Haida Gwaii and autonomous ferry docking prototypes in BC. These trials are supported by temporary regulatory allowances (via Transport Canada) and often involve local port authorities or Canadian Coast Guard oversight to ensure safety. Overall, Canada's mix of coastal proving grounds, naval test exercises, and shared industry testbeds accelerates the development and maturation of MASS technologies by providing realistic operating environments.

#### 4.1.6 Notable Collaborations and Exports

Canada's progress in surface-ship autonomy is being propelled by collaboration across sectors and is starting to generate export opportunities. The federally funded Ocean Supercluster initiative has been a catalyst for industry partnerships, connecting startups with larger firms and academia on projects like Marine Thinking's autonomous fishing vessel pilot (with Vancouver's ACEL Power) and Kraken's involvement in the multi-partner OceanVision™ ocean mapping initiative.

Collaborative demonstrations also raise the profile of Canadian technology: the joint JASCO–Open Ocean Robotics project, demonstrated for DRDC, was an all-Canadian solution that attracted interest in using uncrewed vessels for environmental compliance monitoring. We are now seeing Canadian-developed MASS technology adopted abroad. Kraken Robotics, for example, has supplied its SAS sonars and autonomy-ready systems to NATO allies, its towed KATFISH sonar and autonomous launch-and-recovery winch have been integrated on foreign unmanned platforms for mine countermeasures. GeoSpectrum Technologies (a Halifax-based sonar firm, now part of Elbit Systems) recently exported its compact TRAPS-USV towed sonar for deployment on an Israeli unmanned surface vessel, showcasing Canadian acoustic sensor tech on the world stage<sup>120</sup>. These export successes build on Canada's reputation in niche areas like underwater sensing and indicate a growing global market for our MASS components.

Finally, joint research endeavors bolster Canada's capabilities: NRC's collaboration with Memorial University on autonomous ice navigation and DND's IDEaS program engaging AI startups are two examples where government, academia, and private sector intersect to solve complex MASS challenges. Such collaborations ensure that Canadian MASS stakeholders share knowledge and align R&D efforts, reducing duplication.

In summary, Canada's MASS ecosystem, spanning innovative SMEs, federal agencies, and universities, is leveraging teamwork to drive technological advancement and position Canadian solutions in the emerging global market for autonomous ships.

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<sup>120</sup> <https://elbitsystems.com/news/geospectrum-technologies-launches-game-changing-1f-active-vds-deployable-usvs>

## 5 Canada's Strengths and Challenges

### 5.1 Canada's Areas of Technical Strength

Canada boasts a robust marine technology sector, driven by its rich maritime heritage, cutting-edge research institutions, and strong industrial base. With expertise spanning naval architecture, marine engineering, and advanced sensor technologies, Canada is well-positioned to support the development of MASS.

The country's leadership in Artificial Intelligence (AI) and Machine Learning (ML), combined with its innovations in digital twins, autonomous navigation systems, and sensor fusion, provides a foundation for the design and deployment of intelligent, self-operating vessels.

Canadian companies excel in shipbuilding, cybersecurity, and sustainable maritime solutions, including technologies for reducing emissions and enhancing fuel efficiency. Supported by government initiatives that enhance the culture of collaboration between academia, industry, and research organizations, Canada could drive advancements in marine autonomy, fostering safer, greener, and more efficient global shipping operations.

#### 5.1.1 AI and ML

Canada stands as a global leader in AI and ML with prominent research hubs in cities such as Waterloo, Toronto, Montreal, and Edmonton. Institutions like the Vector Institute, Mila (Quebec AI Institute), and the Alberta Machine Intelligence Institute (Amii) drive cutting-edge research in these fields. The University of Waterloo hosts Waterloo.AI, the institution's central hub for AI and data science research and collaboration. These organizations collaborate with entrepreneurial SMEs to develop AI applications and cultivate skillsets that could be directed towards emerging MASS applications.

For instance, Integrate.ai, based in Toronto, focuses on privacy-preserving machine learning solutions that could enhance data security in autonomous maritime operations. TrojAI, located in Saint John, New Brunswick, develops solutions to protect AI systems from adversarial attacks, ensuring the robustness of AI models used in critical applications like autonomous navigation.

In Newfoundland and Labrador, Compusult offers global geospatial solutions that can support navigation and situational awareness for MASS. Nova Scotia's Global Spatial Technology Solutions (GSTS) specializes in maritime big data analytics, providing insights that can optimize autonomous vessel operations. Ontario-based Zighra focuses on multi-sensor data fusion, which is essential for integrating information from various sensors aboard autonomous vessels. Hike Metal Products Ltd., located in Wheatley, Ontario, has experience in integrating autonomous command and control systems into their vessel designs, contributing to the development of autonomous marine platforms. E-Sonar, operating out of Newfoundland and Labrador, specializes in acoustic noise analysis, a critical component for underwater sensing and navigation in autonomous maritime systems.

In addition, Trinary, an innovative Montreal-based company, has partnered with Mila to integrate AI solutions aimed at improving the operational efficiency of small and medium-sized enterprises (SMEs). While not exclusively focused on the maritime sector, Trinary's expertise in AI optimization methodologies is transferable and could be adapted to enhance autonomous marine operations.

These capabilities are crucial for developing autonomous navigation systems, decision-making algorithms, and predictive maintenance applications within MASS. The ability to tailor AI solutions to specific, targeted needs is under active development, and these methodologies appear to be transferable to the autonomous marine sector.

### 5.1.2 Numerical Modelling, Physical Testing and Simulation

Canada possesses a robust and internationally recognized capability in maritime simulation, numerical modelling, and physical model testing, a triad that forms the backbone for safe, cost-effective, and scalable development of MASS. These capabilities are foundational for training, mission planning, system integration, and validation of autonomous behaviours prior to full-scale deployment.

#### High-Fidelity Maritime Simulators

Canada's simulation infrastructure is rooted in its strength in the aerospace and defence sectors and has been effectively adapted for maritime applications. These simulators are crucial for operator training, mission rehearsal, control algorithm validation, and the development of MASS human-machine interfaces.

- Centre for Marine Simulation (CMS), located at Marine Institute, Memorial University, CMS operates one of the most advanced full-motion ship bridge simulators in North America. Powered by systems from global leaders CAE and L3Harris, the simulator allows users to simulate complex scenarios such as port navigation, collision avoidance, and vessel emergency response. It is used for testing control logic, validating COLREGs compliance, and training operators for MASS supervision or handover tasks.
- Virtual Marine – Paradise, NL  
Specializing in safety and survival training simulators, Virtual Marine offers high-fidelity simulation platforms for lifeboats, fast rescue boats (FRBs), ice navigation, and helicopter ditching. These systems are used to train personnel for high-risk maritime operations in a controlled environment. Their Advanced Coxswain Training Program, delivered in combination with their simulation tools, is particularly relevant for MASS contexts in which remote operators may need to take manual control or oversee multiple vessels.
- GRI Simulations – Mount Pearl, NL  
GRI develops physics-based simulation tools using mission-specific profiles and realistic vessel hydrodynamics. These simulators allow developers to evaluate vessel control responses, autonomy algorithms, and environmental impacts in mission-specific scenarios. This kind of platform can be suited for MASS concept evaluation and design iteration, enabling robust mission planning and behaviour prediction before physical trials.

#### Numerical Modelling for System and Mission Optimization

Advanced numerical modelling tools allow MASS developers to simulate vessel performance, environmental interaction, and autonomy logic in a virtual environment. These tools support rapid design iteration and help anticipate system behaviour in complex, real-world conditions.

- Memorial University (Department of Ocean and Naval Architectural Engineering), C-CORE and NRC OCRE, St. John's, NL and University of British Columbia (Department of Mechanical Engineering), Vancouver, BC  
These institutions are leaders in Computational Fluid Dynamics (CFD) for naval architecture applications. They routinely model ship maneuverability, resistance, propulsion interactions, and stability, providing insights into how MASS platforms will behave under varying conditions. This is essential for optimizing autonomous control strategies and sensor placement.

For modelling ship operations in ice, Memorial University, NRC OCRE, and C-CORE offer specialized expertise to support the development of MASS in the Arctic and northern regions.

- Robert Allan Ltd. (RAL), Vancouver, BC and Vard Marine, Ottawa, ON  
These naval architecture firms use CFD and performance simulation tools to analyze ship hydrodynamics. RAL's methods, developed for precision escort tug control, are being adapted for remote and autonomous vessel maneuvering, with direct relevance to MASS operations in harbours and confined waterways.

### Physical Model Testing and Experimental Validation

Canada hosts world-class facilities for physical model testing, enabling developers to validate simulations, autonomy software, and vessel performance in controlled water environments. This capability provides the final engineering confidence before full-scale MASS deployment.

- NRC's Offshore Engineering Basin, Ice Tank and Towing Tank, St. John's, NL  
These facilities support scale-model testing of MASS hull forms, propulsion systems, and control behaviours in simulated sea states. Developers can test course-keeping, wave impacts, sensor placement, and emergency maneuvers under repeatable conditions, key for risk assessment and classification approvals. Notably, NRC OCRE operates a world-class ice tank facility, enabling advanced simulation of ship-ice interactions.
- Towing Tank, Department of Ocean and Naval Architectural Engineering, Memorial University  
A 58-m towing tank supports testing ship models up to 3m in length.
- The Launch, Marine Institute, Memorial University, offers unique capabilities for testing larger-scale models and full-scale boats and prototypes.

### Relevance to MASS Development

This layered simulation capability, combining simulators, physics-based numerical models, and physical testbeds, enables Canadian developers to:

- De-risk autonomous system development by validating navigation and control logic before sea trials
- Train remote operators and mission supervisors in realistic, risk-free environments
- Optimize vessel design and performance using high-resolution CFD and wave basin testing
- Demonstrate compliance and reliability to regulators and classification societies with empirical test data
- Reduce cost and accelerate innovation through virtual iteration and modular prototype testing

Simulation and modelling are not peripheral tools but a central pillar of Canada's MASS capability. They allow engineers to build, test, and refine autonomous vessel systems efficiently and safely, reducing time-to-field and improving system performance. Through integrated facilities supported by design leaders and researchers, Canada is positioned to play a leading role in the design, validation, and safe deployment of autonomous surface vessels.

### **5.1.3 Cybersecurity and Cyber Defence**

Canada has a well-developed cybersecurity ecosystem with strong public-private partnerships. The Canadian Centre for Cyber Security provides national leadership, and individual centres such as Memorial University's Department of Electrical and Computing Engineering and The Launch, Marine Institute have championed the promotion of marine cyber security.

Cyber defence is critical for safeguarding MASS systems against hacking and other cyber threats. Gaining access to control of, or disrupting control of, a MASS raises significant issues of professional

negligence, liability, insurance, terrorism, and possible criminal negligence. This extends to the Remote Operations Centre as another entry point for intrusion.

#### 5.1.4 Sensors and IoT

Canada boasts advanced capabilities in developing Internet of Things (IoT) devices and sensor technologies tailored for harsh environments. This expertise is deeply rooted in sectors such as ocean research, the blue economy, offshore oil exploration and production, the fishing industry, defence research and development, and Arctic and remote sensing applications. Key contributors to this capability include institutions like Memorial University, Dalhousie University, C-CORE, and numerous SMEs that collectively drive innovation in this field.

For instance, C-CORE specializes in developing remote sensing systems for harsh environments, offering solutions ranging from radio beacons and ice measurement radars to satellite transponders and space-qualified hardware. Their expertise supports industries operating in challenging conditions, ensuring reliable data acquisition and monitoring<sup>121</sup>.

These advanced sensor and IoT technologies are crucial for real-time data acquisition and autonomous decision-making in MASS. Canadian innovations encompass a wide array of technologies, including advanced electro-optical/infrared (EO/IR) sensors, enhanced marine radar systems, sonar systems, data management and recording systems, video recording, acoustic data telemetry, and remote monitoring capabilities. These technologies provide mission-specific solutions essential for the effective deployment of MASS in real-world scenarios.

A significant enabler in this domain is Starlink Maritime, a satellite communication service that delivers high-speed internet connectivity to vessels at sea. Designed for permanent installation, Starlink Maritime can withstand extreme conditions such as severe cold, heat, sleet, heavy rain, and hurricane-force winds. It offers download speeds of up to 220 Mbps, facilitating robust command and control as well as efficient data exchange for both manned and unmanned vessels<sup>122</sup>.

Integrating these advanced Canadian sensor technologies with reliable satellite communication systems like Starlink Maritime significantly enhances the operational capabilities of MASS platforms, ensuring effective performance in the most challenging maritime environments.

#### 5.1.5 Earth Observation and Aerospace Technology

Canada has a longstanding global reputation for excellence in satellite technology, particularly through programs such as RADARSAT and the Canadian Space Agency's (CSA) CubeSat initiative. These platforms are critical for Earth observation, maritime surveillance, sea-ice monitoring, and environmental data acquisition, all of which are highly relevant to the safe and effective deployment of MASS.

The CSA CubeSat program, in particular, offers post-secondary institutions the opportunity to design, build, and launch small satellites from the International Space Station. This initiative not only builds technical capacity in space systems, but also supports innovation in maritime sensing. At Memorial University, researchers and students are developing the Killick-1 CubeSat, which will test existing technologies designed to measure sea ice extent and thickness, a key variable for Arctic navigation and operational planning. Such capabilities could be adapted to support MASS operations in northern regions, where situational awareness and environmental monitoring are mission critical.

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<sup>121</sup> <https://c-core.ca/remote-sensing-systems>

<sup>122</sup> <https://www.starlink.com/us/business/maritime>

## Relevance

Satellite-based sensing and communication technologies provide essential services for MASS, including:

- Enhanced situational awareness, especially in remote or data-poor regions
- Sea ice detection and tracking, vital for Arctic and sub-Arctic operations
- Weather forecasting and ocean condition monitoring, supporting navigation and mission planning
- Broad-area vessel detection and surveillance, complementing onboard MASS systems

With growing strategic and economic interest in Canada’s Arctic approaches and northern coastlines, the ability to integrate space-based data into real-time (or near real-time) MASS navigation and decision-making frameworks is increasingly important. Building a business case for commercializing and operationalizing these technologies for maritime autonomy would strengthen Canada’s position in both national and global MASS development, particularly for operations in harsh and ice-prone environments.

### 5.1.6 Shipbuilding and Design

Canada’s shipbuilding industry is rapidly modernizing, integrating advanced technologies and laying a strong foundation for MASS. The National Shipbuilding Strategy (NSS) has revitalized major shipyards and a network of specialized yards and design firms, positioning Canada to support autonomous and remote vessel operations. Below is a comprehensive overview of key players and capabilities:

#### Major Shipyards under the National Shipbuilding Strategy

- Irving Shipbuilding (Halifax, NS): Irving is a lead NSS shipyard, building naval combatants and Arctic-capable vessels. Irving’s readiness to integrate digital systems is shown by partnerships (e.g., with Lockheed Martin on CSC) and state-of-the-art Land-Based Test Sites for ship electronics, ensuring vessels are “digital twin” tested before launch. These facilities and investments mean Irving can incorporate hybrid-electric propulsion, advanced sensors, and autonomy-ready control systems into new warships or ice-capable patrol craft. To date, Irving Shipbuilding has built six Arctic and Offshore Patrol Ships (AOPS) under the NSS. In addition, two modified AOPS are being built for the Canadian Coast Guard. The program has also driven broader investment in marine innovation, reinforcing ties with the Centre for Ocean Ventures and Entrepreneurship (COVE) and supporting a new trades training initiative with Nova Scotia Community College. These efforts ensure long-term regional benefits and enhance Canada’s Arctic and maritime capabilities.
- Seaspan Shipyards (Vancouver, BC): Seaspan, the other NSS lead, builds Coast Guard and naval support vessels and is at the forefront of shipyard digitalization. In 2022, Seaspan launched HoloShip, an immersive 3D visualization system allowing designers and engineers to virtually walk through a vessel’s digital model. Seaspan is constructing the Canadian Coast Guard’s new Polar Icebreaker and Multi-Purpose Vessels and has started a new Land-Based Test Facility on-site (the first in Canada) to integrate and test communications, navigation, and sensor suites before installing them on ships. This testbed will support the Polar Icebreaker’s advanced electronics and any autonomous features for remote Arctic operations. Seaspan’s NSS work also includes Joint Support Ships and an Offshore Oceanographic Science Vessel, all

benefiting from modernized production. Through NSS “value proposition” investments, Seaspan has funded Canadian tech companies (e.g., Gastops, 3GA Marine, Kognitiv Spark) to advance marine digitalization and fleet maintenance, indicating a strong drive to incorporate smart ship technologies. With these capabilities, Seaspan can build large new vessels that are autonomy-ready (with integrated sensor networks or hybrid drives) and even retrofit existing ships with modern control systems.

- Chantier Davie (Lévis, QC): Davie, Canada’s largest shipbuilder, joined NSS in 2023 to fill urgent needs for ice-capable and hybrid vessels. Davie will build six Program Icebreakers and one Polar Icebreaker for the Coast Guard, plus has been tasked with two large hybrid-powered ferries. Davie’s modernization is critical for building Canada’s most powerful icebreakers and complex hybrids. With new facilities, Davie can integrate electric or hybrid propulsion, advanced automation, and Arctic-specific features (hull strengthening, remote monitoring) into future ships. The yard’s expansion, supported by partnerships (e.g., with Finland’s Aker Arctic on design), will let it build cutting-edge vessels that could easily host autonomous systems for polar operations.

All three major yards are deeply experienced in Arctic-class ships and emerging technologies. Irving’s AOPS are Polar-class 5 and serve as testbeds for cold-weather operations with reduced crew. Seaspan and Davie are now co-leading on two different Polar Icebreakers, each requiring robust automation, remote monitoring, and high-reliability power systems for safety in ice. Davie’s initial NSS package explicitly includes hybrid ferries, underlining Canada’s push for green propulsion (diesel-electric/battery) in new builds. With GE, MAN Energy, and other tech providers involved, Canadian new builds often feature integrated electric drives, common rail engines, and digital control networks. This ensures the platforms coming out of NSS yards have the electrical and data infrastructure to support future autonomous navigation systems or remote operation modules.

Canada’s primary shipyards (Irving, Seaspan, Davie) now operate modern facilities that can build large, complex vessels with hybrid-electric propulsion, sophisticated sensors, and digital systems integration. These yards are already delivering Arctic-capable ships and incorporating virtual design tools and test sites to streamline the addition of new technology. This means Canada’s big shipbuilders can produce MASS-ready ships (e.g., naval combatants, icebreakers, offshore patrol vessels) and have the capacity to integrate autonomy from the keel up.

#### Regional and Specialized Shipyards Enabling MASS

Beyond the NSS giants, Canada has a network of smaller shipyards and boatbuilders known for agility and specialization. These regional players are crucial for smaller craft, patrol boats, and workboats that could be equipped with autonomous control systems or serve as MASS testbeds:

- Hike Metal Products (Wheatley, ON): A respected workboat builder (SAR vessels, patrol craft) that is actively integrating autonomy. In 2019, Hike Metal partnered with Boston-based Sea Machines to install an SM300 autonomous control system on a new 27-foot search-and-rescue RHIB. The goal was to demonstrate remote and autonomous SAR operations, adding capabilities like waypoint navigation, obstacle avoidance, and unmanned control for faster rescues. Trials on Lake Erie showed that with Sea Machines’ system, a Hike Metal boat can operate in minimally manned or unmanned modes, controlled from shore and performing search patterns or towing operations autonomously. Hike Metal’s willingness to retrofit advanced autonomy on its small vessels highlights the innovative culture of Canada’s specialized yards. It

is providing real-world platforms for MASS technology development (SAR is a high-stakes use case), and its collaboration with tech firms could lead to next-gen autonomous lifeboats or patrol craft.

- ABCO Industries (Lunenburg, NS): ABCO builds aluminum boats (patrol craft, workboats, small passenger vessels up to ~60 feet) and has embraced the electric and autonomous revolution. In 2023, with federal support, ABCO launched its first fully electric workboat, converting a 32-foot former police patrol boat to battery-electric drive. The refit included a 300 kW Evoy inboard motor, demonstrating how an older craft can be recycled and modernized with clean propulsion. The project, part of a “Lunenburg Electric Harbour” initiative, showcases not only ABCO’s expertise in retrofits but also the potential to integrate digital control and monitoring inherent in electric systems. ABCO has a history of custom builds for the Coast Guard and Navy, and by adding electric and possibly semi-autonomous capabilities (for harbor or survey operations), it positions itself as a go-to yard for MASS-enabled small craft. The combination of lightweight aluminum design and electric propulsion yields low-maintenance boats that are ideal for remote or unmanned roles requiring reliability and long-term cost savings.
- Ocean Industries (Isle-aux-Coudres, QC), Part of Groupe Océan: this yard is building Naval Large Tugs (NLTs) for the RCN. The four tugs are based on a proven Robert Allan Ltd. RAMparts 2400 design with IMO Tier III engines and modern automation. While crewed tugs, they represent the latest in harbor tug technology and could be candidates for partial autonomy (remote docking assistance, etc.). Notably, Robert Allan Ltd. has developed the RAMora class of unmanned tugs, and Ocean’s new tugs could potentially be retrofitted in future with remote operating capability (the RCN’s interest in autonomy is growing). Ocean Group also operates tugs and barges across Eastern Canada and is known to innovate with technology (e.g., they have explored use of drones for port operations). Building the NLTs domestically demonstrates capacity for complex, small-medium vessel construction, and these tugs will have advanced navigation and propulsion controls that align with MASS trends (high automation tolerance, remote monitoring).
- Other Niche Builders – Across Canada, several smaller yards contribute to the MASS ecosystem. For example, Kantera (formerly MetalCraft Marine) builds fireboats and high-speed craft; Industries Raymond (Quebec) does specialized workboats; and Pacific coast yards build autonomous-capable platforms (like Liquid Roboticswave gliders integration). While not all are engaged in autonomy yet, many are starting to incorporate digital controls or work with marine tech startups. These yards also provide refit services, e.g., rolling out new sensor suites or communication gear on existing government boats, which is crucial for gradually upgrading current fleets with autonomous features.

Canada’s regional shipyards consistently outperform expectations, specializing in the construction and retrofitting of smaller vessels equipped with modern propulsion and advanced control systems. They serve as agile test platforms for MASS, from autonomous rescue boats to electric patrol craft. Their contributions ensure that not only large warships but also workboats, tugs, and patrol vessels can be made MASS-capable, expanding the envelope of autonomous operations in coastal, inland, and Arctic waters.

### Retrofit and Autonomy Integration Capabilities

Canada's shipbuilders and suppliers have considerable experience modernizing vessels and adding new technology, a vital capability for integrating autonomy into existing ships or prototypes.

- **Conversion and Refit Track Record:** The standout example is Davie's conversion of a containership to the naval support ship Asterix. Completed in 18 months, this complex retrofit equipped Asterix with replenishment-at-sea systems, military communications, and new automation, all at a fraction of the cost of a new build<sup>123</sup>. This success gives Canada confidence in tackling future conversions, such as potentially turning commercial vessels into MASS testbeds (e.g., an existing research ship retrofitted to operate unmanned for certain missions). Irving Shipbuilding also regularly performs major refits, like Halifax-class frigate mid-life upgrades and life extensions on Canadian Coast Guard ships. These refits increasingly involve installing modern integrated bridge systems, automated machinery control, and updated sensors, which are stepping stones to full autonomy. For instance, recent Halifax-class upgrades involve digital control for engines and surveillance systems, creating architecture that could support remote operation in emergencies or enhanced decision support for crews.
- **Autonomy Kits and Partnerships:** Canadian industry is linking up with technology firms to add autonomy to workboats. The Sea Machines SM300 kit used by Hike Metal can be installed on new or existing vessels and typically pays back within a year due to operational efficiency. This illustrates that retrofitting autonomy (collision avoidance, remote helm control) is not only technically feasible but also economically attractive for commercial operators. Similar systems from Kongsberg, Rolls-Royce, and L3Harris can be integrated by Canadian yards or defence contractors. Naval in-service support firms in Canada, such as Fleetway in Halifax and L3Harris in Montreal, have demonstrated strong capabilities in integrating complex C4ISR systems, a process that closely parallels the integration of autonomous navigation suites.
- **Lifecycle Support Infrastructure:** Maintaining autonomous or semi-autonomous ships requires strong technical support ashore. Canada has invested in this through initiatives like Seaspan's planned fleet maintenance digitalization and Nova Scotia's COVE, which houses companies focusing on remote vessel monitoring and data analytics. The presence of companies like Gastops (Ottawa), which provides remote machinery health monitoring, and Marimetric (Dartmouth), which offers condition-based maintenance technology, means that Canadian MASS can be supported by real-time data links for predictive maintenance. Moreover, new ships under NSS all come with integrated logistics support systems that stream data back to shore. This infrastructure is inherently autonomy-friendly, since MASS will depend on shore control centers and continuous health monitoring.
- **Training and Simulation:** A subtle but important aspect of retrofit capability is human training to use new technology. In addition to the unique naval architecture undergraduate program at Memorial University and the course-based Master's program at UBC, providing the education and training for autonomy integration in ship design, Canada's simulation companies (e.g., Virtual Marine and OSI Maritime for bridge simulators) and schools such as Marine Institute are gearing up to train operators for remote and autonomous systems. As MASS are introduced, simulators and testing in safe environments (like the Canadian Coast Guard's first autonomous

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<sup>123</sup> <https://federalfleet.ca/2022/08/29/canada-extends-asterix-naval-support-ship-contract-until-2025-with-option-to-buy>

surface vessel<sup>124</sup> delivered in 2022 for training and demo ensure that integration and safety are paramount.

Canada's marine industry can not only build new autonomous-ready ships but also upgrade existing vessels with autonomous capabilities. A history of successful conversions (like Asterix) and partnerships with tech providers (Sea Machines, Kongsberg, etc.) has created a skill base in integrating sensors, control algorithms, and remote operation features. Combined with digital maintenance infrastructure and training ecosystems, Canada is well-equipped to retrofit ships for autonomy and sustain them through their service life.

#### Canadian Naval Architecture and Marine Engineering Firms

Canada's strength in ship design is a critical asset for MASS development. Several homegrown naval architecture firms are internationally recognized, and they're actively creating autonomous-ready, hybrid, and Arctic-capable designs:

- Robert Allan Ltd. (RAL, Vancouver): As a world-leading designer of tugs and workboats, RAL has been anticipating the unmanned revolution. They developed the RAMora series of remotely-operated tugs to meet future demand for unmanned harbour operations. RAL is also collaborating on specialized autonomous vessels. A notable project is the RALamander firefighting drone-boat, a 20 m unmanned fireboat co-developed with Kongsberg Maritime. The RALamander is designed to fight industrial fires in ports without endangering crew, using autonomous dynamic positioning and remote water cannon control. This concept exemplifies Canadian innovation in MASS: a purpose-built autonomous vessel with advanced sensors and control logic. RAL's expertise in high-performance, small crew vessels (tugs, ferries, crew boats) translates perfectly to MASS, since those vessel types often lead in autonomy adoption. RAL has also developed advanced line transfer systems as integral components of their tugboat designs, particularly in their RAMora series of remotely operated vessels. These systems are engineered to enhance safety and efficiency during towing operations, especially when transferring lines between vessels. Additionally, RAL's designs for the RCN's new tugs (Naval Large Tugs) ensure the navy gets cutting-edge hulls that could later incorporate remote or autonomous functions. RAL is also part of international projects, such as partnering with Abu Dhabi Ports to create the world's first fully unmanned commercial tugs, shifting the human element onshore to improve safety and weather tolerance. In summary, Robert Allan Ltd. provides Canada with field-proven autonomous vessel designs, ready to be built domestically.
- Vard Marine (Vancouver and Ottawa) - Formerly STX Canada Marine: Vard Marine is known for complex vessel design including offshore patrol vessels, icebreakers, and research ships. Vard combines Canadian and global expertise (as part of Fincantieri) and has a track record in ice-class design. In fact, Vard is the design lead for the Canadian Coast Guard's upcoming Polar Icebreaker, working with Finland's Aker Arctic to optimize the ship for extreme conditions. Vard Marine's portfolio includes many vessels that could be autonomy-ready: for example, they design offshore patrol vessels (like the Hero-class for the Coast Guard) with advanced C2 systems. Internationally, Vard is at the forefront of remote and autonomous vessel projects. Notably, it's designing 85m robotic vessels for Ocean Infinity's "Armada" fleet, which are optionally manned survey ships operated from shore control centers. That project, though not in Canada, leverages Vard's design know-how in integrating redundant systems for

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<sup>124</sup> <https://www.workboat.com/shipbuilding/the-canadian-coast-guard-takes-delivery-of-its-first-autonomous-surface-vessel>

autonomy (e.g., multiple gyro and failsafe power). With headquarters in Canada, Vard Marine can infuse these global MASS lessons into Canadian designs. They also have expertise in hybrid propulsion and low-emission ships, which are crucial for autonomous vessels that loiter or operate in sensitive environments. Vard’s partnership with Finnish designers and involvement in European innovation (like zero-emission ferries) further strengthen Canada’s design base for MASS, especially in Arctic and specialized craft.

- **BMT (Fleet Technology, Kanata ON):** BMT is a multinational consultancy with a strong Canadian presence. BMT’s Canadian branch has historically specialized in naval architecture for naval and coast guard vessels. They bring systems engineering depth that complements autonomous ship design – BMT has conducted studies on autonomy in marine operations<sup>125</sup> and developed frameworks for degrees of autonomy by ship type. While BMT Canada led designs for mid-shore patrol vessels and science vessels, they can leverage the wider BMT group’s work on unmanned systems (BMT in the UK has done USV prototypes). BMT’s strength is in integration and analysis, meaning they ensure that an autonomous-ready design is safe, class-compliant, and meets mission needs. For instance, BMT has experience designing vessels with modular payloads and remote mission bays (useful for autonomous minehunters or research USVs). They are an asset for concept design and feasibility studies for future Canadian MASS (e.g., advising the Navy on what autonomous platforms can complement crewed ships).
- **Genoa Design International (NL) –** Genoa is a production design firm from Newfoundland and Labrador that provides 3D modelling, detailed design, and digital shipbuilding support. They’ve contributed to many NSS projects (AOPS, JSS) by creating detailed production drawings and virtual models. Genoa’s experience in digitalization ensures that complex systems, like autonomous control networks, are properly integrated into ship plans. They help bridge naval architecture with actual construction, using virtual reality and model-based design. For MASS, a firm like Genoa is key to design flexibility: they can rapidly model changes needed to accommodate autonomous equipment (additional sensor mounts, new compartment layouts for control stations or battery banks, etc.).
- **Other Notable Firms:** Navtech (Quebec) and Concept Naval specialize in custom vessel design and possess the expertise to adapt their capabilities to autonomous applications, including coastal transport and survey operations. Fleetway (Halifax) provides comprehensive engineering and logistics support, including the development of procedures and maintenance routines for the integration of new technologies. Additionally, Canadian marine technology firms like Virtual Marine (NL) create simulators for USV operators, and the Marine Institute of Memorial University runs the Holyrood marine autonomy test range, all feeding back into better design requirements for industry.

Canada’s naval architects and marine engineers are not only designing the ships of today but are actively developing the autonomous and hybrid ships of tomorrow. With Robert Allan Ltd. delivering unmanned tug concepts and Vard Marine blending ice-class expertise with robotic ship projects, Canadian designers can craft MASS solutions tailored to Arctic operations, SAR, port services, and defence needs. These firms give Canada a self-reliant capability to conceive vessels with remote

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<sup>125</sup> <https://cismart.ca/wp-content/uploads/2020/11/CISMART-Report-to-ISED-on-Autonomous-Surface-Ships-Final-Posted-Online-2020.pdf>

operation, modular payloads, hybrid-electric drives, and high-degree automation, which the shipyards can then build.

## 5.2 Fragmented Ecosystem and Innovation Gaps

Canada’s MASS innovation landscape remains fragmented, with pockets of excellence but limited national integration. Regional and sectoral initiatives, from startup-led projects to academic research, often operate in silos. For example, Hike Metal’s partnership to integrate Sea Machines’ autonomous control on a Lake Erie search-and-rescue vessel demonstrated local innovation, and the Ocean Supercluster has begun funding collaborative projects (e.g., an AI-driven vessel automation toolkit led by Marine Thinking in Halifax) to retrofit smart autopilot capabilities. Yet overall, Canada has lagged behind peers in deploying maritime autonomy at scale; even the Royal Canadian Navy has “accomplished the least” among Five Eyes navies in integrating autonomous systems<sup>126</sup>. This gap points to the need for strategic coordination and increased funding to link these isolated efforts. Stakeholders note that stronger collaboration among industry, government, and researchers is driving advancements in vessel AI and digital initiatives<sup>127</sup>, suggesting an opportunity to enhance collaboration. By aligning federal and provincial programs and initiatives, Canada can bridge innovation gaps, avoid duplication, and accelerate the commercialization of MASS technologies.

### 5.2.1 Limited Large-Scale Maritime Operations and Test Infrastructure

The Canadian Coast Guard’s first autonomous surface vessel, a small nearshore ASV, reflects the current limited scale of MASS trials in Canada. Larger, ocean-going autonomous ship operations remain scarce. Canada’s relatively small commercial fleet and sparse test ranges constrain large-scale MASS development. The country’s internationally trading “SOLAS-class” fleet is modest, roughly 1,100 vessels under Canadian flag<sup>128</sup>, limiting domestic platforms to trial autonomous shipping compared to nations with vast merchant fleets.

Many Canadian vessels operate in coastal or Great Lakes trade, with fewer year-round blue-water operations to host cutting-edge autonomy. Moreover, unlike countries that have designated autonomous ship test zones (e.g., Norway’s Trondheim Fjord), Canada lacks extensive large-scale maritime test infrastructure. Trials to date have been limited to pilot projects on small vessels or in contained areas (such as Lake Erie demonstrations and a recently procured Coast Guard ASV in Haida Gwaii) rather than full-sized commercial ships. Stakeholders have therefore called for expanded support to enable more experimentation and at-sea testing, noting that current facilities and programs are insufficient to close key knowledge gaps<sup>129</sup>.

Investments in dedicated test ranges, simulation centers, and joint trials, potentially leveraging Canada’s vast exclusive economic zone or Arctic summer routes, would allow industry and regulators to safely validate MASS technologies at scale. Encouragingly, Transport Canada is engaging with international networks (e.g., the Norwegian Forum and the Smart Ship Coalition) to share test practices. Establishing similar coordinated testbeds at home, in partnership with the Navy and the Coast Guard, would strengthen Canada’s capacity to refine MASS in realistic conditions and build operational experience.

<sup>126</sup> [https://www.cgai.ca/lessons\\_for\\_canada\\_comparing\\_maritime\\_autonomous\\_systems\\_adoption\\_across\\_the\\_five\\_eyes](https://www.cgai.ca/lessons_for_canada_comparing_maritime_autonomous_systems_adoption_across_the_five_eyes)

<sup>127</sup> <https://www.dfo-mpo.gc.ca/about-notre-sujet/blue-economy-economie-bleue/roadmap-feuille-route-eng.html>

<sup>128</sup> <https://www.shipuniverse.com/top-100-flag-states>

<sup>129</sup> <https://www.dfo-mpo.gc.ca/about-notre-sujet/blue-economy-economie-bleue/roadmap-feuille-route-eng.html>

### 5.2.2 Evolving Regulatory Environment

Canada’s regulatory framework for autonomous vessels is in flux, evolving to catch up with technological reality. Current maritime laws (e.g. the Canada Shipping Act 2001 and Collision Regulations) assume crewed vessels, so early MASS deployments rely on case-by-case exemptions and interim policies. Transport Canada has issued guidance for small MASS operations, requiring operators to conduct risk assessments and apply to the Marine Technical Review Board for approval prior to operation<sup>130</sup>. This “exception-based” approach ensures safety equivalency but creates uncertainty and administrative overhead for each project. Recognizing this, Transport Canada in 2022 introduced a Tier I Policy for small MASS to provide an interim framework in the absence of formal regulations. Concurrently, Canada is heavily involved in IMO efforts to develop a standardized MASS Code (with a mandatory code expected by 2030).

Regulatory modernization is both a challenge and an opportunity: stakeholders have urged Canada to align domestic oversight with the IMO timeline and to offer proactive guidance on MASS authorizations ahead of global rules. They also seek clarity on how existing requirements may evolve to accommodate unmanned ships. In response, regulators are working to update statutes and liability regimes in step with autonomy advances, ensuring issues like collision avoidance, remote control, and insurance are addressed. Continued policy agility and interagency coordination will be critical. By streamlining approvals, updating crewing and equipment standards, and engaging industry in rule-making, Canada can provide a stable yet flexible regulatory environment. Such clarity and foresight will give innovators confidence that novel vessels can be tested and deployed under defined conditions, rather than on an ad-hoc exemption basis, thereby accelerating safe adoption of MASS technology.

### 5.2.3 Workforce Skills and Training Gaps

The shift toward autonomous and smart ships highlights gaps in the current maritime workforce’s skills and training. Canada’s seafarers, engineers, and technicians are highly trained for conventional operations, but operating and maintaining MASS demands new competencies in remote vessel supervision, data analysis, AI-driven decision support, and cyber-physical systems. Stakeholder feedback underscores the need to plan for labour implications of increased automation, including dedicated skills development, education, and certification pathways for MASS roles<sup>131</sup>. Over the coming decade, autonomous shipping could be disruptive, changing the types of expertise mariners need and even the nature of certain shipboard and shoreside jobs.

Without intervention, this could create a skills gap where advanced systems are ready before personnel are prepared to use them effectively. At present, there are few formal training programs in Canada for MASS operations (e.g. remote pilot training or AI-enabled navigation management), and standard seafarer certifications (STCW) do not yet incorporate autonomous vessel competencies. However, this challenge can be turned into an opportunity through academic-industry collaboration and upskilling initiatives. Canada’s strong education sector and experience in related fields (such as aviation drones and automotive automation) can be leveraged to update marine training curricula. Institutes like the Canadian Coast Guard College and universities could partner with tech companies to offer courses on autonomous systems, simulation-based training, and cyber awareness for mariners.

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<sup>130</sup> <https://tc.canada.ca/en/marine-transportation/marine-safety-management-system-tp-13585-e-tier-i-policies/tier-i-policy-oversight-small-maritime-autonomous-surface-ships-mass>

<sup>131</sup> <https://www.dfo-mpo.gc.ca/about-notre-sujet/blue-economy-economie-bleue/roadmap-feuille-route-eng.html>

The federal Blue Economy Strategy notes that Canada’s well-educated maritime and IT workforce is well-positioned to adapt, and that the MASS transition is expected to create higher-skilled jobs in fields like computer science and AI. By proactively investing in human capital, scholarships, specialized certifications, and on-the-job training for MASS technologies, Canada can ensure its workforce remains competitive and that the introduction of autonomy augments rather than displaces maritime talent. As one Coast Guard official put it, autonomous vessels are meant to assist, not replace, skilled mariners, enabling them to make more informed decisions in difficult conditions<sup>132</sup>. Preparing personnel now will smooth the integration of MASS and help retain Canada’s maritime safety record even as technology evolves.

#### 5.2.4 Sensor and IoT Scalability in Harsh Environments

Canada’s Digital Seaway, a national initiative aimed at transforming maritime transportation through advanced digital technologies, envisions a network of sensors, data hubs, and connected vessels from the Great Lakes through the St. Lawrence to the Atlantic<sup>133</sup>. Led by the National Research Council and supported by Transport Canada, it seeks to integrate intelligent marine assets, real-time data exchange, and automation across Canada’s coastal and inland waterways. Key elements include investments in smart infrastructure, AI-driven operations, and digital platforms to enhance efficiency, safety, and sustainability. The initiative complements major projects like the modernization of the St. Lawrence Seaway and supports broader goals, such as enabling MASS operations and strengthening Canada’s global maritime competitiveness.

Deploying autonomous ships in Canada’s often harsh and remote marine environments exposes weaknesses in sensor technology and the supporting Internet of Things (IoT) infrastructure. Reliable perception and communications are the backbone of MASS operations as vessels need robust inputs from radar, LiDAR, cameras, satellite/GPS, and weather/ice sensors to navigate safely without on-board crews.

Yet Canada’s geography presents extreme conditions: Arctic sea routes with sub-zero temperatures and moving pack ice, vast coastal stretches with sparse coverage, fog-prone waters, and limited broadband or satellite connectivity at high latitudes. Scaling up IoT and sensor systems to perform in these settings is challenging. For instance, electronic components face reduced battery performance and icing in polar cold, while satellite links in the far north suffer latency or outages. Forecasting and environmental sensing efforts are underway to mitigate these issues. The National Research Council is focusing R&D on autonomous vessel performance in ice and harsh climates, and projects like SmartICE deploy localized sensors on sea ice to provide real-time thickness data for safer route planning.

These initiatives point to solutions (e.g. hardened sensors, mesh networks, better predictive models), but they remain fragmented pilot projects. A concerted approach is needed to build a scalable maritime IoT backbone that can support MASS across Canada’s diverse waters. This includes expanding high-bandwidth coastal and satellite communication networks, deploying weather buoy and AIS upgrades in the Arctic, and integrating data from various agencies (hydrographic, meteorological and defence) into unified platforms. Notably, the NRC’s “digital seaway” concept would harness real-time environmental data, AI predictive models, and digital twins to improve navigation decisions in harsh conditions. Such

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<sup>132</sup> <https://maritime-executive.com/corporate/the-canadian-coast-guard-s-delivery-of-its-first-autonomous-surface-vessel>

<sup>133</sup> <https://nrc.canada.ca/en/research-development/research-collaboration/programs/ocean-program-intelligent-marine-assets-technology-theme>

concepts require significant coordination and investment but offer a path to make Canada’s waterways ‘smart’ and MASS-ready.

By prioritizing joint efforts among government (e.g., the Canadian Coast Guard, Environment Canada), academia, and industry to develop resilient sensors and share data, Canada can overcome the environmental constraints. This not only enables autonomous ships to operate year-round (even in ice-infested or remote regions) but also improves situational awareness and safety for all marine traffic via better monitoring and forecasting systems.

### 5.2.5 Maritime Cybersecurity Adaptation Challenges

As ships become autonomous and hyper-connected, cybersecurity has emerged as a critical vulnerability in Canada’s MASS development. Traditionally, maritime operations relied on isolated, manual systems, but modern vessels use digital controls, satellite links, and remote diagnostics that expose them to cyber risks. Canada’s maritime sector is still catching up to cybersecurity best practices, a concern that spurred the creation of a dedicated Maritime Cyber Security Centre of Excellence in 2021 at Polytechnique Montréal, in partnership with industry (e.g., Neptune Cyber and Davie Shipbuilding)<sup>134</sup>. This five-year federally supported research program aims to harden ship systems against hackers, acknowledging that “the shipping industry is still lagging behind” in technology adoption.

Indeed, critical ship components, such as navigation, propulsion, and cargo management are increasingly internet-connected for maintenance and monitoring, which makes them potential targets for cyber-attacks. A successful breach could disable an autonomous vessel or manipulate its sensors, with dire safety and economic consequences. The 2017 NotPetya ransomware attack on shipping giant Maersk, which cost hundreds of millions and disrupted global operations, is a cautionary example of what a sophisticated cyber incident can inflict.

In the MASS context, such threats could exploit the very systems that allow remote or autonomous functionality, from GPS spoofing and sensor feed manipulation to malware in fleet control centers. Canadian stakeholders have emphasized that cybersecurity must be integral to MASS integration, calling for domestic frameworks to include robust cyber safeguards and incident response measures<sup>135</sup>. This challenge presents an opportunity for cross-sector collaboration: Canada’s expertise in cyber defence (through agencies like the Canadian Centre for Cyber Security and various university labs) can be applied to maritime use cases. Efforts are underway to adapt known solutions, for example, the Polytechnique-led centre is developing maritime-specific cyber tools and resilience testing for ships’ networks.

Going forward, integrating cybersecurity by design into autonomous vessel projects will be essential. Standards and training need updating so that shipbuilders, software developers, and operators follow best practices (e.g., encrypted communications, anomaly detection, secure software updates) as part of normal operations. In addition, ongoing information sharing between the government, navies, port authorities, and shipping companies is vital to keep ahead of evolving threats. By treating cybersecurity not as an afterthought but as a core requirement, supported by targeted funding and academia-industry-government partnerships, Canada can strengthen the resilience of its MASS ecosystem. This will

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<sup>134</sup> <https://lethbridgenewsnow.com/2021/01/28/new-maritime-cybersecurity-centre-to-fight-pirates-and-not-the-swashbuckling-kind/>

<sup>135</sup> <https://www.dfo-mpo.gc.ca/about-notre-sujet/blue-economy-economie-bleue/roadmap-feuille-route-eng.html>

protect public trust and safety as maritime autonomy scales up, ensuring that Canada’s future smart ships and digital ports are guarded against “pirates” of the cyber variety.

## 5.3 Broader Global Challenges and Strategic Opportunities for Canadian MASS Development

### 5.3.1 Global Competition

Canada’s MASS initiatives unfold amid intense international competition. Maritime nations with strong shipbuilding and technology sectors, notably Norway, Finland, South Korea, China, Japan, the US, and the UK, are heavily investing in autonomous ship projects. This global push is driven by the promise of safer, more efficient shipping and strategic advantages. For example, Norway’s Yara Birkeland has become the world’s first fully electric, autonomous container feeder, eliminating ~40,000 diesel truck trips annually and cutting noise and CO<sub>2</sub> emissions. Japan’s government and industry, through the Nippon Foundation’s MEGURI 2040 program, are trialling autonomous coastal ships with the aim for commercialization by the mid-2020s. South Korea has dedicated over \$116 million to autonomous ship R&D, with a goal of deploying Level 4 (fully autonomous) ships by 2030.

Major economies view MASS as both a commercial opportunity and a strategic asset, spurring a race to lead in autonomous maritime capabilities. This competitive backdrop raises the stakes for Canada: without proactive development, Canadian industry risks falling behind global leaders, potentially forfeiting future market opportunities and influence to countries that are better prepared. Canadian stakeholders must therefore monitor global advances closely, benchmark against leading MASS programs, and identify niches (such as Arctic operations or green autonomous vessels) where Canada can be internationally competitive.

### 5.3.2 Regulatory Frameworks (International Comparisons)

Around the world, regulators are grappling with how to adapt maritime laws for autonomous vessels, and Canada can draw valuable lessons from peer jurisdictions:

- **Norway:** A pioneer in MASS, Norway leverages existing maritime laws for each vessel type, supplemented by detailed guidance (2019/2020) for autonomy. Norwegian authorities use IMO interim guidelines to ensure autonomous ships achieve at least equivalent safety to conventional ships. A Norwegian test-bed project (the Yara Birkeland) initially operated with a minimal onboard crew to satisfy legal requirements for a “ship’s master,” but regulators gradually allowed crew reductions (from five to three, and aiming for two) after successful safety trials. Norway’s pragmatic approach, case-by-case exemptions under existing law, plus dedicated test zones, has enabled early autonomous voyages while a permanent legal framework is in progress.
- **United Kingdom:** The UK has been actively updating its maritime regulations to accommodate MASS. Until recently, autonomous vessels in the UK operated via ad hoc exemptions or equivalencies to rules designed for crewed ships. Recognizing the inefficiency of one-off approvals for each trial, the UK undertook a comprehensive regulatory review in 2023. This review identified needed clarifications in maritime law (e.g., definitions of “master” and requirements for remote operation centers) and recommended amending primary legislation to cover all autonomous vessels. In late 2023, the UK’s Maritime and Coastguard Agency introduced new provisions for small unmanned vessels under 24 m, formally defining terms like

“remote operations centre” and providing limited exemptions (e.g., logbook requirements) for uncrewed vessels. The UK’s experience highlights the importance of updating legacy laws (which assumed all ships have crews) and doing so in harmony with emerging IMO standards to avoid regulatory divergence.

- Singapore: Singapore has adopted a sandbox approach to MASS regulation, positioning itself as a hub for autonomous shipping trials. The Maritime and Port Authority of Singapore (MPA) established a MASS regulatory sandbox to facilitate experimental deployments in port waters<sup>136</sup>. Early on, Singapore retrofitted a harbour tug (PSA Polaris) with autonomous navigation tech under the “IntelliTug” project. Starting in 2019, this project was conducted under MPA’s sandbox, which provided a controlled environment and flexible regulatory oversight for testing collision-avoidance and remote control systems. MPA also spearheaded the multi-nation MASSPorts initiative with Norway, China, Japan and others to align standards for MASS trials across ports. Singapore’s model shows how a proactive regulator can enable innovation: by issuing trial guidelines and working with industry on pilot projects (e.g. autonomous tugs, autonomous port craft), Singapore builds operational experience that will inform permanent rules. Its clear commitment, “to be a future-ready port” embracing autonomy, is backed by investments in port 5G networks and smart infrastructure to support unmanned vessels.
- United States: The U.S. currently relies on existing maritime statutes while evaluating needs for new regulations. The U.S. Coast Guard has stated that it can regulate autonomous ships under current law, but acknowledges challenges. Many U.S. statutes mandate minimum crew sizes, which today limit the ability to operate truly uncrewed vessels domestically. The Coast Guard can grant case-by-case waivers or equivalencies, but lacks general authority to waive crewing requirements outside narrow pilot programs. Recognizing these constraints, Congress requested a full review: a 2024 GAO report found that the Coast Guard’s limited examples of autonomous vessels and difficulties harmonizing international and domestic rules could slow U.S. adoption. Meanwhile, the U.S. is active at the IMO, helping craft a global MASS Code expected to be adopted in 2026 (voluntarily) and enter into force by 2032. In effect, the U.S. is taking a cautious regulatory stance: accommodating early projects (like autonomous vessel trials supervised by local Coast Guard captains) within existing law, while contributing to international standards that will eventually guide a more comprehensive domestic framework.
- Japan: Japan has set ambitious autonomous shipping goals (aiming for dozens of crewless ships in coastal service by 2025), but its regulatory framework is still evolving. Current Japanese law effectively requires a human onboard, so full autonomy trials have needed special permission or a crew on standby. To progress, Japan’s government in partnership with industry launched extensive trials under real-world conditions (e.g., the DFFAS consortia demonstrations of remote-controlled coastal ships). In addition, Japan is investing in shore-side infrastructure, such as a newly built Fleet Operation Center, to remotely monitor and control multiple autonomous vessels in trials<sup>137</sup>. Like the UK, Japan is reviewing its maritime laws to incorporate definitions for remote operators and to allow autonomy once safety is proven. By coupling technology trials with regulatory studies, Japan hopes to update its laws in time for the planned rollout of commercial autonomous shipping in late 2020s.

<sup>136</sup> <https://www.seatrade-maritime.com/maritime-technology/psa-marine-wartsila-hail-initial-sea-trials-on-autonomous-tug-a-success>

<sup>137</sup> <https://en.nippon-foundation.or.jp/news/articles/2024/20240718-102859.html>

### Implication for Canada

These international approaches illustrate a range of strategies, from Norway’s flexible exemptions, to Singapore’s sandbox, to the UK’s law revisions, that Canada can benchmark. Canada’s current stance has been to treat MASS under existing rules with case-specific exemptions (e.g., permitting no crew lookout if certain conditions are met). Transport Canada has also issued interim Tier I MASS policies (for small vessel oversight and autonomous navigation systems) to guide industry until the IMO code is ready.

Moving forward, Canada faces a delicate balance: providing enough legal certainty to attract R&D and commercial trials domestically, while remaining aligned with the IMO’s forthcoming international MASS Code (due by May 2026 as a non-mandatory Code and 2030 as a mandatory Code. By 2028, the IMO committee will start developing the mandatory code). Engaging with global regulators will help Canada avoid reinventing the wheel; for instance, adopting best practices from Norway’s testbed rules or Singapore’s sandbox conditions can accelerate Canada’s own regulatory readiness. However, if Canada’s regulatory evolution lags behind, industry may relocate trials to more permissive jurisdictions, and Canada would risk being a “rule-taker” rather than a “rule-maker” in the autonomous shipping domain.

### 5.3.3 Supportive Infrastructure and Ecosystems

Successful MASS development requires more than laws and vessels, and it demands physical test ranges, digital infrastructure, and collaborative ecosystems. Globally, several countries have established dedicated facilities to test autonomous ships in realistic conditions, often supported by clusters of academia and industry:

- **Autonomous shipping testbeds:** Norway led early with the Trondheims fjord as the world’s first sanctioned autonomous ship test zone (established in 2017). This extensive fjord area, with light traffic and proximity to top marine research institutes (NTNU’s Center for Autonomous Marine Operations, MARINTEK, etc.), offers an ideal safe proving ground for new autonomous vessels. The UK’s Smart Sound Plymouth provides another premier test environment, a coastal proving ground equipped with advanced sensors and the world’s first ocean-focused 5G network for real-time communications and data streaming. In Finland, the Jaakonmeri test area (part of the One Sea initiative) is open to companies for trials of remote and autonomous operations in the Baltic, reflecting a public-private push to create a full “autonomous maritime ecosystem” by 2025. These testbeds not only allow technology refinement and safety validation, but also help iron out regulatory procedures (e.g. traffic management, fail-safe protocols) in a controlled setting before wider deployment.
- **Digital and shore-side infrastructure:** Building MASS capabilities also entails robust digital infrastructure, such as ubiquitous broadband at sea, remote control centers, and data integration platforms. Singapore has invested in port-wide communication systems (e.g. 5G networks and ultra-precise GPS) to support its MASS trials, ensuring that autonomous vessels can be monitored and controlled with low latency. Japan recently unveiled a state-of-the-art Fleet Operation Centre to supervise multiple autonomous ships simultaneously, complete with redundant communications and AI decision-support tools. Canada, too, is making strides: Marine Institute is establishing “The Launch,” an autonomous ocean systems innovation hub at Holyrood, NL, which will serve as a testbed to eliminate physical barriers for developers. This site will allow Canadian and international firms to trial drones, unmanned boats, and AI navigation systems in harsh environments without needing to go to the high Arctic. Moreover,

to support remote operations, Canada will need to expand its coastal sensor networks (radar, AIS, satellite monitoring) and perhaps develop regional remote command centers that can oversee unmanned vessels in Canadian waters (similar to air traffic control for drones).

- **Collaboration networks and clusters:** Recognizing that MASS is an emerging field, many countries have formed collaborative networks to share knowledge and pool resources. For example, the International Network for Autonomous Ships (INAS) and Norway’s Forum for Autonomous Ships bring together regulators, researchers, and industry from multiple nations. The MASSPorts consortium (led by Singapore with members like Norway, China, and others) is aligning port authorities on common standards. Canada is an active participant in such networks, for example, Transport Canada engages in the IMO’s MASS work and forums like INAS, and was a founding member of the Smart Ships Coalition focused on Great Lakes autonomous vessel testing. Going forward, strengthening Canada’s MASS ecosystem by supporting marine tech incubators, hosting international conferences and joint exercises, and building regional centers of excellence will be key to keeping pace with global innovation. A well-connected ecosystem can help avoid duplication of effort and ensure Canadian solutions integrate smoothly with global standards and platforms.

#### 5.3.4 Future MASS Challenges in Canada

Notwithstanding progress, Canada faces several strategic challenges in realizing the full potential of maritime autonomy. These challenges are forward-looking issues that could hinder Canada’s competitiveness if not addressed:

- **Fragmentation of effort and governance:** Responsibility for maritime innovation in Canada is spread across multiple federal departments (Transport Canada, ISED, National Defence, Canadian Coast Guard, etc.), provincial authorities (especially for inland and coastal operations), and industry bodies. Stakeholders have noted a lack of clarity in which agencies lead or coordinate MASS efforts, which can result in fragmented strategies. For instance, there may be overlapping initiatives or gaps between transport safety regulators and defence planners working on unmanned naval systems. A coherent national strategy is needed to align civilian and military autonomous programs and to ensure that test results, best practices, and technological developments are shared across sectors. Additionally, without clear inter-agency coordination, businesses may struggle to navigate the approval process for trials, stalling innovation. Canada’s Blue Economy Regulatory Review acknowledged such fragmentation, highlighting the need to streamline regulations and clarify departmental roles for new technologies.
- **Regulatory gaps and uncertainties:** As of 2025, Canada does not yet have bespoke legislation fully addressing MASS operations; it relies on existing shipping laws (Canada Shipping Act 2001) supplemented by interim policies and exemptions. This transitional approach works for small-scale trials but may not suffice once larger, more complex autonomous ships (e.g., international trading vessels or autonomous ferries) arrive. Gaps include defining legal accountability (e.g., Who is the “master” of an unmanned ship, the remote operator or the owner?) and certification of autonomy systems. If these gaps persist, Canada could become a less attractive jurisdiction for MASS deployment, as operators seek countries with clearer rules. Moreover, without updating domestic laws in tandem with the upcoming IMO MASS Code, Canada might face implementation delays or legal incompatibilities after 2030. Proactively identifying and closing these gaps (through modernized regulations or new statutory provisions)

is a challenge that requires timely action. Canada’s regulators will have to strike a balance between not getting ahead of IMO (to maintain international consistency) and not lagging so far that domestic projects stagnate for lack of a clear framework.

- Innovation and investment shortfalls: Compared to some allies, Canada’s level of investment and rapid adoption of maritime autonomous systems remains modest. Allies like the U.S. and France are rapidly integrating maritime autonomous systems into naval and commercial operations, whereas “Canada has been slow to follow suit”. This maritime autonomous systems gap means Canada risks relying on foreign technologies or missing out on the first-mover advantages in the market. Contributing factors include limited venture capital in the maritime tech sector, brain drain of AI expertise to other industries, and the sheer geographic breadth of Canada’s coasts, making concentrated R&D efforts harder.

Without scaling up innovation, the Canadian industry could face an innovation shortfall, e.g., a lack of domestic autonomous vessel manufacturers or AI-navigation software providers, forcing dependence on external suppliers. Furthermore, there may be an educational/training gap: not enough programs to produce specialists in marine AI, autonomy ethics, or remote vessel operations. If unaddressed, this could constrain the talent pipeline needed for a thriving MASS sector.

The challenge for Canada is to create conditions that stimulate homegrown innovation (through funding, competitions, or procurement of Canadian-made solutions) and to attract global expertise to Canadian projects. Recent federal investments, such as NRC’s Ocean Program funding for autonomous systems in harsh environments, and the Ocean Supercluster’s support for startups, are steps in the right direction<sup>138</sup>. However, to overcome innovation shortfalls, these efforts must be sustained and scaled, ensuring Canadian companies can not only adopt MASS technology but also help develop it.

In summary, while Canada has laid the groundwork in policy and pilots, it must confront the looming challenges of governance coordination, regulatory readiness, and innovation capacity. Addressing these will determine whether Canada becomes a leader or a laggard in the next phase of autonomous maritime development. The “weaknesses” identified so far (e.g., slow uptake and unclear rules) could be exacerbated as MASS technology matures, unless deliberate action is taken to unify efforts and fill gaps. This calls for forward-looking strategies, as outlined below, to turn these challenges into opportunities.

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<sup>138</sup> <https://www.dfo-mpo.gc.ca/about-notre-sujet/blue-economy-economie-bleue/roadmap-feuille-route-eng.html>

## 6. Opportunities and Potential Focus for MASS in Canada

### 6.1 Opportunities for Canada

Despite the challenges, Canada is well-positioned to capitalize on unique opportunities in the MASS domain. These opportunities stem from Canada’s geography, expertise, and strategic relationships, and could be harnessed to leapfrog into a leadership role:

- **Natural advantages (geography and use-cases):** Canada’s vast and diverse maritime geography, from busy Atlantic trade corridors to sparsely populated Arctic waters, provides a rich testbed for autonomous solutions. Canada can leverage low-traffic, harsh environments as a differentiator. For example, the icy, remote conditions of the Arctic and sub-Arctic (Newfoundland and Labrador, Hudson Bay, etc.) allow testing of MASS in scenarios that few other countries can easily emulate. This could attract international partners to conduct trials in Canadian waters (much as Norway’s fjords do in Europe), especially for ice navigation autonomy, cold-weather operations, and long-endurance voyages without nearby human support. Canada’s long coastline and numerous ports also offer use-cases for coastal autonomy, such as uncrewed vessels for hydrographic survey, fisheries patrols, or short-sea shipping to remote communities. By focusing on niches like Arctic MASS testing, Canada can both address its own needs (e.g. safer resupply in the North, improved Arctic domain awareness) and develop expertise exportable to other nations preparing for Arctic shipping.
- **Research and development incentives:** Canada’s strong research institutions and government support for innovation present an opportunity to become an R&D hub for autonomous marine tech. Federal programs are already incentivizing R&D: Transport Canada and the National Research Council convene the Canadian Forum for MASS (CFMASS) to unite government, academia, and industry on research needs. The NRC has invested in collaborative projects on AI navigation, autonomous vehicle robustness, and operations in extreme environments. Building on these, Canada can expand targeted funding for MASS prototypes.
- **Arctic and cold-ocean innovation:** As climate change opens Arctic waters to more activity, Canada has an opportunity (and responsibility) to pioneer autonomous solutions for northern safety and security. The Canadian High Arctic, with its sparse infrastructure, is a compelling use-case for uncrewed vessels and drones, whether to monitor ice conditions, support search and rescue, or extend the North American Aerospace Defence Command (NORAD) surveillance of remote waterways. Canada could establish an “Arctic MASS Pilot Zone” in a suitable area where companies and researchers, under Canadian supervision, test how autonomous ships perform in ice-infested waters or months of winter darkness. Partnerships with Arctic communities and Indigenous organizations (discussed below) can ensure these trials are done responsibly and with local benefits. Success in this arena would give Canada leadership in a specialized but increasingly crucial field, Arctic autonomous navigation, which could be exported to other polar operators (like Nordic countries or Antarctic programs). It also aligns with Canada’s sovereign interests: autonomous platforms could vastly improve situational awareness and emergency response in the North. The Government’s existing Oceans Protection Plan investments in Indigenous community marine safety and monitoring could naturally extend to include autonomous systems in the Arctic (e.g., deploying uncrewed surface vehicles to report on oil spills or track vessel movements through Indigenous Protected Areas).

By championing Arctic MASS development, Canada leverages both geography and innovation for global impact.

MASS development is not only a commercial imperative but also a strategic one for national defence. The Canadian Armed Forces and allies are increasingly focusing on autonomous systems to augment naval capabilities, and Canada can harness this trend in several defence-related avenues:

- **NORAD modernization and Continental defence:** As Canada and the U.S. upgrade the NORAD for modern threats, there is a push to improve maritime domain awareness in Arctic and coastal approaches. Autonomous surface or subsurface vehicles could play a significant role in continuously patrolling vast Arctic waters where sending manned ships is costly and dangerous. For example, uncrewed surface vessels equipped with sensors might network with satellites and coastal radar to detect and track vessels or submarines approaching North American shores. The inclusion of such systems in NORAD's toolkit would enhance early warning and surveillance, addressing gaps in monitoring the Arctic archipelago and Atlantic/Pacific approaches. Canada has an opportunity to develop and deploy remote sensing buoys, unmanned underwater vehicles (UUVs), and long-endurance USVs as part of the NORAD modernization investments, which align with securing the northern perimeter. These could be collaborative projects with the U.S., where Canada contributes unique Arctic expertise and testing grounds. By taking initiative in demonstrating these technologies (for instance, conducting a joint NORAD exercise featuring autonomous patrol craft in the Arctic), Canada can ensure its specific defence needs are met while also advancing the state of the art. The payoff would be a more robust, persistent surveillance network guarding Canada's coastline and maritime approaches, deterring adversarial incursions or illicit activities.
- **NATO and allied integration:** Allies in NATO are rapidly expanding their use of Maritime Unmanned Systems (MUS), including autonomous mine hunters, ISR (intelligence, surveillance, reconnaissance) drones, and armed unmanned platforms, to enhance naval operations. NATO has formalized this through initiatives like the MUS Initiative (to pool R&D and ensure interoperability) and regular exercises such as Robotic Experimentation and Prototyping using Maritime Uncrewed Systems (REPMUS), which in 2024 showcased multi-domain operations with MASS, including anti-submarine warfare<sup>139</sup>. Canada, as a NATO member, stands to benefit from and contribute to these developments. Canadian participation in NATO's MUS working groups allows access to the latest technology demonstrations and the ability to shape interoperability standards (so that Canadian and allied unmanned systems can work together seamlessly). The RCN (Royal Canadian Navy) is already examining options for unmanned coastal defence vessels and underwater drones for tasks like mine countermeasures and Arctic surveillance. By investing in its own MASS capabilities, Canada improves its interoperability with key allies, for instance, if Canada procures autonomous mine-clearing UUVs, it can deploy them alongside US or European navies in joint missions. However, failing to keep up could create a capability gap between Canada and its allies.

A strategic opportunity exists for Canada to lead specific niches within NATO: given Canada's geography, it could lead NATO efforts on ice-capable autonomous systems or protecting undersea cables (an area of NATO concern after incidents in Europe). Aligning Canadian defence research (via DRDC and others) with NATO's focus areas will ensure Canadian

<sup>139</sup> <https://natoassociation.ca/special-report-the-mas-gap-canada-falls-behind-as-allies-adopt-maritime-autonomous-systems>

innovations (like advanced under-ice drones developed by Canadian universities) feed into Alliance capabilities. This not only strengthens collective security but gives Canadian industry a chance to be suppliers of niche technology across NATO.

- Arctic security cooperation: Autonomous systems offer a means for Canada to assert presence and monitor activity across its vast Arctic waters efficiently. There is a significant opportunity for collaboration with like-minded Arctic states, such as the U.S. (Alaska), Norway, and Denmark (Greenland), on unmanned systems for Arctic domain awareness.
- Dual-use technology spin-offs: Defence-oriented MASS projects can have civilian spillovers that benefit Canadian industry more broadly. For instance, an autonomous craft developed for naval surveillance could be adapted for fisheries enforcement or search and rescue for the Canadian Coast Guard. Recognizing this, Canada's defence research programs (such as Innovation for Defence Excellence and Security - IDEaS) are funding autonomous system prototypes that could find peacetime applications. Close coordination between National Defence and civilian agencies (Transport Canada, Canadian Coast Guard) in MASS development ensures that investments yield multi-purpose platforms. This not only maximizes return on investment but also enlarges the market for Canadian-developed systems (since a product that serves both defence and commercial needs has greater scale).

A recent example is the Canadian Coast Guard's acquisition of its first autonomous surface vessel for emergency response and environmental monitoring. Although not a weapon system, it leverages autonomous navigation technologies that overlap with naval R&D. Developed in partnership with Canadian firm Shift, this initiative highlights the potential of civil-military collaboration. By continuing to foster such partnerships, Canada can position itself as a leader in non-combat autonomous maritime systems, such as unmanned search and rescue vessels or surveillance drones designed with civilian safety in mind. This approach not only enhances national security but also opens up export opportunities to allied coast guards around the world.

## 6.2 Advancing MASS through Coordinated National Leadership and Collaboration

Canada's progress in MASS should be underpinned by a strong network of innovative companies, research institutions, and collaborative leadership bodies. Two key organizations, the Canadian Network for Innovative Shipbuilding, Marine Research and Training (CISMaRT) and the Canadian Forum for Maritime Autonomous Surface Ships (CFMASS), are well positioned to serve as national conveners and strategic leaders in this emerging field.

Together, CISMaRT and CFMASS can drive MASS development through the following core functions:

- Technological innovation  
By facilitating and supporting the advancement of AI-enabled control systems, autonomy architectures, and integrated platform technologies, these organizations can enhance the performance, reliability, and operational flexibility of Canadian MASS platforms. Their leadership fosters an environment that promotes both applied research and the commercialization of autonomous systems.

- Collaborative ecosystem development  
As a national network/forum, CISMART and CFMASS provide critical venues for bringing together government agencies, shipbuilders, academia, technology developers, regulators, and end-users. These platforms enable coordinated dialogue, accelerate standard-setting, and create a unified approach to solving regulatory, technical, and operational challenges associated with MASS deployment.
- Real-world implementation and demonstration  
Through partnerships with organizations such as the Canadian Coast Guard (CCG) and Royal Canadian Navy (RCN), these bodies can support the testing and deployment of autonomous platforms like the OceanSled® Ranger. The CCG has already provided ship time for technology demonstration, and future integration with Arctic and Offshore Patrol Ships (AOPS) operated by the RCN is expected. These field implementations offer valuable data and validation, showcasing the practical readiness and operational value of Canadian-built autonomous systems.

By leveraging the convening power, cross-sectoral expertise, and national reach of CISMART and CFMASS, Canada can more effectively align research, investment, and regulatory development. This coordinated approach will enable Canada to capitalize on targeted MASS opportunities, support scalable innovation, and enhance its position in the global maritime technology landscape.

A list of key organizations supporting MASS in Canada is provided in Appendix A.

## 6.3 Potential Canadian MASS Operations Focus

### 6.3.1 Areas of Operation

Canada's vast and challenging maritime geography, including the Arctic, inland waterways, and remote coastal areas, presents compelling opportunities for the deployment of MASS. These vessels can enhance maritime domain awareness, improve the efficiency of critical missions, and extend the operational reach of Canada's maritime forces. Key application areas are outlined below.

#### 6.3.1.1 Arctic Sovereignty Patrols and Monitoring

With increasing Arctic traffic, geopolitical interest, and environmental change, protecting Canadian sovereignty in the North has become a pressing national priority. MASS platforms offer a persistent and scalable means to monitor remote waters, deter unauthorized access, and support NORAD modernization efforts<sup>140</sup>.

#### Applications:

- Autonomous patrol vessels equipped with surveillance and communication systems to detect and report vessel movements and illegal activity.
- Long-endurance autonomous surface or underwater vehicles (ASVs/AUVs) for remote patrol missions.

#### Challenges:

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<sup>140</sup> NORAD Modernization Report, DND 2023

- Limited Arctic communication infrastructure.
- Harsh conditions affecting sensors and propulsion.
- Navigation algorithms for ice-infested environments.

### 6.3.1.2 Icebreaking and Ice Navigation Assistance

MASS technologies can assist icebreaking fleets and improve the safety of Arctic and northern shipping routes, including in the Gulf of St. Lawrence and coastal Newfoundland and Labrador.

Applications:

- Small autonomous icebreakers operating continuously in advance of manned vessels.
- Drones or AUVs for real-time ice mapping and charting optimal paths through dynamic icepacks.
- Port and lock navigation assistance in the St. Lawrence Seaway through autonomous vessel integration with shore-based systems.

Challenges:

- Dynamic ice formations and sensor reliability in freezing conditions.
- Integration with traditional icebreaking operations.

### 6.3.1.3 Hydrographic Data Collection and Mapping

Much of Canada's Arctic and remote coastal regions remain poorly charted. MASS platforms can rapidly and safely augment hydrographic survey capacity<sup>141</sup>.

Applications:

- Autonomous survey vessels conducting continuous seabed mapping and bathymetry. Ice-capable AUVs operating beneath ice to gather hydrographic and environmental data.

Challenges:

- Harsh operating environments and limited battery life.
- Requirement for remote data retrieval or shore-based control hubs.

### 6.3.1.4 Search and Rescue (SAR) Operations

The Canadian Arctic and many remote maritime zones present challenges to timely SAR response. MASS can augment current systems by providing rapid-response platforms.

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<sup>141</sup> Canadian Hydrographic Service reports on Arctic charting gaps (CHS, 2022)

**Applications:**

- Autonomous SAR drones or surface vessels to locate survivors and provide situational updates to SAR centers.
- Delivery of survival equipment via autonomous aerial or surface craft.

**Challenges:**

- Reliable real-time communications.
- Robust navigation in severe weather and ice.

### 6.3.1.5 Environmental Monitoring and Response

Protecting Canada’s marine ecosystems, especially in the Arctic and coastal zones, requires scalable and persistent monitoring tools. MASS can support early detection and response<sup>142</sup>.

**Applications:**

- Continuous environmental monitoring using autonomous surface vessels (e.g., for water quality, pollutant detection).
- Rapid deployment of autonomous oil spill containment and response craft.

**Challenges:**

- Adaptability to changing environmental conditions.
- Integration into Canada’s broader environmental emergency response plans.

### 6.3.1.6 Fisheries Management and Enforcement

Canada’s large Exclusive Economic Zone (EEZ) makes enforcement against Illegal, Unreported and Unregulated (IUU) fishing critical, especially in regions where IUU fleets are active<sup>143</sup>.

**Applications:**

- Uncrewed surveillance vessels and aerial drones for monitoring fishing vessel activity and detecting violations.
- Autonomous data collection to support stock assessments and habitat monitoring.

**Challenges:**

- Identifying unauthorized activities in real time.
- Sustaining long-duration operations in remote waters.

### 6.3.1.7 Hazardous and Specialized Maritime Operations

MASS can be deployed in roles that involve risk to human life or require persistent presence in difficult environments.

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<sup>142</sup> Oceans Protection Plan, Transport Canada

<sup>143</sup> DFO reports on IUU fishing, 2022

**Applications:**

- Autonomous firefighting or tug support in hazardous port operations.
- Offshore oil and gas or wind farm maintenance with MASS workboats.
- Arctic community resupply via barge support, with mother-ship-based deployment.
- Port-based autonomous ferries, crew shuttles, and aid-to-navigation maintenance systems.

**Challenges:**

- Operating in high-traffic areas with manned vessels.
- Designing vessels with appropriate sea-keeping characteristics for varied environments.

### 6.3.2 Implementation Considerations

Effective implementation of MASS across Canadian waters, particularly in the Arctic and nearshore zones, will depend on a balanced approach integrating technical, operational, social, and regulatory considerations.

#### 6.3.2.1 Indigenous Community Support

Ensuring the success of autonomous technologies in northern regions requires early and meaningful engagement with Indigenous communities. MASS platforms can support community-led environmental monitoring, transport, and economic development<sup>144</sup>.

**Applications:**

- Autonomous supply vessels for delivering goods and medical supplies.
- Early-season operations with vessels overwintered in the North to extend navigation access.
- Support for economic assessments (e.g., fisheries or marine infrastructure zones).

**Challenges:**

- Cultural and operational acceptance.
- Navigation in poorly mapped waters.
- Adapting systems for extreme Arctic conditions.

#### 6.3.2.2 Development Planning and Marine Spatial Integration

Integrating MASS operations into Canada's busy coastal and inland marine zones will require forward-looking marine spatial planning, particularly in high-use corridors and port environments.

**Key Considerations:**

- Continuous environmental monitoring in Marine Protected Areas (MPA) and monitoring whale migration routes.
- Regulatory clarity for MASS operations in shared waterways.
- Integration with human-operated systems and shore-based logistics.
- Protection of Indigenous rights and access, and environmental safeguards.
- Infrastructure for local control centers and hydrographic data sharing.

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<sup>144</sup> Oceans Protection Plan Indigenous Marine Programs

### Implementation Pathway:

- Stakeholder consultation and regional workshops.
- Pilot deployments co-developed with Indigenous and remote communities.
- Expansion of hydrographic surveys and communications coverage in Arctic regions.

Canada's unique maritime environment, spanning ice-bound Arctic passages, complex coastal regions, and vast inland waterways, presents a broad range of mission-driven use cases for MASS technologies. From sovereignty patrols to environmental protection, autonomous systems can improve safety, reduce costs, and enhance Canada's presence in remote and strategically vital areas. By integrating technical development with regional and community engagement, Canada can ensure these innovations are practical, inclusive, and aligned with national priorities.

## 6.4 Opportunities for Testing MASS in Canadian Ports and Harbours

### 6.4.1 Controlled Testing Scenarios

Implementing MASS in Canadian ports requires a phased and controlled testing approach to ensure safety, compliance with regulatory frameworks, and operational effectiveness. Initial trials should occur in designated low-traffic zones and combine simulation with real-world testing, allowing iterative learning before broad deployment. Collaboration between port authorities, regulators, and technology developers is essential to define clear testing protocols, enable effective risk mitigation, and support early operational confidence.

#### Pilotage Systems

Testing how autonomous systems interface with Canada's existing pilotage regimes presents an early opportunity. Innovative designs, such as Robert Allan Ltd.'s electric and hybrid pilot boats, could serve as MASS-ready platforms.

#### Key Considerations:

- Leverage mandatory pilotage areas (e.g., Vancouver, Halifax, St. Lawrence Seaway) as structured environments for MASS–human pilot integration testing.
- Explore hybrid pilotage models with remote operation centers monitoring and guiding autonomous vessels.
- Use existing pilot control centers as Remote Operations Centres (ROCs).

#### Tugboat Operations

Robert Allan Ltd.'s RAmora tug series includes advanced line transfer systems that reduce human risk in heavy-seas or large-vessel towing scenarios. These features are ideally suited for MASS validation.

#### Applications:

- Motion-compensated line transfer testing.
- Harbor maneuvering and towline delivery automation.

#### Approaches and Navigational Challenges

Canada's varied port environments, ranging from ice-prone waters to narrow tidal channels, offer ideal settings to test MASS navigation systems.

**Key Considerations:**

- Test in ports like Prince Rupert and Montreal to validate autonomous handling of shallow drafts and complex routes.
- Engage the Canadian Coast Guard (CCG) to simulate real-world conditions and validate collision avoidance systems.

**12-Mile Sovereignty Limits**

Evaluate MASS systems' transition from international to domestic waters, and how systems adapt to regulatory changes.

**Key Considerations:**

- Verify COLREGs compliance in high-traffic zones.
- Assess communication handoff from international vessel traffic services (VTS) to Canadian authorities.

**Vessel Traffic and Situational Awareness**

High-traffic ports such as Vancouver and Halifax (including Bedford Basin) provide environments to test MASS interoperability with manned vessels.

**Key Considerations:**

- Combine live and simulated trials to evaluate MASS interactions with fishing boats, recreational users, and commercial traffic.
- Pilot real-time data sharing between MASS and existing VTS systems.

**Real-Time Navigation Warnings**

Evaluate MASS responsiveness to dynamic maritime safety information such as Notices to Mariners (NOTMAR).

**Key Considerations:**

- Test integration with e-navigation systems and real-time data feeds.
- Validate automated routing adjustments in response to new navigational hazards.

**6.4.2 Safe Adoption in Ports**

Encouraging MASS adoption in Canadian ports aligns with national goals for safer, greener, and more efficient maritime operations. However, the transition must prioritize safety, workforce integration, and environmental protection.

**Key Principles:**

- Develop and implement robust safety standards.
- Protect sensitive marine habitats and port infrastructure.
- Support workforce reskilling for shore-based MASS supervision.

**6.4.3 Regulatory and Governance Support**

A clear regulatory framework is fundamental to successful MASS deployment.

**Recommendations:**

- Move beyond case-by-case exemptions by expanding Transport Canada’s Tier I MASS policy framework.
- Introduce a Canadian MASS Code modelled after IMO’s ongoing MASS Code, but tailored to Canadian environments.
- Continue active participation in IMO and classification society forums to align with global best practices.
- Empower port authorities to develop and enforce MASS-specific procedures and risk controls.

#### 6.4.4 Infrastructure and Innovation Partnerships

Robust infrastructure and strong partnerships are essential to scaling MASS across Canadian ports.

Priorities:

- Designate dedicated MASS testbeds (e.g., Bedford Basin, Halifax; The Launch, NL and COAST, BC). There is a need for a testbed in St. Lawrence River, e.g., Rimouski QC, to cover all (or most) of the Canadian Regions.
- Establish Remote Operations Centres (ROCs) to support live MASS oversight and data analysis.
- Pilot the use of Canadian-developed platforms in cold-water scenarios to validate system resilience.
- Coordinate with industry leaders, research institutions, and agencies like ISED and ACOA to prioritize funding and technology transfer.

#### 6.4.5 Industrial and Economic Benefits

The deployment of MASS technologies presents substantial economic and industrial advantages.

##### Technology Leadership

- Position selected ports (e.g., Halifax, Vancouver) as MASS innovation hubs.
- Attract global investment and create exportable IP through Canadian-developed MASS systems.

##### Workforce Development

- Expand training and certification for MASS-related occupations (design and integration, remote pilots, system technicians).
- Collaborate with educational institutions to develop Standards of Training, Certification and Watchkeeping (STCW)-compliant MASS programs and retraining for existing mariners.

##### Economic Growth

- Enhance port efficiency and throughput via automated logistics.
- Stimulate local manufacturing for MASS components and support services.

#### 6.4.6 Environmental Leadership

MASS vessels offer significant environmental advantages, particularly when powered by hybrid or electric propulsion.

Opportunities:

- Support green shipping initiatives through emissions reduction and optimized fuel use.
- Leverage Canada’s clean electricity grid to power electric MASS fleets.

- Improve environmental monitoring and response capabilities via persistent autonomous platforms.

#### 6.4.7 Next Steps for MASS Integration in Canadian Ports

To capitalize on MASS opportunities, Canada should pursue a national strategy for port integration. Immediate steps include:

- Conduct feasibility studies in key ports to identify optimal MASS test locations and traffic corridors.
- Launch pilot projects with CCG, port authorities, and industry to validate systems in real operations.
- Secure capital investment for infrastructure (ROCs, VTS upgrades) and MASS-specific retrofits.
- Advance regulatory reform, including full MASS Codes and integration into the Canada Shipping Act.
- Support workforce readiness via targeted training programs and industry-academic collaboration.
- Promote international partnerships to position Canada as a global leader in MASS deployment.

### 6.5 Cyber Security Testing and Evaluation for MASS

#### 6.5.1 Importance of Cybersecurity in MASS Operations

Cybersecurity is a critical enabler and risk factor in the safe and reliable operation of MASS. The technologies underpinning MASS, including navigation, propulsion, sensor networks, and communication system, are all vulnerable to cyber intrusions. These vulnerabilities, if exploited, could result in safety failures, environmental damage, disruption to maritime commerce, or even national security incidents.

A comprehensive and proactive approach to cybersecurity must be adopted to safeguard MASS platforms and infrastructure. This includes protection of both traditional IT systems and Operational Technology (OT), such as machinery control and automation systems, as well as the remote operation centres. Given the interdependence between these systems, a cyberattack on one could cascade into broader system failures. This reinforces the need for a holistic, layered cybersecurity strategy.

#### 6.5.2 Implementation Considerations

According to the American Bureau of Shipping (ABS) Guide for Cybersecurity Implementation for the Marine and Offshore Industries, cybersecurity risk management must address both networked computers and industrial control systems (ICS) within a vessel's architecture. While traditional IT systems are increasingly hardened, many marine OT systems, such as integrated platform management systems (IPMS), lack historic exposure to external networks and therefore remain more vulnerable.

For example, L3Harris MAPPS has developed IPMS platforms widely used in naval and commercial vessels that embed hundreds of sensors across propulsion, electrical, and auxiliary systems. While highly effective for automation, these networked systems are susceptible to cyber interference. Emerging Canadian cybersecurity SMEs such as Akimbo Technologies are developing passive cyber defense solutions specifically designed to shield maritime ICS and IPMS environments from external attacks, using anomaly detection and hardware-based filtering.

#### 6.5.3 Best Practices for MASS Cybersecurity

ABS and other classification societies recommend the following best practices:

- System segmentation: Isolate critical systems (e.g. propulsion) from non-essential or public networks.
- Regular updates and patch management: Maintain software and firmware updates to close known vulnerabilities.
- Incident response protocols: Define clear operational procedures for responding to cybersecurity breaches, especially to protect safety-critical systems.
- Simulation and testing: Conduct vulnerability assessments and red-teaming exercises to test security posture under realistic conditions.
- Stakeholder collaboration: Involve equipment vendors, port authorities, and remote operation centers in comprehensive cybersecurity planning.

#### 6.5.4 Testing and Evaluation Opportunities

To ensure cyber-resilience of MASS technologies, structured testing programs must be implemented using dedicated maritime testbeds and simulation environments.

##### 1. Real-World Trials in Controlled Maritime Testbeds

Designated MASS test sites, such as Marine Institute’s “The Launch” facility in Holyrood Bay, Newfoundland and Labrador, offer a geographically advantageous and low-traffic area for live cybersecurity testing. The site’s proximity to transatlantic shipping routes and collaboration potential with the Canadian Coast Guard make it an ideal venue for controlled testing of cyber vulnerabilities and defence mechanisms under realistic operational conditions.

Focus Areas:

- Network security validation (firewalls, intrusion detection systems).
- Assessment of GPS spoofing and communications jamming scenarios.
- Validation of encrypted command-and-control communications.

##### 2. Hardware-in-the-Loop (HIL) Simulations

HIL simulation allows for high-fidelity, repeatable testing of MASS systems under simulated cyberattack conditions. Real hardware components (e.g., actuators and bridge controls) can be integrated with simulated software to analyze system resilience and operator response.

Key Testing Objectives:

- Validate fault tolerance and recovery strategies.
- Assess impacts of cyberattacks on propulsion and navigation control.
- Simulate human-in-the-loop responses to cyber anomalies.

##### 3. Red Teaming and Penetration Testing

Red teaming involves simulating adversarial cyberattacks to identify and remediate vulnerabilities. These tests are especially valuable when conducted with an understanding of maritime operational contexts and MASS-specific architectures.

Applications:

- Testing MASS control systems against known and emerging threats.
- Verifying incident response plans under stress.

- Assessing fail-safe measures under simulated hostile takeovers.

#### 4. International Collaboration and Standards Development

Cybersecurity in MASS must align with international best practices to ensure interoperability and trust in global maritime operations. Canada can contribute to and benefit from participation in standards-setting forums (e.g., IEC, ISO and IMO MASS Code development).

Recommended Actions:

- Encourage Canadian experts to participate in international standards committees.
- Align domestic cybersecurity testing with IMO and classification society frameworks.
- Support international threat intelligence exchange and cooperative testing.

#### 5. Emerging Technologies and Research

Canada should continue investing in R&D for next-generation cybersecurity tools that can be applied to MASS.

Focus Areas:

- AI and ML for threat detection and predictive analytics.
- Passive protection hardware to guard the industrial control system (ICS) and the integrated platform management system (IPMS).
- Blockchain for secure data exchange and software integrity verification.
- Quantum-resistant encryption and exploration of post-quantum cyber risks.

Canadian universities with AI expertise (e.g., University of Waterloo and Mila, Amii) are well positioned to lead research in this area, and partnerships with marine technology developers can help translate theory into application.

#### 6.5.5 National and Economic Benefits

Robust MASS cybersecurity will offer Canada a competitive edge in both domestic and international maritime sectors.

Key Benefits:

- Enhanced maritime security: Protecting MASS platforms, coastal assets, and ports from digital intrusion.
- Economic growth: Driving innovation through the commercial application of cybersecurity tools and services.
- International leadership: Positioning Canada as a trusted contributor to global MASS cybersecurity standards.
- Research and workforce development: Creating high-value jobs and new training programs in the cybersecurity and maritime tech sectors.
- Resilient infrastructure: Ensuring continuous safe operation of MASS even under cyber stress or denial-of-service attacks.

Cybersecurity, not a peripheral issue, is central to the safe and successful deployment of MASS technologies in Canadian waters. Canada has both the technical capability and institutional foundation to become a global leader in maritime cyber resilience. By developing structured testing protocols,

supporting domestic innovation, engaging in international standards development, and investing in targeted infrastructure like The Launch, Canada can ensure that its MASS platforms are not only autonomous, but secure, reliable, and trusted.

## 6.6 Skills, Certifications, and Workforce Development for MASS in Canada

The successful development and deployment of MASS in Canada will require a highly skilled and adaptable workforce. As technology evolves and vessel autonomy increases, so too must training, certification, and education systems. While existing maritime frameworks, such as the Standards of Training, Certification and Watchkeeping for Seafarers (STCW 1978 as amended), provide a foundation, new skillsets and qualifications tailored to autonomy are emerging as priorities.

### 6.6.1 Required Skills for MASS Operations

As MASS technologies progress toward IMO Autonomy Degrees 2 and beyond, roles will expand beyond traditional seafaring competencies. The following areas will be essential for MASS operators, designers, and support personnel:

#### 1. Technical and Digital Skills:

- **Robotics and automation:** Understanding of autonomous control systems, AI integration, and adaptive decision-making frameworks.
- **Preventive maintenance, upgrades and emergency management.**
- **Cybersecurity:** Protection of vessel networks, operational systems, and data against cyber threats, including knowledge of maritime OT vulnerabilities.
- **Data science and analytics:** Proficiency in interpreting sensor data, predictive maintenance analytics, and route optimization.
- **Navigation and remote sensing:** Advanced skills in ECDIS, radar, GPS, computer vision, and remote sensor integration for autonomous navigation.
- **Integration of systems:** Advanced skills in MASS ship design and system integration

#### 2. Maritime and Operational Skills:

- **Traditional seamanship:** Knowledge of international maritime law, collision regulations (COLREGs), and safety protocols under STCW.
- **Human-machine interaction (HMI):** Competency in supervising or intervening in autonomous operations and interpreting system behavior.
- **Remote operations:** Experience or training in teleoperation and supervisory control from Remote Operations Centres (ROCs).

#### 3. Professional and Interdisciplinary Skills:

- **Project management:** Coordination of complex, multi-technology projects.
- **Critical thinking and decision-making:** Adaptive judgment in unstructured or emergency scenarios.
- **Team collaboration and communication:** Interdisciplinary cooperation across engineers, operators, and regulatory personnel.

### 6.6.2 Certifications and International Training Standards

International standards, such as the STCW Convention (1978 as amended), remain the global benchmark for maritime training. However, STCW currently assumes human presence aboard vessels and does not directly address remote or autonomous operations.

The MASSPeople Initiative, launched in 2021 by Fugro, SeaBot XR, and the UK Maritime and Coastguard Agency, has taken steps to address this gap. MASSPeople is developing internationally recognized training standards for operators of remote and autonomous vessels. It aims to:

- Define training requirements for MASS operators and supervisors.
- Propose updates to STCW to accommodate MASS competency standards.
- Support future certification schemes for autonomy-specific roles.

Canada should maintain active participation in such international efforts to ensure that national training aligns with global expectations and to influence revisions to STCW for future MASS roles. In addition, various training programs can be developed and delivered by CISMART due to their experience.

### 6.6.3 Future Training Priorities

A preliminary assessment conducted in 2019 on the compatibility of the STCW framework with IMO Autonomy Degree 2 operations identified nine priority training areas for Officers in Charge of a Navigational Watch (OICNW):

1. Fire prevention and control
2. Radar and Automatic Radar Plotting Aid (ARPA) navigation
3. Leadership and teamwork
4. Navigational watchkeeping with electronic systems
5. Safety of personnel and vessel
6. Environmental and pollution prevention
7. Emergency and cargo handling procedures
8. Celestial and terrestrial navigation
9. Visual signalling and situational awareness

To prepare for operations at and above Degree 2, Canada will need to invest in:

- Scenario-based simulation training.
- Certification for remote watchkeeping roles.
- Updated STCW-aligned training courses reflecting autonomy-specific responsibilities.

### 6.6.4 Current Skills and Certification Gaps in Canada

Despite strengths in ship design, shipbuilding, AI, and marine simulation, Canada faces clear skills gaps in fields critical to MASS readiness:

#### 1. Technical and Applied Engineering Skills:

- Limited availability of specialists in maritime AI/ML applications.
- Shortage of experts in maritime operational technology (OT) cybersecurity, especially for machinery control and IPMS.

- Lack of maritime-specific data scientists and sensor integration engineers.

## 2. Maritime-Specific Competencies:

- Need for professionals trained in the integration of autonomous and conventional systems.
- Gaps in human-machine interface (HMI) design and remote vessel supervision training.
- Inadequate domestic training for shore-based MASS operators and support staff.

## 3. Certification and Program Gaps:

- Absence of standardized national or international MASS operator certifications.
- Limited post-secondary and vocational curricula aligned with MASS applications.
- Minimal adaptation of STCW courses to cover remote operation or autonomy monitoring roles.

### 6.6.5 Strategic Recommendations for Workforce Development

To address these gaps and ensure a future-ready workforce, Canada should implement a national MASS training and workforce strategy with the following pillars:

#### 1. Intersectoral Collaboration

- Establish national taskforces or working groups (e.g., via CFMASS and CISMART) with representation from regulators, academia, industry, and Indigenous communities.
- Promote joint R&D and training program development between universities, colleges, and MASS developers.

#### 2. Curriculum Development and Certification

- Enhance the existing naval architecture program by including MASS technologies and their integration in ship design.
- Develop new certificate and diploma programs focused on MASS technologies, remote operations, and AI-enhanced navigation.
- Work with international partners and Transport Canada to create recognized certifications for MASS-specific roles.
- Stay engaged with the IMO's review of STCW and advocate for updates reflecting Autonomy Degrees 2–4.

#### 3. Upskilling and Transition Programs

- Launch federal/provincial upskilling initiatives to retrain marine professionals in autonomy-support roles (e.g., ROC operators and data analysts).
- Integrate MASS awareness modules into existing STCW training to prepare current officers for hybrid or semi-autonomous operations.

#### 4. Research and Training Investment

- Expand funding for applied research in maritime autonomy, cybersecurity, and AI through federal and regional development agencies.
- Support training simulators and testbeds (e.g., Virtual Marine's simulators and the Marine Institute's full-motion bridge simulator) with MASS scenarios and HIL integration.

Canada's MASS future will depend as much on its human capital as on its technology. While current training systems provide a strong foundation, the shift toward autonomy requires rethinking both the content and delivery of maritime education and professional development. By closing existing skills and certification gaps, aligning with international standards, and fostering innovation-ready talent pipelines, Canada can ensure that its workforce is prepared to safely and effectively manage the next generation of autonomous maritime operations.

## 6.7 Sector Growth Projections: Canada's Marine Autonomy Opportunity

The Canadian marine autonomy sector is poised for significant growth, driven by advances in artificial intelligence, robotics, and remote sensing, as well as increasing global demand for sustainable and efficient maritime operations. With strategic investment, regulatory modernization, and focused support for innovation, Canada can develop a globally competitive marine autonomy industry with high economic and social returns.

### 6.7.1 Growth Potential by Category

#### 1. Growth in the Number of Companies

- New entrants: Canada can expect increased entry of SMEs focused on developing MASS-relevant technologies, including AI-enabled control systems, maritime robotics, and smart sensor integration.
- Expansion of existing players: Traditional shipbuilders, offshore service providers, and marine technology firms are increasingly diversifying into autonomy by developing or integrating MASS-capable platforms and tools, particularly for ice-class, Arctic, or nearshore commercial applications.

#### 2. Revenue Growth and Market Share

- Global market opportunity: According to Fugro, the global market for marine autonomy is projected to grow from approximately US\$6 billion in 2020 to \$14 billion by 2030<sup>145</sup>. Canadian companies are well-positioned to capture a share of this expansion, particularly in niche segments such as Arctic operations, cold-weather surveillance, and environmental monitoring.
- New revenue streams: Emerging applications include:
  - Oceanographic research and observation
  - Offshore energy support (e.g., wind farms, oil and gas)
  - Aquaculture monitoring
  - Port automation and short-sea transport
  - Transportation of dangerous goods (e.g., clean fuels such as hydrogen and ammonia)

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<sup>145</sup> <https://www.fugro.com/news/long-reads/2023/shaping-the-future-of-remote-and-autonomous-marine-operations>

- Operational efficiency: Fugro and others have demonstrated that the use of unmanned surface vessels (USVs) in offshore operations can reduce fuel costs, personnel requirements, and operational risks, offering a measurable increase in productivity and profitability.

### 3. Employment and Workforce Development

- New job creation: The sector will create demand for high-skilled positions, including:
  - Autonomous systems engineers
  - Remote operators and mission supervisors
  - Cybersecurity specialists
  - Marine data analysts and sensor integration engineers
- Upskilling existing workforce: Retraining programs will enable current maritime personnel to transition to MASS-related occupations, particularly in shore-based operations and control center roles.
- Indirect employment: Growth in MASS will stimulate jobs across related sectors, including advanced manufacturing, simulation, communications, logistics, software development, and environmental services.

### 4. Supporting Growth Indicators

- Research and development: Public and private investment in MASS-related R&D is expanding across Canada, with institutions such as Memorial University, Dalhousie, University of British Columbia, University of Victoria, NRC and others contributing to advancements in Arctic navigation, AI, and remote operations. Canada will need to drive research networks, like CISMART and CFMASS, to speed up collaboration among industry, academia, government and international partners, throughout the entire logistics chain, with sufficient funding support.
- Government support: Sustained federal and provincial investment through infrastructure, procurement, regulatory innovation, and targeted funding programs will be essential. This includes supporting pilot projects, national test ranges, and indigenous-inclusive deployment initiatives.
- International collaboration: Joint projects and alliances with countries leading in MASS development (e.g., Norway, Singapore, Japan and UK) will help Canadian companies enter export markets and align with global best practices.

#### 6.7.2 Factors Influencing Growth

- Technological advancements: Continued breakthroughs in autonomous control, machine learning, perception systems (radar, LiDAR, sonar), and ultra-low-latency satellite communication (e.g., Starlink Maritime) are crucial.
- Regulatory environment: A predictable and supportive regulatory framework will drive investment and accelerate adoption. Canada's progress in developing Tier I policies and participation in IMO standards development is an encouraging start.
- Domestic market demand: Use-cases in Arctic surveillance, short-sea shipping, port automation, and search and rescue are growing, driven by both public and private sector interest.
- Global competition: Canada must compete with nations aggressively pursuing MASS innovation. To differentiate itself, Canada should emphasize unique value propositions such as:
  - Arctic and ice-infested operations
  - Long-range environmental monitoring
  - Indigenous and community-driven maritime solutions

- Demonstrated use-cases: For instance, companies like CSL and Algoma have introduced automated lock navigation systems for the St. Lawrence Seaway and Great Lakes, improving operational efficiency and safety. Such practical examples of Level 1 MASS provide proof-of-concept for broader adoption.

### 6.7.3 Strategic Implications for Canada

The economic opportunity presented by marine autonomy is significant. With proper support, Canada can:

- Develop domestic manufacturing and export-ready services in marine autonomy.
- Increase national sovereignty and surveillance through persistent, autonomous presence in remote regions.
- Train a next-generation, tech-savvy marine workforce ready to supervise, maintain, and innovate autonomous systems.
- Demonstrate global leadership in sustainable, autonomous maritime operations, especially in Arctic and climate-sensitive environments.

By investing in the convergence of autonomy, clean technology, and digital infrastructure, and by leveraging Canadian expertise in marine systems, shipbuilding, AI, and cold-weather operations, Canada can position itself as a top-tier global innovator and supplier in the marine autonomy market.

## 7. Conclusions and Recommendations

### 7.1 Conclusions

#### 7.1.1 Canada's Strengths in MASS

Canada emerges from this assessment with a foundation of notable strengths to build upon. It has world-class expertise in relevant technologies, from artificial intelligence and robotics to advanced sensors and satellite communications, which are all critical enablers for autonomous ships. A network of innovative companies and research institutions is active in domains like autonomous vessel design, ocean sensor systems, and maritime cybersecurity. Canada's shipbuilding and marine services industry, while smaller than some nations, provides a base for experimenting with and deploying MASS (including agile small shipyards and test facilities that can serve as proving grounds for new technology). The country also benefits from unique geographic and operational niches: extensive Arctic and coastal waters that present specialized use-cases (ice navigation, long-range uncrewed surveillance) where Canada could lead in developing solutions. Early collaborative initiatives, such as the Canadian Network for Innovative Shipbuilding and Marine Research and Training (CISMaRT) and the CFMASS forum, indicate a willingness among government, academia, and industry to coordinate on autonomy. These strengths, technical know-how, industrial capability, natural laboratories, and emerging networks, form a solid platform for Canada's future in MASS.

#### 7.1.2 Challenges and Gaps

Notwithstanding its assets, Canada faces significant challenges that have limited progress in the MASS domain to date. A main obstacle is the lack of a unified national strategy or policy framework for MASS. Efforts so far have been ad hoc or fragmented, without a clear long-term plan. Regulatory adaptation is still in the early stages: current laws do not fully accommodate uncrewed ships, and reliance on case-by-case exemptions creates uncertainty for developers. This regulatory gap, if not swiftly addressed, could slow innovation as companies await clearer rules. Industry adoption of MASS in Canada has been cautious, and by some measures, Canada trails its peers, for example, the Royal Canadian Navy has integrated autonomous systems more slowly than other Five Eyes navies.

Contributing to this lag are limited investment and R&D support specific to maritime autonomy; while programs like the Ocean Supercluster have begun funding projects, overall funding levels and venture capital in this sector are modest compared to the U.S. or Europe. Canada risks a talent and innovation shortfall if homegrown start-ups cannot scale (or if AI experts drift to other industries) due to insufficient support.

Another gap lies in test infrastructure and operational experience: unlike countries with dedicated MASS test zones (e.g., Norway's autonomous shipping fjords), Canada lacks large-scale demonstration sites and has conducted only small trials. This makes it harder to validate technologies in real-world conditions and develop standards. Finally, there is a skills gap emerging – Canada's maritime training and certification regimes have only begun to incorporate autonomous systems, so the workforce (from seafarers to engineers) needs new competencies for operating and maintaining MASS. These challenges, including fragmented governance, regulatory uncertainty, slow industry uptake, limited investment, scarce testing opportunities, and nascent training pipelines, represent critical gaps that Canada must address to keep pace in the autonomous shipping era.

### 7.1.3 Strategic Implications

The findings carry important implications for Canada’s future in the MASS space. Globally, maritime autonomy is expected to progress incrementally over the next decade or two (full autonomy for large ocean-going ships may take time to materialize, offering Canada breathing room to prepare). However, the window for leadership is finite: countries that move early will set standards, develop intellectual property, and capture new markets. For Canada, the strategic stakes are high. If it leverages its strengths and tackles the identified gaps, Canada can position itself as a leader and innovator in MASS, reaping economic growth (through new high-tech jobs, companies and exportable solutions) and enhancing its maritime security and environmental stewardship.

Proactive investment in MASS could enable Canada to better monitor its vast waters (improving Arctic domain awareness and sovereignty), increase the efficiency and safety of domestic shipping, and contribute to global advancements in green and smart shipping. However, failing to act decisively could leave Canada falling behind, dependent on foreign technologies and standards, and potentially missing out on the first-mover advantages in this emerging industry. In essence, Canada stands at a crossroads: with coordinated effort, it can turn MASS into a strategic national asset, but it must overcome current challenges through focused policy, investment, and collaboration. These conclusions point to the need for deliberate action. Canada has the talent and tools to succeed; the following recommendations outline how government, industry, academia, and regulators can jointly strengthen Canada’s leadership and preparedness in the MASS ecosystem.

## 7.2 Recommendations

To capitalize on the opportunities of MASS and address the gaps identified, a set of prioritized, actionable recommendations is proposed for government, industry, academia, and regulators. These measures are designed to build a cohesive MASS ecosystem in Canada, spanning policy, technology, skills, and partnerships, and to secure Canada’s leadership in maritime autonomy:

- Establish a National MASS Strategy and Regulatory Framework  
Government and regulatory authorities should develop a coordinated national strategy for MASS, setting clear objectives and timelines for adoption. This includes modernizing maritime regulations to incorporate autonomous vessels. In the near term, Transport Canada should move beyond case-by-case exemptions by expanding its interim Tier I MASS policy and developing a comprehensive Canadian MASS Code (aligned with the IMO’s framework). Key maritime laws (e.g., Canada Shipping Act and collision regulations) should be updated to provide certainty around the operation of unmanned vessels, while ensuring safety and liability issues are addressed. A unified strategy and supportive regulatory environment will give industry a clear pathway to innovate and deploy MASS in Canadian waters.
- Invest in Infrastructure and Pilot Projects  
Government (federal and provincial) in partnership with industry should invest in dedicated test infrastructure and demonstration projects to jump-start MASS implementation. This entails designating MASS testbeds in Canadian waters (for example, in a sheltered harbour or a specific coastal corridor) where autonomous ships can be tested safely. Establishing one or more shore-based Remote Operations Centres (ROCs) is critical to support real-time monitoring and control of trial vessels. Concurrently, launch pilot projects with the Canadian Coast Guard, Navy, port authorities, and private operators to operate prototype autonomous vessels in various scenarios, from Arctic resupply missions to autonomous ferries or survey vessels, in order to

gain operational data and experience. Such pilot projects should include trials in challenging conditions (e.g., winter ice and high-traffic ports) to ensure Canadian MASS technology is proven under domestic operating realities. Governments can co-fund these initiatives to de-risk industry participation. The insights from pilot programs and testbeds will inform standards development, infrastructure needs, and best practices for broader deployment.

- Accelerate Innovation and Industry Adoption

To grow a competitive MASS industry, government and industry stakeholders must collaborate to stimulate R&D, commercialization, and early adoption of autonomous ship technologies. It is recommended to expand funding and incentives for MASS innovation, for instance, increasing support through federal and provincial programs, innovation clusters and networks, and defence research projects targeting autonomy. Public agencies can use procurement as a lever by piloting Canadian-made autonomous solutions (e.g., contracting local firms for unmanned vessel prototypes or port automation systems). Industry players (shipbuilders, tech firms and shipping companies) are encouraged to form consortia to develop and integrate MASS solutions, sharing costs and expertise. Strengthening links between traditional marine companies and the tech sector (AI and robotics startups) will spur the creation of homegrown MASS products.

In addition, Canada should attract private investment into this sector by promoting success stories and potentially establishing maritime-specific innovation funds or tax incentives. The goal is to ensure Canadian companies not only adopt existing MASS technologies but also help develop next-generation systems, creating intellectual property and export opportunities. By nurturing a vibrant domestic MASS supply chain now, Canada can capture a share of the global market and reduce reliance on external technologies.

- Develop Skills and Training Programs

Academic institutions, training organizations, and industry must work together, supported by government, to build a future-ready maritime workforce. A national MASS human capital plan should be launched to update mariner training and introduce new curricula related to autonomous systems. This includes developing specialized courses and certifications for roles such as design, remote vessel operators, MASS maintenance technicians, and maritime data analysts. Universities and colleges (in concert with bodies like Transport Canada and the IMO) should create programs that blend naval architecture and marine engineering with AI, robotics, and cybersecurity, ensuring that Standards of Training, Certification and Watchkeeping (STCW) evolve to reflect autonomous operations.

Existing maritime professionals should be offered upskilling opportunities, for example, system integration for naval architects, simulator-based training on supervising autonomous vessels and conversion courses for displaced seafarers to transition into shore-based control center roles. Government can facilitate this by funding workforce development initiatives and partnerships (as outlined in the report's Strategic Workforce Recommendations). Building abundant local expertise in MASS design, operation, software, and support will be essential for safe adoption and will create high-quality jobs across Canada.

- Enhance Coordination and Governance

To overcome fragmentation, all stakeholders (government, industry, academia, military, and regulators) should be engaged through a stronger coordination mechanism. It is recommended

to expand existing forums like CFMASS and CISMaRT. These bodies would facilitate steer implementation of the national strategy, track progress, and ensure that efforts across different regions and departments are aligned. Regular multi-stakeholder exercises (e.g., workshops and joint projects) should be conducted to share knowledge and address cross-cutting issues (e.g., standardizing data for vessel traffic systems or developing common safety cases for autonomous operations).

Within government, better interdepartmental coordination is needed, for instance, Transport Canada, the Department of National Defence, Innovation, Science and Economic Development (ISED), and regional development agencies should coordinate funding and regulatory approaches so that military, commercial, and research use of autonomous vessels progress in tandem. Clear governance and communication channels will help avoid duplication, concentrate resources on priority areas, and present a united Canadian position in international discussions.

- Promote International Collaboration and Leadership

Canadian authorities and industry should actively deepen international partnerships in the MASS arena. Canada should continue its leadership role at the IMO and in classification society working groups to help shape global MASS standards. Bilaterally, partnering with leading MASS nations on joint projects will accelerate learning, for example, Canada could participate in Europe's autonomous shipping corridors or collaborate with the U.S. and the U.K. on transoceanic unmanned vessel trials. Establishing mutual recognition agreements for MASS certifications and sharing best practices (such as harmonizing testing protocols with countries like Norway, Singapore or Japan) will smooth the path for Canadian MASS vessels operating abroad and foreign vessels testing in Canada. International R&D collaboration should also be pursued: Canadian researchers and firms can join multinational consortia on autonomy, AI and cybersecurity (leveraging programs like Horizon Europe or US-Canada defence innovation partnerships). By showcasing Canadian MASS pilot successes on the world stage and co-developing solutions with allies, Canada can play a prominent role in autonomous shipping. This will not only boost Canada's influence over emerging regulations but also open export markets for Canadian technology and services.

Each of these recommendations is actionable and mutually reinforcing. Together, they address policy and regulatory modernization, infrastructure and innovation investment, workforce skills, and collaborative governance, the critical levers to strengthen Canada's preparedness for MASS. By implementing these steps, Canada can accelerate safe MASS adoption, seize economic and strategic benefits, and ensure it remains at the forefront of the maritime autonomy revolution.

# Appendix A. Organizations Supporting MASS in Canada

## A.1 National Network and Forum

### A.1.1 CISMART

The Canadian Network for Innovative Shipbuilding, Marine Research and Training is a national initiative focused on advancing innovation, research, and workforce development in Canada's marine and shipbuilding industries. It serves as a collaborative platform that brings together industry stakeholders, academic institutions, and government agencies to address critical challenges in the maritime sector. CISMART is dedicated to fostering cutting-edge research and technology development, particularly in areas such as autonomous systems, ship design, and environmental sustainability. Its work helps to position Canada as a global leader in maritime innovation.

One of CISMART's notable contributions is its emphasis on autonomous technologies. For example, its 2019 Workshop on Autonomous Surface Ships provided a forum for discussing technological advancements, regulatory issues, and operational applications of autonomous systems. CISMART workshops foster the exchange of knowledge among researchers, engineers, policymakers, and maritime professionals, while also supporting the development and implementation of collaborative R&D projects, ensuring Canada remains a leader in maritime innovation. Beyond its technological focus, CISMART is deeply committed to education and training, recognizing the critical need to equip the workforce with the skills required to innovate, manage and operate next-generation maritime technologies.

CISMART also plays a critical role in aligning Canada's maritime research priorities with global trends and regulatory frameworks. Through collaborative partnerships and research projects, the network helps to bridge gaps between academic research and industry needs, ensuring practical applications of new technologies. By fostering innovation and building a skilled workforce, CISMART contributes significantly to the development of MASS and other advanced maritime solutions, reinforcing Canada's competitive position in the global maritime industry.

### A.1.2 CFMASS

The Canadian Forum for Maritime Autonomous Surface Ships (CFMASS) is a collaborative initiative designed to bring together key stakeholders from across Canada's maritime sector to facilitate the development and implementation of MASS technologies. CFMASS serves as a central hub for dialogue and cooperation among government agencies, port authorities, ship operators, technology developers, and academic institutions. Its primary aim is to ensure that Canada develops a unified approach to autonomous shipping, addressing technical, regulatory, and operational challenges. By providing a platform for knowledge sharing and strategic planning, CFMASS plays a crucial role in shaping policies and standards that align with global regulatory frameworks, such as those established by the IMO.

CFMASS emphasizes the importance of stakeholder collaboration to advance research and development, create testing opportunities, and foster innovation in the autonomous maritime sector. Its activities include hosting workshops, conducting studies, and building partnerships to promote the safe and efficient deployment of MASS technologies. By engaging with both industry leaders and regulatory bodies, CFMASS helps to identify gaps in Canada's maritime ecosystem and proposes actionable solutions to enhance its competitiveness. The forum also works to raise awareness about the economic and environmental benefits of autonomous vessels, advocating for their role in advancing

sustainability and operational efficiency within the maritime industry. As a driving force in Canada's MASS landscape, CFMASS is critical to ensuring the country's leadership in this rapidly evolving field.

## A.2 Capability to Support MASS Development in Canada

Canadian entities, companies, organizations, and groups that could support the development and commercialization of MASS technologies include (but are not limited to) the following:

### Technology Companies

- Software and AI: BlackBerry, Desjardins Labs, Microsoft Canada, NVIDIA Canada
- Robotics and Automation: Cellular Robotics, Clearpath Robotics, Kinova Robotics, Sanctuary AI
- Telecommunications: Starlink, Bell Canada, Rogers Communications, Telus
- Sensor and Navigation: Teledyne Optech, Magellan Aerospace, Rutter, L3 Harris, Lockheed Martin Canada, Raytheon Canada.

### Maritime Companies

- Shipyards: Seaspan Shipyards, Irving Shipbuilding, Davie Shipbuilding, Groupe Océan.
- Shipping and Logistics: Canadian Pacific Railway, CN Rail, Fednav, CSL, Leeway Marine, Desgagné, Horizon Maritime.
- Oil and Gas: Suncor Energy, Imperial Oil, Cenovus Energy, Equinor, Chevron
- Fisheries and Aquaculture: Ocean Choice International, Cooke Aquaculture, Qikiqtaaluk Fisheries Corp., Baffin Fisheries.

### Naval Architecture and Associated Companies

- Vard Marine (Vancouver and Ottawa) - Formerly STX Canada Marine: Vard Marine is known for complex vessel design including offshore patrol vessels, icebreakers, and research ships. Vard combines Canadian and global expertise (as part of Fincantieri) and has a track record in ice-class design. In fact, Vard is the design lead for the Canadian Coast Guard's upcoming Polar Icebreaker, working with Finland's Aker Arctic to optimize the ship for extreme conditions. Vard Marine's portfolio includes many vessels that could be autonomy-ready: for example, they design offshore patrol vessels (like the Hero-class for the Coast Guard) with advanced C2 systems.
- Robert Allan Ltd.: Established in 1930 in Vancouver, British Columbia, Robert Allan Ltd. is Canada's oldest privately owned consulting naval architectural firm. The company has established a reputation as a globally competitive designer of special-purpose workboats and have developed a line of remote-controlled workboats for hazardous operations (RAVEN autonomous vessels; RAMPARTS Tugboats; RALAMANDER Fireboats; RAMPAGE offshore supply tugs). The company has also developed a groundbreaking technology to allow an unmanned vessel to pass a line to a tug or other support vessel. The Line Transfer System has already been tested at sea in a number of autonomous vessels.
- Gregory C. Marshall Naval Architect Ltd.: Founded in 1994 and based in Victoria, British Columbia, this firm specializes in the design of yachts and commercial vessels. Some of their 400 projects include hybrid electric ferries, research survey vessels, crew transfer vessels, and commercial workboats.

- Concept Naval: Operating since 1987 in Quebec City, Concept Naval provides innovative and customized solutions for vessel operators and shipyards. Their expertise spans various vessel types, and they have completed over 500 successful design and major work projects (Toronto Island Ferries with electric propulsion).
- Allswater: offers comprehensive ship design, and marine engineering, emphasizing innovation and efficiency. Allswater, in collaboration with Oceans North, Miawpukek Horizon Maritime Services, and MEOPAR, is contributing to the design of a multi-use, zero-emission ocean research vessel to assess the feasibility of zero-emission propulsion technologies in Canadian waters.
- Lengkeek Vessel Engineering Inc. (LVE): Headquartered in Dartmouth, Nova Scotia, LVE has over 40 years of experience in developing progressive marine engineering solutions. Customers include government, commercial marine, and offshore energy, and they are ISO 9001:2015 certified (ice-capable pilot boats, offshore supply vessels and ferries).
- Fleetway Inc.: With a team of accredited naval architects and structural hull designers, Fleetway has been involved in all major Canadian Navy warship designs. Their experience encompasses concept design through to detailed production design, supporting both naval and commercial projects.
- BMT Group: An international design, engineering, and risk management consultancy, BMT has a significant presence in Canada. They have been involved in notable defense projects, including the design of the Queen Elizabeth-class aircraft carriers and the Tide-class Royal Fleet Auxiliary tankers.
- Canal Marine & Industrial Inc. (CANAL), based in St. Catharines, Ontario, was responsible for the complete electrification retrofit, encompassing the design, development, and installation of the new electric power and propulsion system. This work included the development and installation of the Toronto Island Ferry Automatic Shore Charging System (ASCS), the first of its kind in North America.
- Genoa Design International: Genoa has been an innovator in providing 3D modelling and production design services to shipbuilding and ocean industries around the globe since 1995. The company has extensive design and production experience on Navy and Coast Guard programs in both Canada and the USA.

### Research and Development

Robert Allen, L3 Mapps, OSI, Rutter, Marine Thinking, Cellula Robotics, Shift Coastal Technologies, Kraken Robotics, International Submarine Engineering, CAE with simulation and training technologies, and MDA with its LaunchPad Program, Maritime C and C for NATO, and advanced surveillance and intelligence.

### Government Agencies:

- Public Service and Procurement Canada: Responsible for all procurement and acquisition for all government departments including CCG and RCN.
- Transport Canada: Responsible for maritime regulations and safety.
- Innovation, Science and Economic Development Canada (ISED): Provides funding and support for innovation and technology development.

- Natural Resources Canada: Supports research and development in areas such as ocean technology.
- Fisheries and Oceans Canada: Conducts research and manages fisheries and oceans resources.
- DND: The Royal Canadian Navy is responsible for maritime defence of Canadian waters, including the EEZ. Works closely with USN, USCG, DOD and NATO on R&D through Defence Research and Development Canada (DRDC).
- Canadian Coast Guard: The Coast Guard is responsible for safety of mariners and to protect the marine environment. It provides search and rescue, pollution response, and icebreaking services.

#### Research Institutions:

- National Research Council Canada (NRC): Conducts research and development in various fields, including ocean technology
- Universities: Numerous Canadian universities have research programs in areas relevant to marine autonomy, such as naval architecture, robotics, AI, and oceanography (e.g., Memorial University, University of British Columbia, Dalhousie University, University of Manitoba (UoM). Should be noted that UoM was involved with the Arctic Research Centre Autonomous Boat, collaborating with Denmark/Greenland and the University of Florida to obtain bathymetric and ocean current data safely in dangerous environments such as near icebergs. A small ocean data vessel was used to collect data).
- Marine Institute of Memorial University and “The Launch” facility, including its training of mariners and recent MASS-specific adjunct training.

#### Industry Associations:

- Association of British Columbia Marine Industries
- Atlantic Canada Aerospace and Defence Association
- Canadian Manufacturers & Exporters (CME)
- Chamber of Marine Commerce
- Canadian Association of Defence and Security Industries
- OceansAdvance (Newfoundland and Labrador)
- Ocean Technology Council of Nova Scotia

#### Other Potential Contributors:

- Venture Capital Firms: Investing in promising MASS startups
  - Pelorus Venture Capital, NL
  - Innovacorp, NS
- Incubators and Accelerators: Providing support and resources to early-stage ocean technology companies:
  - COVE, Dartmouth, NS
  - Ocean Supercluster, St. John’s, NL
  - TechNL Innovation Centre, St. John’s, NL

- PIER, Halifax
- Centre for Ocean Applied Sustainable Technologies (COAST), Vancouver

Note: This is not an exhaustive list, and there are many other companies and groups in Canada that could play a role in the development and commercialization of MASS technologies.

This information can be used to identify potential partners for collaboration and to develop strategies for supporting the growth of the Canadian marine autonomy sector.

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