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Task 2 Report – Site Confirmation and Infrastructure Evaluation

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Task 2 Report – Site Confirmation and Infrastructure Evaluation

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Contents

1. Executive Summary

Port Detroit is investigating the development of a Maritime Innovation Terminal to support future maritime technologies, vessel retrofitting, research and demonstration activities, vessel electrification, alternative-fuel readiness and related industrial innovation uses.

Task 2 translates the market and use-case direction identified in the previous phase into the physical infrastructure decisions required to confirm whether the site can support these activities, what upgrades would be required, and how development should be phased to manage cost, technical risk and future flexibility.

The assessment indicates that the terminal has strong potential as a flexible, phased innovation platform. The most realistic near-term role is to support smaller research and demonstration vessels, testing and validation activities, vessel retrofits, digital maritime technologies, component handling, mobile electrification solutions and controlled pilot-scale fuel-handling activities. These uses are aligned with the current site constraints and can be supported through adaptable infrastructure that avoids committing too early to a single vessel type, fuel pathway or operating model.

Research vessel Mudpuppy II
LOA = 33 ft., B=8.5 ft., D=2.0 ft.

Research vessel Muskie
LOA = 70 ft., B=18 ft., D=5.5 ft.

Demonstration vessel
Varying vessel dimensions dependent on specific purpose

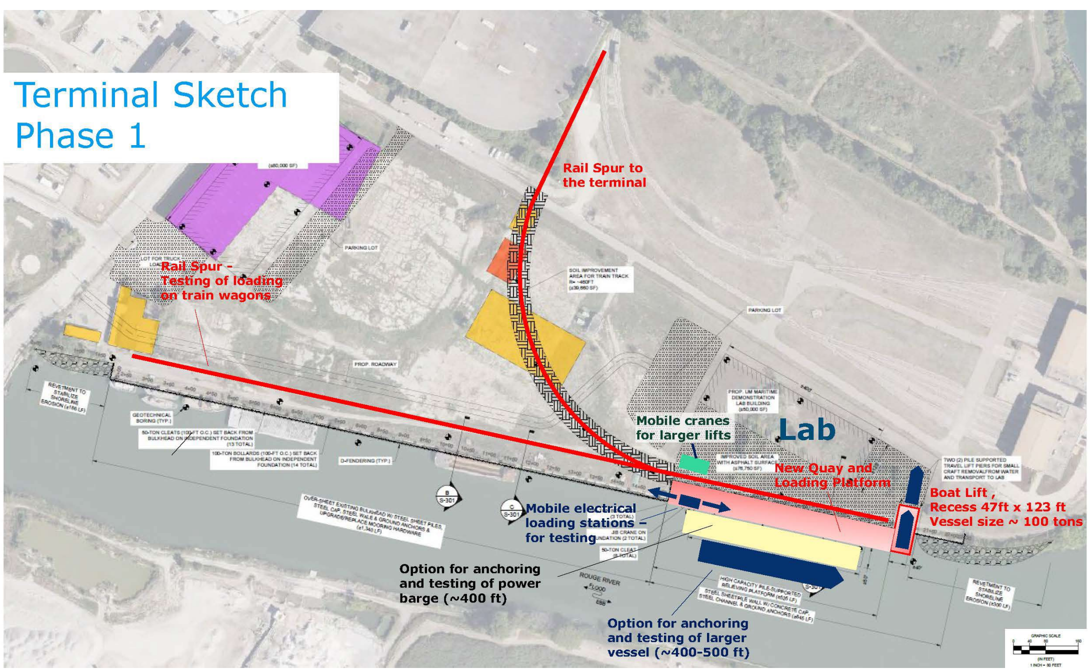
The evaluation also shows that higher-capacity or more complex use cases would require substantial additional investment and technical clarification. Existing water depths, quay wall condition, available terminal space, navigation constraints, safety distances and the potential presence of contaminated sediments all influence what can realistically be implemented. Without dredging, the terminal would primarily support smaller research vessels, demonstration vessels, workboats, barges and floating test platforms. Dredging to accommodate larger vessels could increase operational flexibility, but would also trigger more significant quay wall strengthening, permitting, sediment management, maintenance dredging and navigation considerations.

Alternative-fuel readiness should be treated as a future-proofing and validation opportunity rather than the primary basis for first-phase infrastructure investment. Biofuels and methanol are the most suitable near-term candidates for controlled pilot-scale testing. LNG and bio-LNG are technically mature but require cryogenic systems and should only be advanced where a confirmed user or demonstration program justifies the additional complexity. Ammonia, compressed gaseous hydrogen and liquid hydrogen should remain future research pathways because they introduce larger safety, permitting, storage and emergency response requirements.

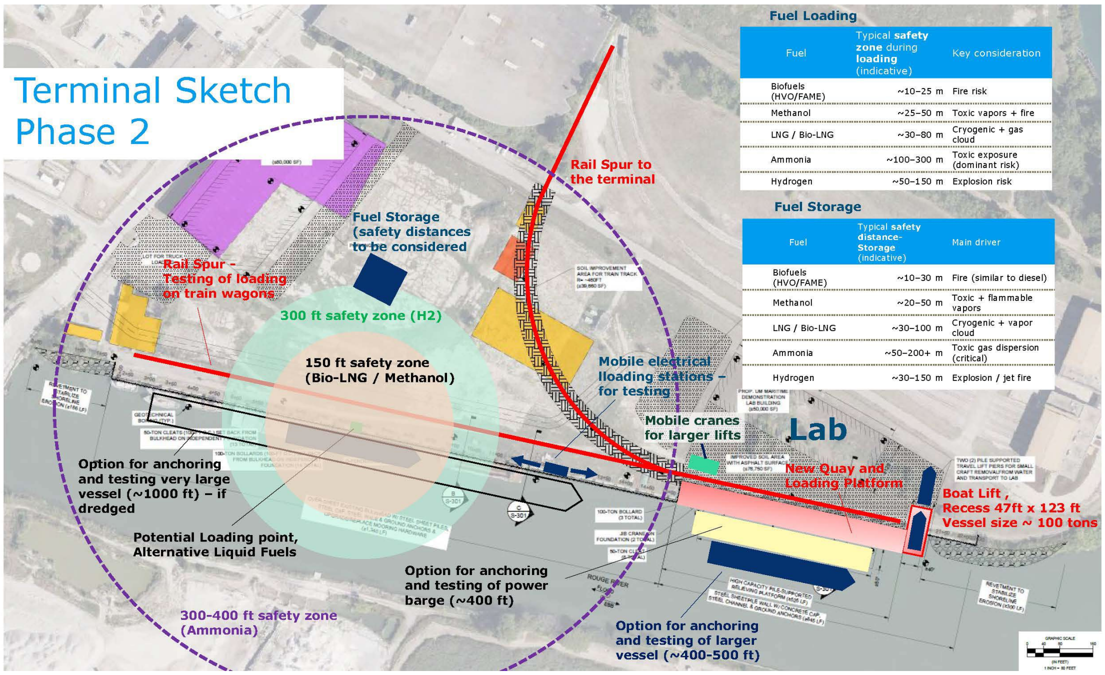
Vessel electrification is well aligned with the Innovation Terminal concept, but the first phase should focus on electrical readiness rather than fixed high-power charging infrastructure. Mobile or semi-mobile charging arrangements, protected shore-side connection points, cable management systems, Battery Energy Storage System (BESS)-ready space and reserved utility corridors would allow the terminal to support charging demonstrations, battery-system testing and retrofit activities without locking the layout to a single vessel interface. Fixed high-power charging should only be considered in a later phase if vessel users, charging frequency, battery capacity and grid connection requirements are confirmed.

The recommended development strategy is therefore to progress with a phased approach.

Phase 1 should be defined as the base case development: a lower-regret, flexible innovation platform including the lab, a new approximately 500–525 ft quay, flexible quay apron, mobile handling and lifting capability, smaller-vessel berthing, laydown and retrofit areas, mobile charging readiness, BESS-ready space and reserved utility corridors. Phase 1 should not assume full-depth dredging, permanent fuel tanks, fixed pipelines, fixed high-power charging towers, marine loading arms or dry dock infrastructure as base-case requirements.



Phase 2 should be treated as a set of trigger-based expansion options rather than an automatic next step. Potential Phase 2 elements may include rehabilitation of the existing western quay, targeted or full-depth dredging, larger-vessel access, a floating dry dock, fixed or semi-fixed alternative-fuel infrastructure, fixed high-power charging, grid upgrades and expanded BESS capacity. These elements should only be advanced where confirmed users, defined design vessels, safety cases, permitting pathways, sediment management strategies, grid requirements and funding justify the investment.



This report sets out phased infrastructure options for the redevelopment of the port site, covering quay structures, dredging, shoreline protection, electrification, utilities, and digital systems.

Phase 1 establishes early operational capability through a new suspended deck quay at the southeastern end of the site (the preferred structural form given unknown ground conditions and the opportunity to integrate a rock revetment), together with dedicated rock revetment shoreline protection at the eastern and western extents to address existing erosion and subsurface sinkholes.

Phase 2 delivers a new anchored steel sheet pile bulkhead riverward of the existing western quay — with the existing bulkhead retained as a secondary retaining element only — unlocking larger vessel operations, alternative fuel handling, floating dry dock capability, intermodal connectivity, and high-power vessel charging. The existing shoreline structures are assessed as Poor to Fair based on the Foth inspection observations, and Ramboll agrees with the Foth proposal to upgrade and substitute the wall across the entire frontage, adding design considerations relating to bollard/SSP interaction, rail spur surcharge, a potential piled crane loading platform, and alternative fuel infrastructure. Contrary to the Foth position, Ramboll's view is that dredging may in fact be required depending on the selected design vessel, with sediment contamination, wall stability impacts, and ongoing maintenance dredging (OPEX) as key considerations.

Phase 1 electrification and utilities focus on establishing a flexible civil foundation — reserved corridors, ducts, hardstandings, and BESS-ready footprints — to enable Phase 2 fixed installations without disruptive retrofit.

Significant information gaps remain across ground conditions, existing structure configuration, sediment quality, and ecological baseline data, and a targeted programme of surveys and investigations — prioritizing geotechnical, bathymetric, underwater inspection, and sediment characterization works — is recommended prior to detailed design. Three key decisions are required from the project sponsors to enable the next phases: the vessel spread for design, the operational surcharge and loading on the shore (including any rail spur), and confirmation of site use for testing of alternative fuels. Timely resolution of these decisions, alongside early engagement with regulatory authorities and the utility provider, will allow the project to progress efficiently and to deliver a coherent, cost-effective, and future-proofed port development.

The main conclusion from Task 2 is that Port Detroit should advance the Maritime Innovation Terminal through a flexible base-case design that activates the site for near-term research, testing, retrofitting, handling and vessel electrification activities, while preserving—but not prematurely constructing—larger investments such as deep dredging, major quay wall strengthening, fixed fuel-handling systems or high-power charging.

2. Current and previous use of terminal area

The terminal area has historically been used for marine-industrial and bulk-handling activities. The original quay is understood to have served larger bulk-related operations, although the extent to which the existing quay wall and berth depths can still support similar activities must be confirmed through further structural, geotechnical and bathymetric investigations.

Current use appears to be more limited than the site's historic industrial role. The quay is used for temporary mooring or "parking" of barges and tugboats, reflecting the continued operational relevance of the Rouge River for barge traffic and tug-assisted vessel movements. The river corridor remains an active working waterfront environment, and tugboats are frequently used to support barge movements and other vessel traffic.

The difference between the terminal's historic and current use is important for the feasibility assessment. Historic bulk activity suggests that the site was originally developed for heavier maritime operations, while today's more limited use indicates that additional investment would likely be required before the terminal could support innovation-related activities such as equipment handling, vessel lifting, retrofitting, vessel electrification testing or fuel-handling trials. The existing terminal condition should therefore be treated as a baseline for feasibility assessment rather than as a confirmed operational platform for future innovation uses. The future development concept will need to determine which elements of the existing waterfront function can realistically be retained, upgraded or repurposed.

Available inspection information indicates that shoreline structures are generally in poor to fair condition. Observed issues include erosion, sinkholes, steel sheet pile section loss, deterioration of concrete elements, exposed reinforcement, damaged bollards and other mooring infrastructure. These observations are relevant to the assessment of current conditions, but the implications for future terminal activities are addressed in later chapters dealing with handling equipment, dredging and quay wall rehabilitation.

Before the terminal can be advanced into more detailed design, the existing quay wall systems, ground conditions, underwater conditions, water depths, sediment conditions and potential obstructions should be verified in greater detail. This will confirm whether the existing waterfront can be rehabilitated for continued maritime use or whether replacement, dredging or other enabling works will be required.

Figure 2-1 Existing terminal area and waterfront conditions (image from Google Earth)

3. Anticipated activities and vessels at the Innovation Terminal

The Market and Industry Assessment identified the segments and use cases most relevant to the future Maritime Innovation Terminal. The strongest near-term demand is expected in digital maritime technologies, automation, advanced components and maritime manufacturing, while alternative fuels and logistics are considered secondary or opportunistic focus areas.

<u>Short term / near term activities</u>

For the first phase, the terminal should be planned around repeatable testing, validation and demonstration activities. Anticipated activities include unloading materials, components and modules at the quay; installing equipment on vessels; testing sensors, automation systems and digital maritime technologies; validating components and systems; and supporting vessel retrofitting either alongside the quay or in adjacent landside areas.

Demand for a shared demonstration vessel was identified, but it should be linked to defined and repeatable use cases. The demonstration vessel should therefore be treated as a flexible testing platform rather than a single-purpose asset. Relevant capabilities may include modular or plug-and-play interfaces, instrumentation and data capture, support for remote or semi-autonomous operations, and the ability to test components or systems under real operating conditions.

The anticipated vessel profile is expected to include smaller research vessels, demonstration vessels, workboats, tugboats, barges and other crafts capable of supporting innovation-related activities. Larger vessels may become relevant if the Port chooses to preserve optionality for bulk carriers, larger research vessels or alternative-fuel vessels, but these uses would require additional assessment of water depth, berth geometry, navigation constraints, mooring requirements and quay wall capacity.

Near-term infrastructure should therefore prioritize flexibility. The terminal should be able to accommodate different vessel geometries, equipment packages, charging interfaces, sensors, testing setups and retrofitting workflows without requiring major permanent infrastructure for each individual use case. This supports the use of mobile or modular equipment where possible, including mobile cranes, adaptable vessel-handling systems, mobile charging solutions and temporary testing arrangements.

<u>Medium term / long term activities</u>

Alternative fuel activities may also be relevant, but they should be treated as a secondary near-term focus. The most appropriate role for the terminal is likely to be fuel-handling validation, safe bunkering procedures, port-readiness testing, emergency response planning and controlled pilot-scale trials, rather than full-scale fuel production (and bunkering) or large permanent storage. These activities would require careful consideration of safety zones, permitting, fuel-specific handling systems, and separation from laboratories or personnel-intensive areas.

Overall, this chapter translates the market findings into operational requirements to be tested in the following infrastructure chapters. These requirements define the basis for assessing vessel access and navigation constraints, handling and lifting equipment, alternative fuel readiness, vessel electrification, dredging needs, quay wall rehabilitation and potential development phasing.

4. Vessels and navigation constraints

This chapter assesses the vessel and navigation constraints that influence the feasibility of the Maritime Innovation Terminal. The analysis links the demonstration vessel market assessment to the physical navigation conditions at the site, including existing water depths, potential dredging scenarios, design vessels with and without dredging, and other navigational restrictions within the Rouge River. The purpose is to define a realistic vessel basis for the first phase of the terminal while preserving optionality for future expansion if larger vessels become a confirmed requirement.

4.1 Demonstration vessel market assessment

The market assessment indicates that the strongest near-term opportunity for the Maritime Innovation Terminal is linked to demonstration, testing and validation activities rather than large-scale commercial vessel operations. This includes digital maritime technologies, automation, advanced components, vessel systems, mobile vessel electrification and retrofit-oriented innovation. The demonstration vessel examples listed in Table 4-1 and presented in Figure 4-1 to Figure 4-6 summarizes a set of reference vessels that illustrate the potential range of vessel types and onboard equipment potentially relevant to the Innovation Terminal.

The examples include unmanned and autonomous surface vessels, multipurpose research vessels, retrofitted innovation vessels, workboats and prototype naval craft. Vessel dimensions vary significantly, from small workboats of approximately 33 ft LOA to larger research or prototype vessels of around 85–102 ft LOA, with drafts generally within the shallow to moderate range where information is available. The onboard equipment listed in the table highlights the technical focus of the potential user base, including sensor packages, LiDAR, cameras, GPS and IMU systems, dynamic positioning, cranes, autonomous navigation systems, remote-control and communication systems, digital twin capabilities, modular payload arrangements and alternative propulsion or fuel retrofit solutions. Overall, the table indicates that the first-phase vessel basis for the Innovation Terminal should prioritize flexibility, shallow-to-moderate draft capability, adaptable berthing arrangements, power and data connectivity, and support for modular testing, autonomy, electrification and retrofit-oriented activities.

Vessel	Type	LOA	Beam	Draft	Displacement	Onboard equipment
eM/S Salama	Unmanned Surface Vessel	22.3 ft (6.80 m)	9.8 ft (3.0 m)	Unknown	Unknown	Fitted with a sensor data collection setup, comprising RGB cameras, thermal cameras, and stereo vision cameras, a LiDAR sensor, IMU, and GPS antenna.
R/V Gunnerus	Multipurpose research vessel	102.5 ft (31.25 m)	32.5 ft (9.9 m)	8.9 ft (2.7 m)	Unknown	Fitted with a dynamic positioning system and a variety of sensors to support a variety of technological and scientific research activities. Used for various digital twin studies, one of which features a knuckle boom crane onboard the vessel.
Ahti	Former fishery patrol vessel retrofitted for innovation and development	Reliable information has not been found.				Equipped with: navigation automation control system, high-resolution short-range radar, among others Soon to have: DP laser sensor, advanced sensors and high-accuracy ship control systems for semi-autonomous sailing, remote control and satellite connectivity features, among others
Haeyangnuri	Autonomous test vessel	86.9 ft (26.5 m)	17.7 ft (5.4 m)	4.4 ft (1.35 m)	97 tons	Equipped with: intelligent autonomous navigation systems, remote control & communication systems, and a digital twin bridge, among others
Lochin 33	Workboat	33.0 ft (10.06 m)	11.8 ft (3.6 m)	3.3 ft (1.0 m)	7 tons	Powerboat, no particular onboard equipment Converted into a dual-fueled vessel acting as a testbed to prove the concept of a retro-fit green hydrogen solution for marine transport
Stiletto	Prototype naval ship	88.6 ft (27.00 m)	39.4 ft (12.0 m)	2.6 ft (0.8 m)	60 tons	Equipped with a wide range of options for adaptability, integration, and data collection, thanks to its high modularity for project customization Soon to have: automated propulsion systems

Table 4-1 Demonstration and research vessel examples considered for the Innovation Terminal

The following descriptions translate the vessel characteristics and onboard equipment listed in Table 4-1 into practical implications for the Innovation Terminal.

Figure 4-1. eM/S Salam

eM/S Salama is a small unmanned surface vessel with a compact footprint, approximately 22.3 ft in length and 9.8 ft in beam. Although draft and displacement data are not available, the vessel is clearly representative of the smaller end of the demonstration vessel range. Its sensor package, including RGB cameras, thermal cameras, stereo vision cameras, LiDAR, IMU and GPS, makes it relevant for perception, navigation, data collection and autonomy-related testing. For the Innovation Terminal, this type of vessel supports the need for flexible small-craft berthing, data connectivity, charging or power interfaces, and safe testing areas for autonomous and remotely monitored operations.

Figure 4-2. R/V Gunnerus

R/V Gunnerus represents a larger multipurpose research vessel, approximately 102.5 ft in length, 32.5 ft in beam and 8.9 ft in draft. The vessel is equipped with dynamic positioning and a range of sensors used for technological and scientific research activities. Its use in digital twin studies, including configurations with onboard lifting equipment such as a knuckle boom crane, makes it relevant for testing vessel monitoring, data acquisition, research instrumentation and onboard equipment integration. For the Innovation Terminal, this vessel illustrates the need for deeper small-to-medium vessel access, stable berthing, personnel access, utility connections, data infrastructure and support for deck-based equipment handling.

Figure 4-3 Stiletto

Stiletto is a prototype naval vessel approximately 88.6 ft in length, 39.4 ft in beam and 2.6 ft in draft, with a displacement of around 60 tons. Its shallow draft and wide beam are notable from a berth and handling perspective. The vessel is designed for adaptability, integration and data collection, with high modularity for project customization and planned automated propulsion systems. For the Innovation Terminal, Stiletto represents a prototype or advanced demonstration craft requiring flexible berthing, modular equipment interfaces, space for integration works, data collection infrastructure and support for testing automated propulsion or other advanced maritime technologies.

Figure 4-4 Haeyangnuri

Haeyangnuri is an autonomous test vessel of approximately 86.9 ft in length, 17.7 ft in beam and 4.4 ft in draft, with a displacement of approximately 97 tons. The vessel is equipped with intelligent autonomous navigation systems, remote-control and communication systems, and a digital twin bridge. It is therefore representative of a medium-sized vessel focused on autonomy, digital operations and remote supervision. For the Innovation Terminal, this vessel type is highly relevant because its shallow draft and technology-focused configuration align with the first-phase concept.

Figure 4-5Lochin 33

Lochin 33 is a small workboat of approximately 33 ft in length, 11.8 ft in beam and 3.3 ft in draft, with a displacement of around 7 tons. The table indicates that the base vessel is a powerboat without particular onboard equipment, but that it has been converted into a dual-fuel vessel acting as a testbed for a retrofit green hydrogen solution for marine transport. This makes it especially relevant as an example of small-vessel retrofitting and alternative propulsion demonstration. For the Innovation Terminal, Lochin 33 supports the need for light vessel handling, simple berthing, access for retrofit works, fuel-system testing areas and flexible support for low-emission technology validation.

Figure 4-6 Ahti

Ahti is a former fishery patrol vessel retrofitted for innovation and development purposes. Although reliable dimensional information has not been identified, the vessel is relevant because it has been adapted as a test platform for autonomous and remotely operated vessel technologies. Its onboard equipment includes navigation automation control systems and high-resolution short-range radar, with planned upgrades including DP laser sensors, advanced sensors, high-accuracy ship control systems, semi-autonomous sailing capability, remote-control features and satellite connectivity. For the Innovation Terminal, Ahti highlights the importance of supporting retrofit activities, autonomy testing, communication systems, control interfaces and shore-side monitoring arrangements.

The vessel examples provide the basis for the navigation assessment that follows. In particular, they indicate that the near-term vessel envelope should focus on smaller research vessels, demonstration vessels, workboats and barges that may be compatible with the existing or minimally improved depth conditions at the site. Larger vessels may remain relevant as future options, particularly for alternative fuels, bulk cargo innovation or larger-scale demonstrations, but they should only define the terminal layout if supported by confirmed users, vessel requirements and the water-depth, berthing and navigation assessments presented in the following sections.

4.2 Navigation assessment – Existing conditions

This section establishes the existing navigational baseline for the terminal frontage, focusing on available water depths, berth usability and the implications for vessel draft before any dredging is considered. The assessment is based on available hydrographic information for the Rouge River and the terminal frontage, including a hydrographic survey carried out by the U.S. Army Corps of Engineers in April 2025.

The development area is divided into two areas / scenarios, with adjacent quays, cf. Figure 4-7 below. The figure provides a spatial basis for understanding how each scenario would affect berth usability, vessel access, quay wall requirements and the extent of marine works required.

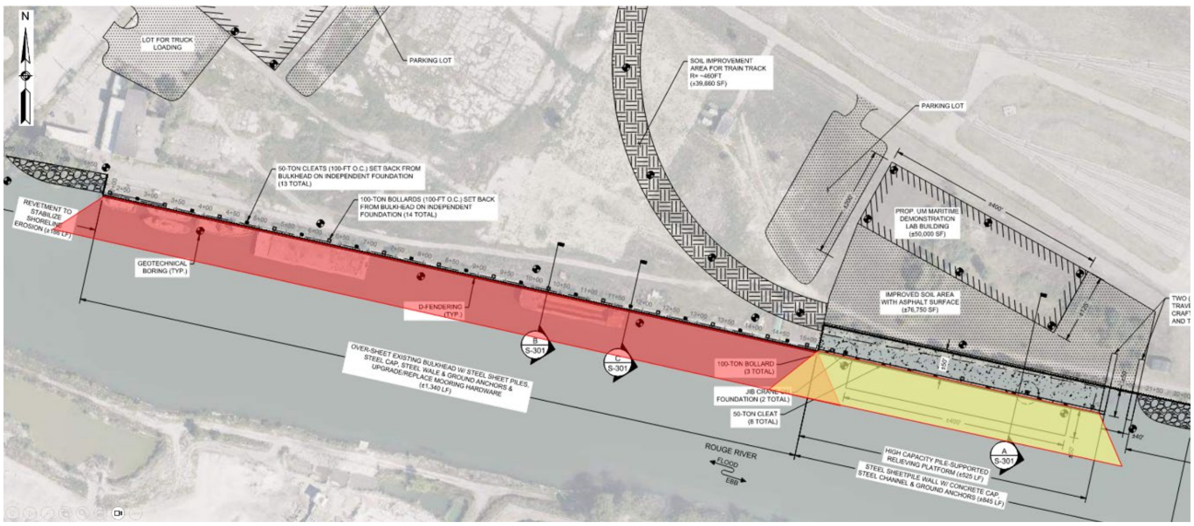


Figure 4-7 Presentation of two proposed quay areas/scenarios (Scenario A- yellow area, Scenario B – red area)

As illustrated in Figure 4-8 (below), existing water depths vary significantly between the proposed new quay, the existing quay and the main Rouge River channel. At the potential future quay structure, natural water depths are generally between approximately 5 and 11 ft at low water. The existing quay appears to provide deeper water, with depths in the range of approximately 12 to 15 ft at low water. By comparison, the main river channel is understood to have a guaranteed water depth of approximately 27 ft; however, this depth is not available directly at the proposed berth areas without significant dredging.

For this stage of assessment, an indicative under-keel clearance of approximately 2 ft has been assumed. This is a high-level planning assumption and should be confirmed during later design stages based on vessel type, operating procedures, riverbed conditions, water-level variation and applicable navigation requirements. On this basis, if no dredging is carried out at the new quay, the berth would mainly be suitable for barges and smaller vessels with shallow to moderate drafts.

The allowable vessel draft would vary along the berth depending on local riverbed morphology. Lower allowable drafts should be expected toward the downstream end, while greater available depth is present toward the upstream end. This means that vessel positioning along the quay may become an important operational consideration, particularly for demonstration vessels, research craft or workboats approaching the upper end of the available draft range. The existing quay may provide more flexibility for moderately deeper vessels, but its use depends not only on available water depth but also on the condition and structural capacity of the quay wall, bollards and related marine infrastructure.

Overall, the existing navigation conditions support a first-phase concept focused on vessels that can operate within existing or slightly improved depth conditions. This aligns with the demonstration vessel market assessment and reduces the need for early investment in deep dredging, major quay wall strengthening and more complex navigational controls. If larger or deeper-draft vessels are later confirmed as a priority, dredging becomes the primary intervention to increase berth usability, as discussed in Section 4.3.

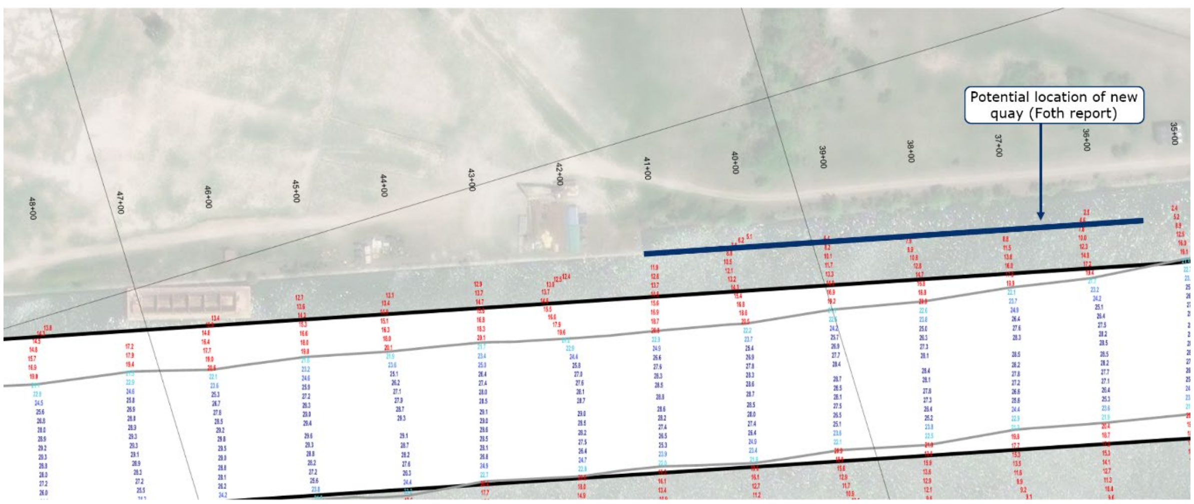


Figure 4-8 Existing water depths at the proposed and existing quay areas

4.3 Navigation conditions – Dredging scenarios

Dredging should be considered as an enabling option rather than a default first-phase requirement. It would only be required if the terminal is intended to accommodate larger or deeper-draft vessels than those compatible with the existing water depths described in Section 4.2. The dredging scenarios considered in this assessment assume dredging to approximately -27 ft, equivalent to the guaranteed water depth in the main Rouge River channel. This depth is used as a common benchmark for comparing future navigation options and should be understood as a strategic planning assumption rather than a confirmed design depth.

Three dredging scenarios have been considered at this stage:

Scenario A – dredging at the new quay only. This would focus investment on the future terminal frontage and could improve vessel access directly in front of the planned Innovation Terminal. However, the usable vessel envelope may remain constrained by the proposed quay length and by the interface with the adjacent existing quay. If the adjacent existing quay is not upgraded, the dredged area and usable vessel length may need to be reduced. The new quay is sketched to have a length of 525 ft. and will get a water depth of 27 ft. after dredging.

Scenario B – dredging at the existing quay only. This would improve vessel access to the existing berth and could make use of the longer existing quay frontage. However, it would likely require significant strengthening or reconstruction because the existing quay is not understood to be designed for the deeper dredged condition. This scenario may be relevant if larger vessels require a longer berth than the proposed new quay can provide. The existing quay has a length of 1340 ft and will get a water depth of 27 ft. after dredging.

Scenario A+B – dredging at both the existing and new quay areas. This would create the greatest operational flexibility and the longest combined berth frontage, but it would also involve the highest capital cost, greatest interface risk and most extensive permitting, sediment management and quay wall implications.

In addition to full-depth dredging to -27 ft, partial or localized dredging could be considered in later design stages if the selected design vessels require only modest depth improvements. This could include targeted dredging at the upstream end of the new quay, berth pockets for specific vessels, or localized deepening to improve under-keel clearance for selected demonstration or research vessels. Such options may reduce cost, sediment volumes and quay wall impacts compared with full-depth dredging.

The principal benefit of dredging is that it could expand the range of vessels able to berth at the terminal. However, dredging would also trigger a series of related requirements, including confirmation of quay wall stability, geotechnical conditions, dredge slope stability, sediment quality, contaminated-material disposal requirements, environmental permitting, maintenance dredging requirements, mooring arrangements and navigation safety. Dredging would also increase the retained height acting on quay structures, which may require more substantial quay wall strengthening or replacement.

The decision to dredge should therefore be linked to confirmed users, defined design vessels, required operating draft, quay wall upgrade strategy, sediment management requirements, permitting risk and funding availability. If the terminal is primarily intended to support smaller demonstration vessels, research craft and modular testing activities, dredging to the full channel depth may not be required in the first phase.

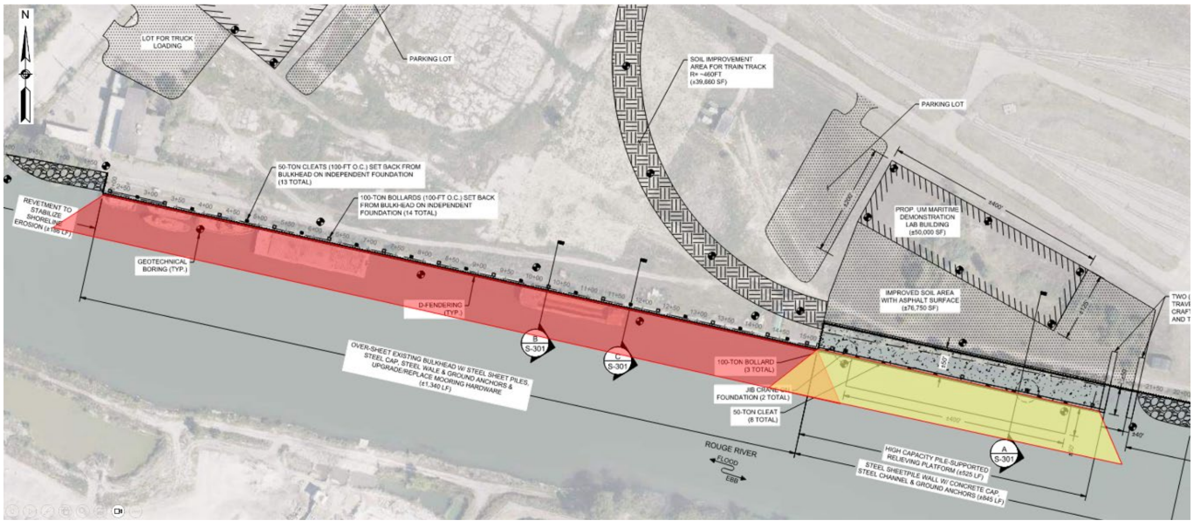


Figure 4-9 Indicative dredging scenarios for the existing and proposed quay areas (Scenario A- yellow area, Scenario B – red area)

Figure 4-9 illustrates the three dredging scenarios considered for the terminal frontage, distinguishing between dredging at the existing quay, dredging at the proposed new quay, and a combined dredging option covering both areas. The figure provides a spatial basis for understanding how each scenario would affect berth usability, vessel access, quay wall requirements and the extent of marine works required.

4.3.1 Design vessels if no dredging is performed

Without dredging, water depths along the proposed new quay (scenario A) are expected to range from approximately 5 to 11 ft. The upstream part of the quay (scenario B) is deeper than the downstream part, with approximately 8 to 11 ft available upstream compared with approximately 5 to 8 ft downstream. This means that shorter vessels may be able to achieve slightly greater draft if berthed toward the upstream end, while deeper-draft vessels would remain constrained.

Given the proposed new quay length of approximately 525 ft (scenario A), draft rather than berth length is expected to be the main limitation for vessels using the new quay without dredging. In the downstream end of the berth, vessels would generally be limited to drafts of approximately 3 to 6 ft. The upstream end could accommodate vessels with drafts around 6 to 7 ft, and may allow vessels with drafts approaching approximately 9 ft only in the deepest upstream area, subject to detailed bathymetric confirmation, under-keel clearance requirements and operational restrictions.

The most relevant design vessels which can be accommodated, if dredging is not performed, are therefore smaller research vessels, demonstration vessels, workboats and barges. Research vessels comparable to smaller Great Lakes vessels such as Mudpuppy II and Muskie are expected to be more compatible with the available depth conditions. By contrast, larger research vessels such as Lake Guardian, with a draft of approximately 11 ft, would not be accommodated at the new quay if dredging is not performed.

For demonstration vessels, the key point is that vessel dimensions and draft can be selected or designed around the terminal's constraints. As shown by the vessel examples in Figures 4-1 to 4-6, demonstration vessels can vary significantly depending on their purpose, including autonomous operations, electric propulsion, sensor testing, alternative propulsion systems or modular equipment trials. For the first phase, the terminal should therefore focus on demonstration vessels that can operate within the existing draft envelope rather than forcing early investment in deeper berthing conditions.

The indicative vessels shown in Figure 4-10 illustrate the type and scale of vessels that could be considered under the existing water-depth conditions, without dredging at the new quay. These examples are intended to represent a practical first-phase vessel envelope, including smaller research vessels, demonstration vessels, workboats, barges or floating test platforms with shallow to moderate drafts. The figure supports the assessment that, without dredging, the terminal should focus on vessels that can operate within the available depth range while still supporting testing, retrofitting, electrification and modular innovation activities.

Research vessel Mudpuppy II
LOA = 33 ft., B=8.5 ft., D=2.0 ft.

Research vessel Muskie
LOA = 70 ft., B=18 ft., D=5.5 ft.

Demonstration vessel
Varying vessel dimensions dependent on specific purpose

Figure 4-10 Representative design vessel envelope without dredging

A power barge or similar floating test platform could also be considered, provided it is designed to fit the available water-depth constraints. This reinforces the importance of treating the first-phase vessel basis as a flexible operational envelope rather than a fixed vessel list.

4.3.2 Design vessels if dredging is performed

With dredging to approximately -27 ft, the draft limitation at the berth would be substantially reduced and vessels with operating drafts of up to approximately 24 ft could potentially be considered, assuming an indicative under-keel clearance of approximately 2 ft. Under this condition, the controlling constraints would shift from water depth to berth length, quay wall capacity, mooring arrangements, vessel maneuverability, passing vessel clearance and operational safety. The larger-vessel examples shown in Figure 4-11 illustrate the scale of vessels that may become relevant only if deeper access and associated infrastructure upgrades are advanced.

Large bulk carriers such as Stewart J Cort currently operate on the Great Lakes and demonstrate the upper end of the vessel scale that could theoretically be considered. However, this type of vessel is significantly larger than the expected first-phase demonstration vessel profile. Its length, beam and draft would create important berth geometry, navigation and operational constraints. Due to quay length limitations, accommodating vessels of this scale would only be relevant under dredging scenarios that include the existing quay or a combined existing and new quay arrangement.

Even if dredging is provided, large bulk carriers would introduce constraints beyond water depth alone. The Rouge River arm does not appear to provide turning areas suitable for very large vessels to turn independently near the terminal. Such vessels may therefore need tugboat assistance, restricted maneuvers or operational controls when arriving or departing. They may also affect passing vessel movements while alongside.

Alternative fuel vessels could also become relevant under a dredged condition, particularly if the terminal were to support methanol, hydrogen, ammonia, liquid CO2 or other future fuel pathways. The Northern Lights liquid CO2 vessel shown in Figure 4-11 provides an example of the scale and operational requirements that may be associated with this type of vessel. However, these vessels typically require more stringent mooring arrangements, larger safety distances, fuel-specific handling systems and additional operational restrictions. The proposed 525 ft new quay may not be sufficient for some vessels of this type without additional mooring dolphins or other berth infrastructure.

From a berth-geometry perspective, Scenario B would provide deeper water at the existing quay only and would rely on the rehabilitation or reconstruction of that longer berth. Scenario A would provide deeper water at the new quay only, but the usable vessel envelope may remain constrained by quay length and interfaces with the existing quay. Scenario A+B would provide the greatest flexibility by combining the existing and new quay areas, but it would also represent the most significant investment and risk profile. Overall, dredging would expand the potential vessel envelope, but it would not remove all constraints. Larger vessels would still require compatible berth geometry, adequate mooring arrangements, confirmed quay wall capacity, tug-assisted maneuvering arrangements where needed, safety controls and potentially additional berth infrastructure such as dolphins or dedicated mooring points. For this reason, the dredged vessel envelope should be treated as a future-phase option linked to confirmed vessel demand and business case justification, rather than as the basis for the first-phase terminal layout.

Figure 4-11 Stewart J Cort bulk carrier and Northern Lights LCO2 vessel examples

4.4 Other navigational restrictions

Other navigational restrictions must also be considered before confirming the future vessel basis for the terminal. Vessels entering the Rouge River pass through the guiding structure at the river mouth and under the nearby bridge. The available width at this location has been assessed at approximately 124 ft. This indicates that large vessels do navigate within the Rouge River system, but it also confirms that beam, maneuverability and safe transit clearances must be considered for any larger design vessel.

The bridge also introduces a potential air-draft limitation, unless (or to which extent) it can open the main girder. This may not be critical for smaller research or demonstration vessels, but it could affect larger vessels, vessels with high superstructures, temporary equipment installed on deck, cranes, masts, sensor arrays or alternative-fuel systems. Air-draft requirements should therefore be confirmed once the design vessel envelope is defined.

Passing vessels and river safety are also important considerations. A large vessel berthed at the terminal would occupy more of the available river width than the smaller vessels expected in the first phase. This could affect passing vessel operations and may require restrictions, coordination with river traffic, tug assistance or temporary controls during berthing and departure. These requirements would be particularly important for large bulk vessels or vessels associated with alternative fuels.

If liquid bulk or alternative-fuel vessels are berthed at the terminal, additional safety restrictions may apply. These could include larger safety distances, stricter controls on passing vessels, emergency response requirements, exclusion zones, mooring restrictions and more detailed operational procedures. These restrictions could affect the terminal layout and the feasibility of accommodating multiple activities at the same time.

4.4.1 River mouth access and beam constraint

Vessels entering the Rouge River must pass through the guiding structure at the river mouth and under the adjacent bridge. The available width through the guiding structure is estimated at approximately 124 ft, with at least 100 ft of width with full draft clearance. This indicates that large vessels can navigate within the Rouge River system, but it also confirms that beam, maneuverability, tug assistance and safe transit clearances must be assessed for any larger design vessel considered for the Innovation Terminal.
The aerial image in Figure 4-12 shows the guiding structure and confirms that commercial vessels use this river access. However, the presence of this constraint means that larger vessels should not be assessed on berth depth alone; access geometry and safe navigation through the entrance must also be considered.

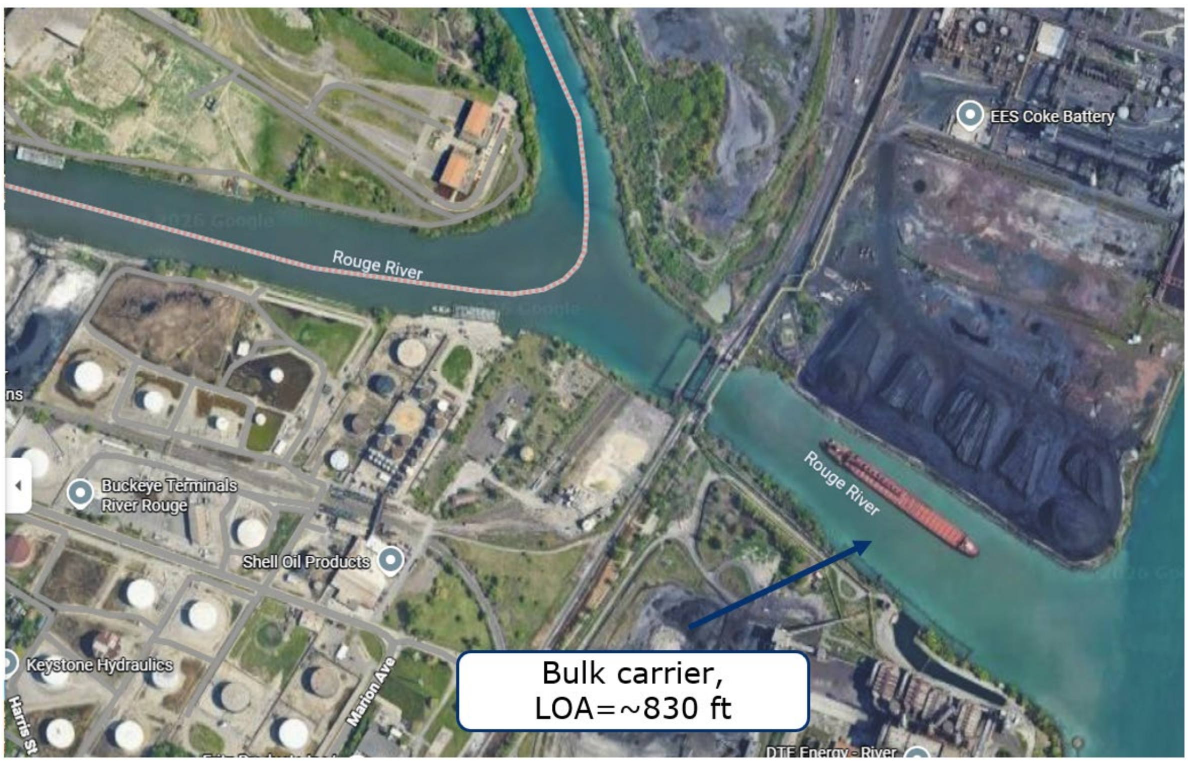


Figure 4-12 River mouth guiding structure and available navigation width

4.4.2 Passing vessels and safety

Passing vessel movements within the Rouge River may constrain the feasibility of berthing larger vessels at the terminal. A large bulk vessel or liquid bulk vessel alongside the quay would occupy a greater portion of the river width than smaller research, workboat or demonstration vessels. This could reduce available clearance for passing traffic and may require traffic coordination, temporary passing restrictions, tug assistance or defined berthing windows.

If vessels carrying liquid bulk or alternative fuels are berthed at the terminal, additional safety restrictions may apply. These could include exclusion zones, restrictions on passing vessel movements, emergency response requirements, mooring controls and fuel-specific operational procedures. These requirements should be confirmed during later navigation and safety assessments if alternative-fuel vessel calls are retained as a future option.

Navigation is difficult for large vessels, and tugs are most likely needed. Turning can take place in nearby connecting side rivers. From arial images large vessels can be seen in the river system, so the captains and pilots are apparently used to operating under rather narrow conditions. Navigational constraints should however be investigated further, especially if to consider large vessels using the terminal.

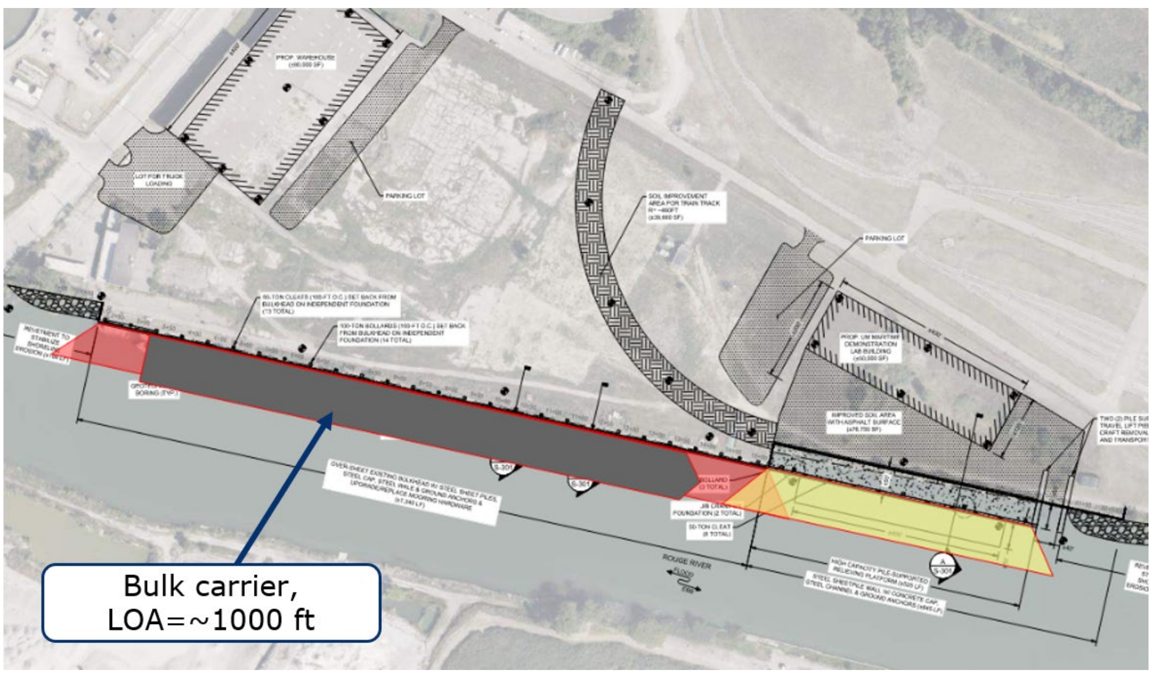


Figure 4-13 Passing vessel clearance and berth safety considerations

4.4.3 Bridge clearance and air-draft limitation

The bridge near the river mouth may also introduce an air-draft limitation for vessels entering the Rouge River, unless (or to which extent) the bridge can open the main girder. This constraint is unlikely to control the first-phase vessel envelope if the terminal is focused on smaller research, workboat and demonstration vessels. However, it may become relevant for larger vessels, vessels with high superstructures, deck-mounted cranes, masts, sensor arrays, communication equipment or temporary testing installations.

Air-draft requirements should therefore be confirmed once the design vessel envelope is defined. This is particularly important for innovation-related vessels, where temporary onboard equipment may increase the effective vessel height above the waterline.

Figure 4-14 Bridge clearance and air-draft constraint at Rouge River entrance

Overall, the navigation assessment supports a phased approach. In the near term, the terminal should be planned around smaller research, demonstration, workboat and barge-type vessels that can operate within existing or minimally improved depth conditions and safely access the

Rouge River under current navigation constraints. This aligns with the market assessment and the demonstration vessel examples shown in Figures 4-1 to 4-6. Dredging and larger-vessel accommodation should be preserved as future options, but only advanced if confirmed users, vessel requirements, quay wall upgrades, navigation controls, safety constraints and funding justify the additional investment.

5. Handling and lifting equipment

This chapter assesses the handling and lifting equipment required to support the anticipated vessel retrofitting, component installation, testing and demonstration activities at the Innovation Terminal. The assessment follows the same phased logic as the vessel and navigation assessment: near-term infrastructure should prioritize flexible, lower-regret equipment that can support smaller demonstration vessels and component handling, while larger or more permanent systems should be treated as future options linked to confirmed users, design vessels and operational requirements.

The main handling requirements are expected to arise from three activity groups. First, the terminal will need to receive, move and install equipment, components and modules associated with vessel retrofitting and technology demonstrations. Second, the terminal may need to lift smaller vessels onto the quay or into an onshore work area for retrofit, inspection or integration works. Third, larger or more complex vessels may require floating or dry-dock solutions if the works cannot be safely or efficiently performed alongside the quay or by lifting the vessel onto land.

For this stage of assessment, the key objective is not to select a final equipment supplier, but to identify which handling concepts are compatible with the likely first-phase vessel envelope, site constraints, quay wall capacity, available land area and future operational flexibility. Final equipment selection should be confirmed during later design stages once vessel displacement, component weights, lift radii, quay load capacity, bathymetry, ground conditions and preferred retrofit workflows are defined.

5.1 Handling equipment for components and retrofit materials

Component handling will be required for unloading, installing and removing equipment, modules and vessel components used in shipbuilding, retrofitting and demonstration activities. These activities may include delivery of propulsion components, battery systems, fuel-system modules, sensors, autonomous navigation equipment, communication systems, deck equipment, research instrumentation and temporary test packages. The handling system should therefore be able to support a broad range of component sizes and weights rather than being optimized for one fixed cargo type.

For the first phase, a mobile crane is considered the most flexible solution because it can serve different vessel positions, support temporary project-specific lifts and avoid early commitment to a fixed crane structure. A mobile crane could also support both vessel component handling and, for smaller vessels, occasional vessel lifting if sufficient capacity, reach and safe rigging arrangements are available. This flexibility is particularly important for an innovation terminal, where users, vessel types and test configurations may change over time.

The feasibility of using mobile cranes will depend on crane capacity, lifting radius, ground bearing pressure, outrigger loads, available set-up area, quay wall capacity and the distance between the crane position and the vessel or laydown area. These parameters should be checked against the structural design of the quay and the expected operational envelope. In practice, the quay apron may need to be designed for defined crane loading zones rather than assuming that heavy crane operations can occur anywhere along the waterfront.

Safe lifting will also require suitable rigging arrangements, certified lifting points, slings, spreader beams or other attachment systems agreed with equipment suppliers and vessel owners. For technology demonstrations, the lifting plan may vary from project to project; therefore, the terminal should maintain a flexible laydown area, clear access routes and procedures for temporary lifting operations, while ensuring that lifting activities do not conflict with pedestrian movement, vessel access, charging equipment or other test activities.

Figure 5-1 Example of mobile crane equipment for vessel component handling. Source: www.liebherr.com

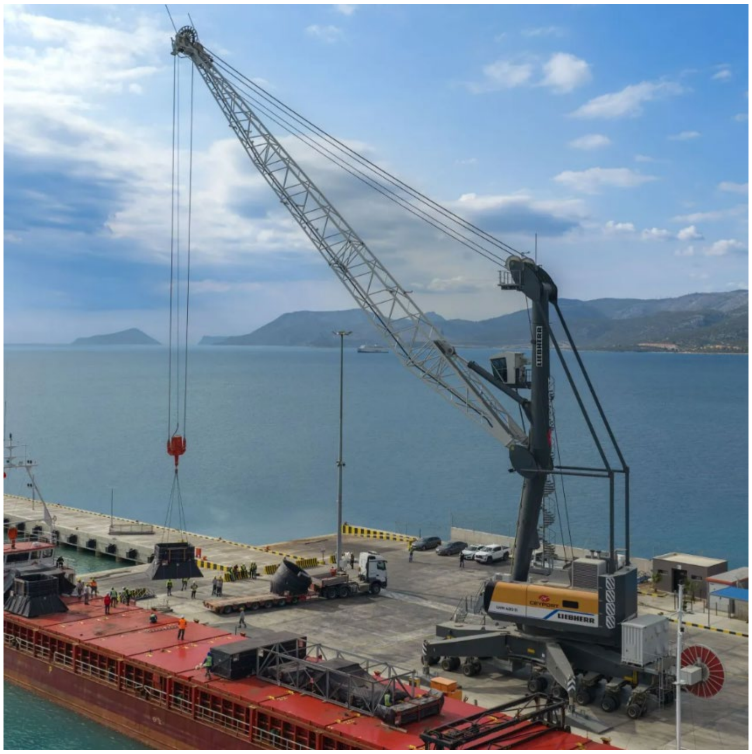


Figure 5-2 Example of lifting arrangement for vessel components using crane and rigging equipment. Source: www.liebherr.com

Overall, component handling can be supported in the first phase through mobile equipment, provided that the quay structure, apron layout and operational procedures are designed to accommodate crane set-up, laydown, vehicle access and safe lifting zones. Fixed lifting equipment should only be considered if repeated users, component weights and operational demand justify a more permanent investment.

5.2 Vessel launch and recovery systems

This section assesses practical options for moving smaller vessels from the water onto the quay or into an adjacent onshore retrofit area. The requirement is most relevant for demonstration vessels, workboats and prototype craft that are small enough to be handled outside a dry dock. Larger or heavier vessels would normally require floating or dry-dock solutions, as discussed in Section 5.3.

Three options are relevant at this planning stage: mobile crane lifting, a slipway and a boatlift. These options are not equivalent: a crane is best suited to occasional or project-specific lifts, a slipway is most appropriate where repeated vessel movements can justify the required waterfront footprint, and a boatlift provides a controlled vertical lifting solution that can be integrated with a dedicated transfer route to the retrofit area. The preferred solution should be selected once the vessel displacement range, beam, draft, lifting frequency, bathymetry, quay level and onshore workflow are confirmed.

5.2.1 Mobile crane lifting

A mobile crane could be used for occasional lifting of smaller vessels that approach the quay. This option provides flexibility during the first phase because the crane can potentially be rented when required and can also support component handling. However, crane lifting is only appropriate where the vessel weight, lift radius, rigging configuration, ground bearing pressure and quay load capacity are compatible. Vessel-specific lifting points, straps, spreader beams and certified lifting procedures would be required to avoid hull damage or damage to onboard equipment.

Figure 5-3 Example of mobile crane lifting arrangement for smaller vessels. Source: Alamy

5.2.2 Slipway

A slipway is a ramp extending from the shore into the water, allowing vessels to be moved between land and water either frontways or sideways. Slipways are simple and robust and can be suitable for repeated vessel movements. Typical gradients may vary from approximately 1:10 for very small vessels to 1:25 for very large vessels, depending on the vessel and transfer system. A sideways slipway may be more compatible with the available land area than a frontways slipway, which could occupy a significant portion of the lab facility area.

Preliminary dimensional checks indicate that a sideways slipway could become substantial in size. Assuming a 1:20 gradient and an approximate 18.2 ft elevation difference between deck level and dredged seabed level, the slipway length could exceed 380 ft. The indicative width could be approximately two times the maximum vessel beam, or around 66 ft.

Figure 5-4 Example of slipway arrangement for vessel launch and recovery. Source: Dreamstime

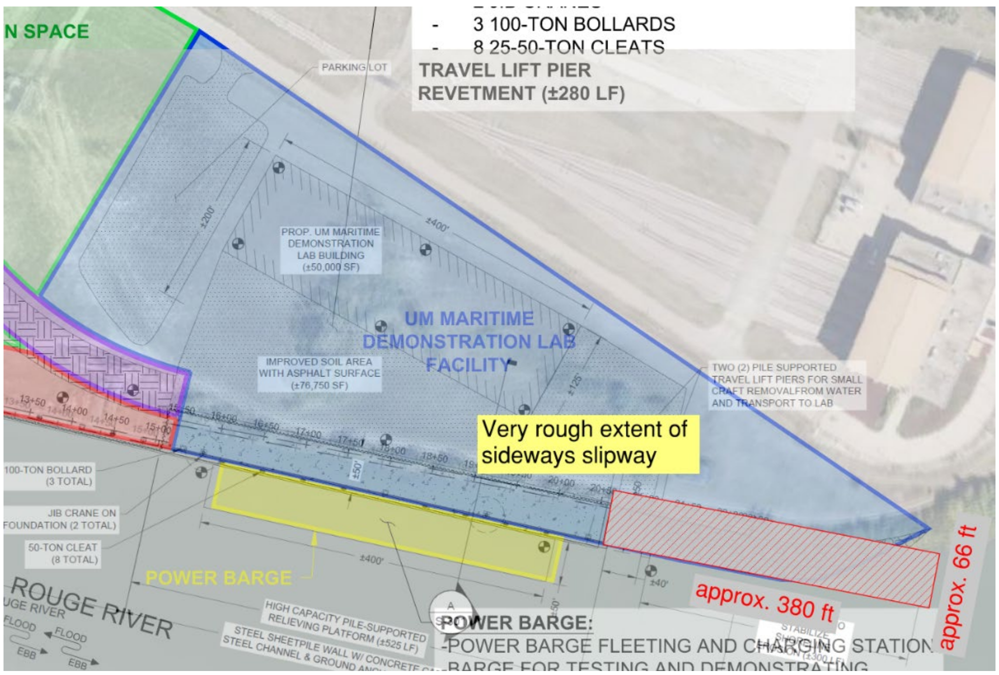


Figure 5-5 Indicative sideways slipway arrangement and required waterfront footprint

The Figure 5-5 illustrates the indicative footprint of a sideways slipway arrangement, showing the land and waterfront area required to transfer vessels between the water and the onshore retrofit area.

5.2.3 Boatlift vessel transfer

A boatlift consists of a structural lifting platform lowered into the water using synchronized hoists. The vessel is floated into position above the platform and then raised to quay level. This option provides a controlled and repeatable solution for lifting smaller vessels and may be particularly suitable if the terminal expects regular retrofit, inspection or demonstration vessel movements.

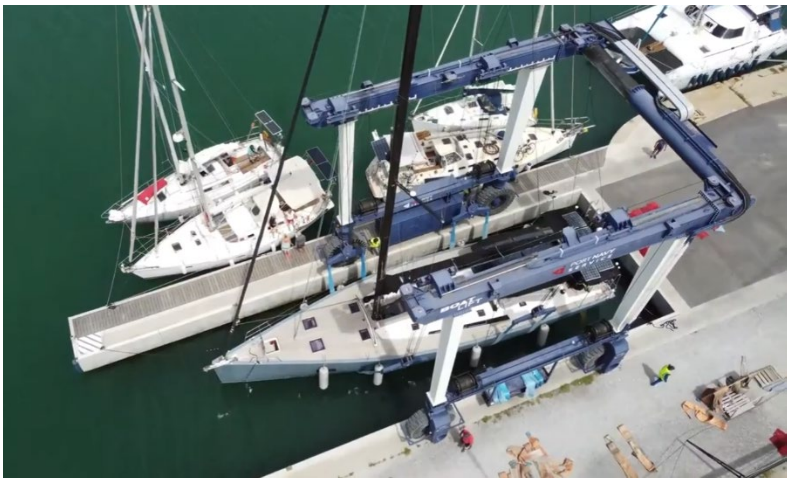


Figure 5-6 Example of vertical boatlift system for small and medium-sized vessels. Source: Boat Lift YouTube channel

Commercial boatlift systems are available across a broad range of capacities. The required capacity should be determined from the confirmed vessel displacement range, while the platform geometry should reflect expected vessel beam and hull forms. A stretchable hoist or variable-span arrangement may be relevant if the facility is expected to accommodate vessels of different sizes.

The main design implications differ by option. Crane-based lifting requires defined crane set-up areas, adequate outrigger support and sufficient lift radius from the quay edge. A slipway requires significant waterfront footprint, suitable gradients and integration with landside movement routes. A boatlift may require a dedicated recess or basin at the quay edge, structural support for the lifting system, local dredging or depth control, and a clear transfer route between the lift and the onshore retrofit area.

On balance, mobile crane lifting should be retained as a flexible first-phase option for occasional lifts, provided that quay capacity and certified lifting procedures can be confirmed. If repeated vessel lifting becomes a core terminal function, a boatlift is likely to offer the most controlled and operationally efficient solution, while a sideways slipway remains a possible alternative where the required waterfront footprint can be accommodated. The final selection should be coordinated with the quay structural design, bathymetry, vessel envelope, retrofit workflow and the desired level of permanence for the lifting system.

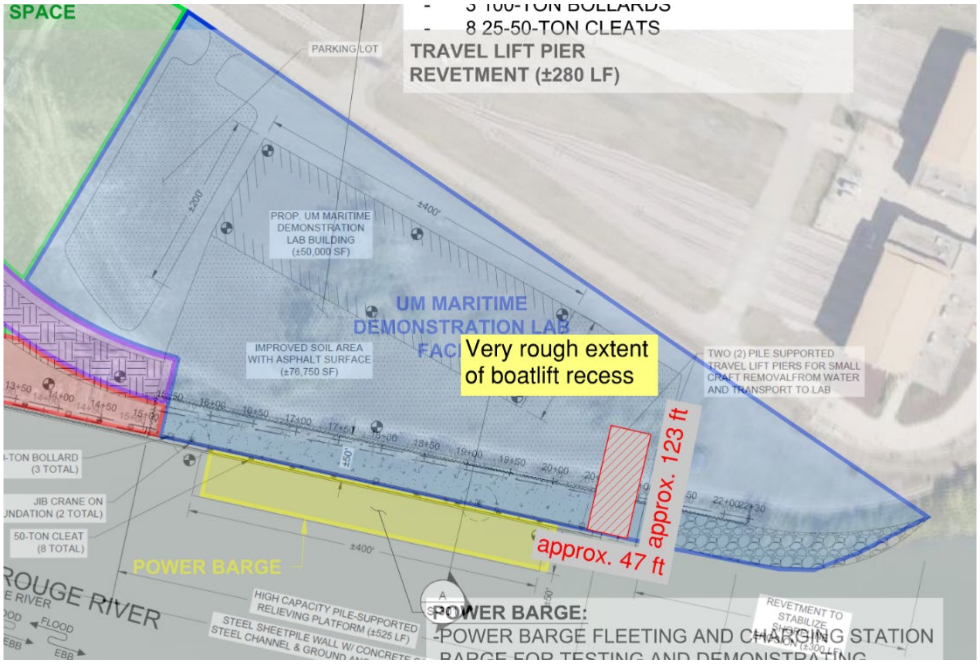


Figure 5-7 Example of variable-span boatlift arrangement for vessels with different beam requirements

The Figure 5-7 shows an example of a variable-span boatlift arrangement, where the lifting system can be adjusted to accommodate vessels with different beam widths and hull configurations.

5.3 Dry-dock solutions for retrofit works

Dry-dock solutions may be required where retrofit works cannot be performed alongside the quay or by lifting vessels onto land. This is mainly relevant for larger vessels, heavier retrofits, hull works, below-waterline inspections, propulsion conversions or works requiring controlled dry access to the hull.

For the Innovation Terminal, dry-dock infrastructure should be treated as a future capability rather than a first-phase requirement. The initial terminal concept is expected to focus on smaller demonstration vessels and retrofit activities that can be supported by mobile cranes, a boatlift, a slipway or alongside works. A dry dock would only be justified if confirmed users require regular dry access for larger or more complex vessels.

Two dry-dock concepts have been considered at a high level: a floating dry dock and a graving dry dock. A floating dry dock uses ballast tanks to submerge and raise the dock structure, allowing the vessel to enter while the dock is submerged and then be lifted clear of the water. A graving dry dock is a permanent basin structure built into the ground, fitted with a gate and dewatered after vessel entry.

A floating dry dock is considered the more realistic option for this project because it is less permanent, can potentially be relocated, and avoids the extensive civil works associated with a graving dock (Figure 5-8). By contrast, a graving dry dock would require major excavation, permanent structural works, a dock gate, dewatering systems and significant capital investment (Figure 5-9). For this reason, a graving dock is not considered suitable for the base terminal concept and has been ruled out at this stage.

Figure 5-8 Example of floating dry dock arrangement. source: Solis Marine

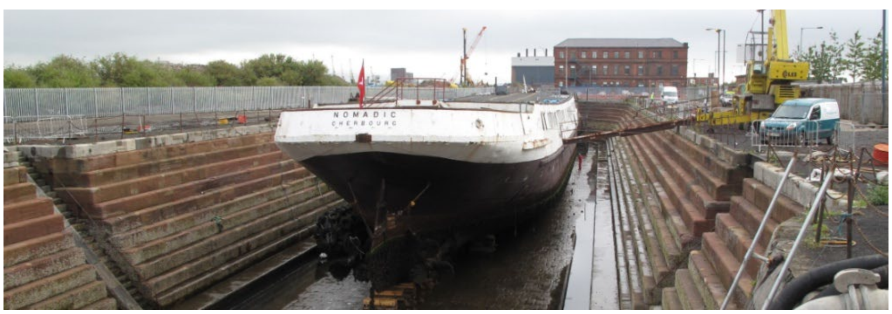


Figure 5-9 Example of graving dry dock arrangement at Belfast Harbour. Source: Doran Consulting

A floating dry dock could support larger or more complex retrofitting activities if sufficient water depth, mooring capacity, access arrangements and utility connections can be provided. It would offer more flexibility than a permanent dry dock and could potentially be sized around a defined vessel envelope; however, it would still require coordination with dredging, quay rehabilitation, mooring design and landside operations.

The water-depth requirement for a floating dry dock would be greater than the vessel draft alone, as it must account for the dock pontoons, support blocks, vessel draft, clearance for vessel approach and safe submergence. Based on the preliminary assumptions currently available, the required water depth could be in the order of approximately 25 ft, which is significantly deeper than the existing shallow-water conditions at parts of the proposed quay. Localized dredging would therefore likely be required if a floating dry dock is pursued.

Two operating concepts could be considered. The first is to perform retrofit works directly on the floating dry dock, which would require safe access, utilities, working platforms, lifting support and adjacent laydown space. The second is to use the floating dry dock mainly as a lifting platform, raising the vessel to deck level for transfer into an onshore retrofit area. This second concept would be more complex because it would require close coordination of dock elevation, quay level, transfer equipment, vessel supports and landside space.

The main quay and site design implications include mooring loads on the quay wall, safe personnel and vehicle access, utility connections, lighting, drainage, emergency access, equipment laydown and potential need for additional crane support. Dry-dock-mounted cranes may not be sufficient for all component lifts, particularly for heavier retrofit equipment, so a quay- or pier-mounted crane, or a mobile crane operating from a dedicated load zone, may still be required.

Operationally, a floating dry dock would occupy waterfront space and could limit simultaneous use of the quay for testing, charging, component handling or smaller-vessel activities. These interactions should be assessed before any dry-dock solution is included in the base layout.

Given the likely first-phase focus on smaller demonstration vessels, a floating dry dock should be preserved as a future option rather than included as a base-case requirement. It would become relevant if the terminal is expected to support larger vessels, repeated below-waterline works, intensive retrofit programs or users requiring controlled dry access to the hull.

Figure 5-10 Indicative floating dry dock images for a 1,000-ton capacity dock. Source: hegerdrydock.com

In summary, a floating dry dock is the only dry-dock concept considered potentially realistic for the Innovation Terminal, but it should remain a future-phase option linked to confirmed demand. It would require dredging, mooring design, quay wall coordination, access planning, utility provision and operational controls. A graving dry dock is not recommended due to its permanence, cost and civil works requirements. For the first phase, the terminal should prioritize mobile cranes, boatlift or slipway solutions for smaller vessels while preserving layout flexibility for a floating dry dock if future demand justifies it.

6. Testing of containerized systems and intermodal container handling

6.1 Role of container handling at the Innovation Terminal

The Innovation Terminal is unlikely to function as a conventional intermodal container terminal in the first phase. However, limited container-handling capability may be useful because many innovation systems are delivered in containerized or modular form, including battery systems, fuel skids, mobile charging units, power conversion equipment, laboratories, sensors and temporary workshop modules.

Activities at the terminal might include:

- moving containerized equipment to/from the terminal area (hard stands);
- moving containerized equipment to/from vessels at the quay side;
- testing containerized maritime technologies;
- supporting modular test skids;
- simulating intermodal logistics;
- demonstrating digital tracking, automation or sensor systems;
- supporting temporary project setups.

Potential test scenarios could include:

1. **Containerized technology modules**
    - battery containers,
    - BESS modules,
    - mobile charging units,
    - fuel-handling skids,
    - sensor and data-acquisition containers.
2. **Vessel-to-quay transfer tests**
    - loading/unloading containerized test equipment onto barges or workboats;
    - testing lifting procedures and interface with mobile cranes.
3. **Quay-to-rail or quay-to-road transfer**
    - small-scale demonstration of multimodal transfer;
    - testing rail spur usefulness;
    - road/yard handling with reach stackers, forklifts or mobile cranes.
4. **Digital logistics testing**
    - RFID/GPS/container tracking;
    - automated inventory;
    - customs/security simulation and port community system integration;
    - cargo visibility demonstrations.

5. **Training and demonstration**
    - operator training;
    - emergency response for containerized fuel/battery systems;
    - testing safety procedures for containerized hazardous or energy systems.

6.2 Rail spur option

It has been suggested to consider implementing option for intermodal container handling.

If a rail connection from the main rail line outside the terminal is established, and a rail spur is directed into the terminal, this might indeed be an option.

A rail spur along or near the quay could support intermodal demonstration activities, but it may also constrain quay flexibility, safety zones, crane operations and future vessel-handling layouts. Therefore, the rail alignment should be treated as an optional preserved corridor rather than a mandatory first-phase installation.

6.3 Infrastructure requirements

If to include the listed activities at the terminal, this will imply the following potential requirements:

- reinforced quay/apron area for mobile crane or reach stacker;
- defined container laydown area;
- road access for trucks;
- possible rail spur connection or protected rail corridor;
- container sockets/utility connections if using power modules;
- drainage and spill containment depending on container contents;
- separation from pedestrian/lab areas;
- clear traffic circulation;
- lighting, CCTV and security;
- data/power connections for smart-container testing.

6.4 Suitability and phased recommendation

In relation to potential phased implementation, the following are suggested:

Phase 1

- Use mobile crane / forklift / reach stacker;
- provide container laydown area;
- allow truck access;
- preserve space for rail spur if useful;
- avoid fixed container terminal equipment.

Phase 2

- Add rail spur only if confirmed users need rail-interface testing;
- consider dedicated container handling equipment if repeated demand exists;
- integrate with smart logistics, digital tracking, containerized energy systems or intermodal demonstrations.

7. Testing of alternative fuels

This chapter assesses the potential role of the Innovation Terminal in testing and validating alternative marine fuels. The purpose is not to define the terminal as a full-scale fuel production or bunkering hub, but to identify which alternative-fuel activities could be realistically accommodated within the site constraints, safety requirements, available waterfront, and phased development strategy.

The global maritime fuel transition remains at an early stage. Conventional fuel oil and diesel or gas oil still accounts for the vast majority of fuel consumed by larger ships, while alternative fuels are gaining momentum through vessel orders, pilot projects, regulatory development and port-readiness initiatives. Large players such as Maersk Lines and others have officially proclaimed that investments in new container vessels will be vessels that can run on alternative fuels.

For the Innovation Terminal, this means that alternative fuels should be treated as an important future-proofing opportunity, but not as the sole basis for first-phase infrastructure investment.

The relevant opportunity for the terminal is therefore not large-scale fuel production or commercial bunkering. Instead, the most suitable role is likely to be controlled testing, validation and demonstration of fuel-handling systems, bunkering procedures, safety management, emergency response, small-scale storage, vessel interfaces and port-readiness requirements.

This approach is consistent with the broader Innovation Terminal concept, which prioritizes flexible research and demonstration uses over high-volume cargo or fuel operations.

At this planning stage, the alternative-fuel assessment focuses on five main aspects: the maturity and suitability of different fuel pathways; the transfer and bunkering methods that could be used at pilot scale; the storage concepts required for testing; the safety distances and spatial implications associated with each fuel; and the phased role that alternative fuels could play in the terminal development plan.

7.1 Alternative fuel pathways and maturity

The fuels considered for the Innovation Terminal include biofuels, methanol, LNG or bio-LNG, ammonia, compressed gaseous hydrogen and liquid hydrogen. These fuels differ significantly in maturity, safety profile, storage requirements, transfer complexity and suitability for pilot-scale testing. Table 7-1 summarizes the relative maturity and implementation implications of each option.

Fuel Pathway	Storage State	Maturity	Complexity	Suitability - Recommended role at the Innovation Terminal
Biofuels (HVO, FAME)	Low Risk Liquid, ambient conditions	High drop-in/blended use commercially available (TRL 9)	Low can often use conventional liquid-fuel systems	High Near-term pilot candidate / Phase 1 compatible
Methanol fuel	Moderate Risk Liquid, ambient conditions	Medium - High increasing marine adoption (TRL 8–9)	Medium - High toxic and flammable, requires compatible materials and safety procedures	Medium - High Strong pilot candidate, subject to safety controls
LNG / Bio-LNG	Moderate Risk Cryogenic liquid	High emerging for bio-LNG supply (TRL 9)	High cryogenic storage, boil-off control and specialist transfer equipment	Medium - Low Conditional option; only confirmed user or demonstration program
Ammonia fuel	High Risk Refrigerated or pressurized liquid	Emerging marine fuel; limited port bunkering experience (TRL 5–7)	Very High toxic, corrosive and requires closed transfer systems	Low – for Phase1 Future research pathway only, subject to dedicated safety case
Compressed gaseous hydrogen	High Risk High-pressure gas	Emerging Emerging for small vessels and fuel-cell demonstrations (TRL 6-8)	Very High low energy density, high-pressure storage, leak detection and explosion controls	Medium – Low * Future research / small-scale fuel-cell testing only * for small demonstrations only
Liquid hydrogen	High Risk Cryogenic liquid	Early Stage for marine applications (TRL 4–6)	Very High cryogenic storage, boil-off control, specialist transfer and high capital cost	Not for Phase 1 Long-term research option; not recommended for Phase 1

Ramboll

Table 7-1 Alternative marine fuel pathways: maturity, operational considerations and suitability for pilot-scale testing

Note: TRL values are indicative and refer to marine fuel use, bunkering and port-handling readiness, rather than the general industrial maturity of the fuel or its production pathway.

The Table 7-1 indicates that biofuels and methanol are the most realistic near-term candidates for controlled testing at the Innovation Terminal. Biofuels are the least disruptive option because they can often be handled using conventional liquid-fuel infrastructure and may be used as drop-in or blended fuels. Methanol is more complex because it is toxic and flammable, but it remains a liquid fuel at ambient conditions and is increasingly relevant to the commercial vessel orderbook. LNG and bio-LNG are technically mature but require cryogenic systems, boil-off management and more specialized transfer equipment, making them less attractive as a first-phase innovation focus unless a specific user is confirmed.

Ammonia, compressed gaseous hydrogen and liquid hydrogen should be treated as longer-term or high-complexity options. Ammonia has potential as a future zero-carbon fuel pathway, but its toxicity and corrosiveness introduce substantial safety, permitting and emergency response requirements. Compressed gaseous hydrogen is relevant for fuel-cell demonstrations and short-duration testing, but its low volumetric energy density, high-pressure storage requirements and leak detection challenges limit its suitability for general vessel operations at this site. Liquid hydrogen is more compact than compressed gaseous hydrogen, but it introduces cryogenic storage, boil-off management and substantially higher technical complexity. These fuels may be appropriate for research partnerships, but only with a dedicated safety case and carefully controlled testing envelope.

7.2 Fuel handling and bunkering concepts

Alternative fuel testing may require controlled transfer of fuel from a supply source to a vessel, test skid or temporary storage system. At this stage, the most relevant bunkering concepts are truck-to-ship, shore-to-ship and ship-to-ship transfer (Table 7-2). Each concept has different implications for infrastructure permanence, safety controls, operational flexibility and space requirements.

Fuel	Truck-to-Ship	Shore-to-Ship	Ship-to-Ship	Mobile / Modular	Key limitation
Biofuels (HVO/FAME)	Full	Full	Full	Full	None (fully compatible)
Methanol fuel	Full	Full	Moderate	Full	Toxicity (requires controlled handling)
LNG / Bio-LNG	Limited	Full	Full	Limited	Cryogenic complexity
Ammonia fuel	Limited	Moderate	Not Available	Pilot Only	High toxicity, safety constraints
Hydrogen	Pilot Only	Limited	Not Available	Niche Only	Storage and transfer complexity

Table 7-2 Alternative fuel transfer systems and bunkering technologies applicable to pilot-scale testing

Truck-to-ship transfer is the most flexible concept for pilot-scale testing because it avoids early investment in fixed storage tanks and permanent pipework. It can support small fuel quantities and occasional test campaigns, provided that safe truck access, temporary exclusion zones, spill containment, emergency response arrangements and fuel-specific transfer procedures are established. This concept is most suitable for biofuels and methanol and may also support selected pilot activities for other fuels if delivered through certified specialist suppliers.

Shore-to-ship transfer using fixed or semi-fixed storage and transfer systems would only be justified if regular testing demand is confirmed. It would require dedicated fuel storage, pumps or compressors, transfer lines, emergency shutdown systems, detection systems and defined loading points. Ship-to-ship transfer using a bunker barge or specialist supply vessel could be considered as a future option, but it would introduce additional navigation, mooring and safety controls and is not recommended as the first-phase basis for the terminal.

Ship-to-ship transfer involves the delivery of fuel from a bunker vessel or barge directly to the receiving vessel. This approach minimizes the need for landside fuel infrastructure and can provide operational flexibility where suitable bunker vessels are available. However, it requires additional marine operations, berth management procedures, mooring arrangements and safety controls. For the Innovation Terminal, ship-to-ship transfer is unlikely to be warranted during the initial phase due to the expected low frequency of alternative-fuel testing activities. The concept may become relevant in the future if testing programmes expand or if third-party bunkering providers become available within the region.

Mobile and modular fuel systems comprise containerized storage units, portable transfer skids, mobile tanks and temporary fuel-handling equipment that can be deployed only when required for a specific test campaign. These systems offer a high degree of flexibility and can significantly reduce upfront infrastructure investment compared with permanent storage and transfer facilities. They are particularly attractive for innovation and demonstration environments where fuel types, testing requirements and user needs may change over time. Their main limitations include lower throughput capacity, operational setup requirements, temporary permitting considerations and the need to manage fuel deliveries for each individual test program.

Each fuel-transfer concept presents advantages and limitations. Truck-to-ship transfer offers maximum flexibility and the lowest infrastructure commitment, but it is generally suited to lower transfer frequencies and volumes. Shore-to-ship systems can support regular operations but require dedicated storage, transfer infrastructure and higher capital investment. Ship-to-ship transfer reduces reliance on landside facilities but introduces additional marine operational complexity, including berth management, vessel scheduling and mooring requirements. Mobile and modular systems provide the greatest adaptability for pilot-scale testing and innovation activities, although they may not be suitable for high-frequency or large-volume fuel operations. Consequently, a phased approach based on truck-to-ship transfer and mobile or modular systems is considered the most appropriate strategy for the initial development of the Innovation Terminal.

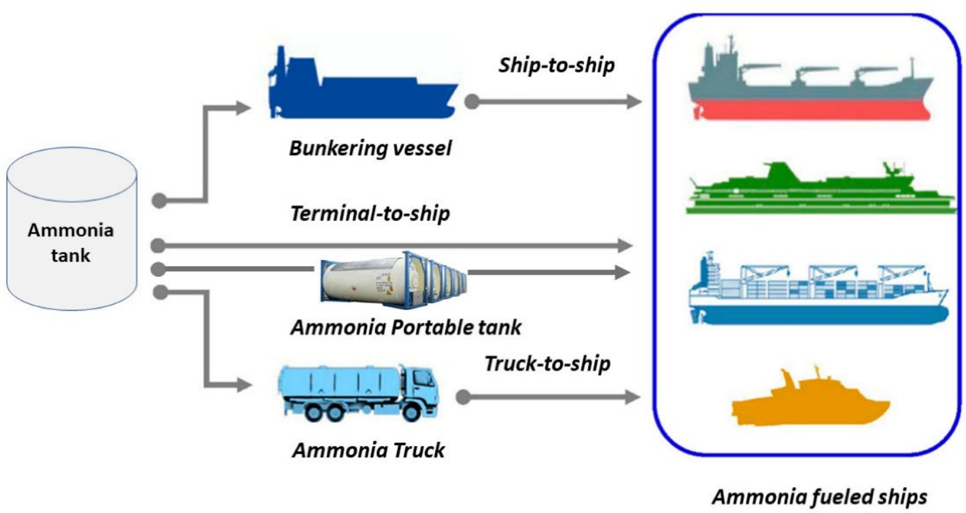


Figure 7-1 Conceptual ammonia transfer arrangements from storage to vessel

Figure 7-1 shows that ammonia bunkering can be configured through different transfer pathways depending on the location of the storage tank, the distance to the vessel, and the level of fixed infrastructure installed at the terminal. These arrangements may include direct transfer from a nearby storage tank, transfer through intermediate piping or loading equipment, or modular configurations where transfer components are deployed only for specific test campaigns. Although these concepts are technically feasible, ammonia transfer requires a higher level of control than conventional liquid fuels due to toxicity, vapour management requirements and the need for closed transfer systems.

7.3 Transfer systems and marine loading arms

Transfer systems are the interface between the fuel supply source and the receiving vessel. Depending on the fuel and transfer concept, these systems may include flexible hoses, marine loading arms, pumps, compressors, vapour return lines, emergency release couplings, leak detection, ventilation, grounding and bonding systems, and emergency shutdown controls. For the Innovation Terminal, the key issue is not only whether a transfer system is technically available, but whether it is compatible with pilot-scale testing, temporary deployment, safety requirements and the phased development strategy.

Fuel	Piping requirements	Hose type	Pumps / compressors	System type	Technical complexity	Primary risk drivers
Biofuels (HVO/FAME)	Standard (diesel-type)	Standard marine fuel	Conventional	Open	Low	Low Fire (low intensity)
Methanol fuel	Dedicated (material compatibility required)	Chemically resistant, sealed connections	Conventional (adapted materials)	Semi-closed	Medium	Medium Fire + toxicity
LNG / Bio-LNG	Cryogenic (insulated)	Cryogenic	Cryogenic	Closed	Medium - High	Medium - High Fire + explosion + cryogenic
Ammonia fuel	Pressurized or refrigerated, corrosion-resistant	Fully sealed, dry-disconnect	Specialized / compressors	Fully closed	High	High Toxicity dispersion
Hydrogen (compressed)	High-pressure	High-pressure	Compressors (no standard pumps)	Closed	Very High	Very High Explosion + fire
Hydrogen (liquid)	Cryogenic (-253°C)	Cryogenic	Cryogenic	Closed	Very High	Very High Explosion + cryogenic

Table 7-3 Comparison of transfer system requirements for alternative marine fuels

Alternative fuels impose different levels of complexity on transfer infrastructure. Biofuels and methanol can generally be handled through relatively mature liquid-fuel transfer systems, while LNG, ammonia, compressed gaseous hydrogen and liquid hydrogen require more specialized equipment and operational controls. This distinction is important because the Innovation Terminal is expected to operate as a flexible testing and demonstration facility rather than as a permanent commercial bunkering terminal.

The Table 7-3 shows that biofuels represent the lowest-complexity pathway. Existing oil-product transfer systems and marine loading arms can generally be used without substantial modification, and mobile truck or shore-based systems are widely available. This makes biofuels the most straightforward option for early-stage testing activities, particularly where the objective is to validate operational procedures, fuel logistics or vessel compatibility without major infrastructure investment.

Methanol requires additional safeguards compared with biofuels, including corrosion-resistant materials, sealed or closed-loop sampling devices, enhanced tank-cleaning procedures and ventilation at transfer points. However, methanol transfer technologies are commercially available, and modular truck or shore-based deployment appears feasible. Methanol therefore offers a practical balance between future fuel relevance and implementation complexity. It is more demanding than biofuels, but still compatible with a flexible pilot-scale testing environment if appropriate safety procedures and equipment are provided.

LNG and bio-LNG introduce a step change in infrastructure requirements. Cryogenic transfer systems, vacuum-jacketed or insulated equipment, vapour return systems, boil-off gas management and emergency release systems become necessary. Although LNG bunkering infrastructure is commercially mature, it is more complex and less flexible than liquid-fuel transfer systems. For the Innovation Terminal, LNG or bio-LNG should therefore only be considered where a specific user or demonstration program justifies the additional infrastructure and operational requirements.

Ammonia presents a different and more challenging risk profile. The primary constraint is not only flammability or cryogenic handling, but toxicity and vapour dispersion. Ammonia transfer requires fully closed systems, corrosion-resistant materials, dry-break couplings, detection systems, release recovery arrangements and dedicated safety procedures. The table indicates that mobile systems are currently limited to pilot deployments, with no commercial port availability. This suggests that ammonia could be relevant for future research partnerships, but it should not define the first-phase infrastructure unless a clearly scoped project and safety case are developed.

Compressed gaseous hydrogen and liquid hydrogen present the highest technical complexity among the fuels assessed. Compressed gaseous hydrogen requires specialized high-pressure connections, hydrogen-compatible materials, continuous leak detection and explosion-proof equipment. Liquid hydrogen introduces even more demanding requirements, including cryogenic systems operating at extremely low temperatures, vacuum-jacketed transfer arms, vacuum integrity monitoring and specialized emergency release systems. Because marine hydrogen transfer systems remain at pilot scale, both forms of hydrogen should be treated as longer-term research pathways rather than near-term base-case requirements.

Overall, Table 7-3 highlights that transfer-system maturity, equipment availability and infrastructure complexity vary significantly by fuel. Biofuels and methanol can generally be supported through commercially available technologies and mobile or modular deployment strategies, making them the most suitable fuels for early-stage testing at the Innovation Terminal. LNG may be feasible where a specific project justifies the additional complexity. Ammonia, compressed gaseous hydrogen and liquid hydrogen should be considered future research pathways requiring dedicated transfer systems, enhanced safety controls and clear operational justification before implementation.

For this reason, the first phase of the Innovation Terminal should avoid permanent marine loading arms, fixed pipelines or large dedicated fuel-transfer systems unless these are directly linked to confirmed demand. A more appropriate initial strategy would be to preserve space and operational flexibility for mobile transfer systems, temporary test skids, controlled truck-to-ship operations and project-specific transfer equipment. Permanent shore-to-ship systems should only be considered in a later phase if testing demand becomes regular and fuel-specific infrastructure can be justified.

Fuel	MLA availability OCIMF 4th ed. scope	Key requirements	Leak / vapour management	Regulatory reference	Mobile systems availability
Biofuels HVO / FAME	Standard Oil & oil products MLAs	No special requirements; compatible with existing oil-product infrastructure. ISO 8217:2024 permits blends up to 100% FAME with no MLA modification.	Standard drip trays; no vapour return required	ISO 8217:2024	High Truck and shore systems widely available
Methanol	Available (adapted) Chemical MLAs; material upgrade required	Corrosion-resistant materials (stainless steel / PTFE seals). Sealed / closed-loop sampling devices. Enhanced tank-cleaning procedures before bunkering. Ventilation systems at transfer points	Vapour return line recommended; sealed drip containment	IGF Code (MSC.1/Circ.1621); Singapore TR 85:2024	High Modular truck/shore deployment feasible
LNG / Bio-LNG	Standard cryogenic MLAs Explicitly covered in OCIMF 4th ed.; LNG bunkering arms normalised	Vacuum-jacketed / cryogenic insulation. Vapour return arm (mandatory). Emergency Release System (ERS / PERC). Cold-shock-resistant materials (−162 °C)	Boil-off gas (BOG) management system required; vapour return to shore or vessel	IGF Code; ISO 20519 (LNG bunkering); EN 1474-2	Medium Cryogenic mobile units available but limited
Ammonia	Specialised MLAs Covered in OCIMF 4th ed.; dedicated arms required	Fully closed systems — no open connections permitted. Corrosion-resistant alloys (no copper, zinc, or galvanised parts). Dual ERS with dry-break couplings. Ammonia detection at ≥25 ppm (local) and ≥110 ppm (global alarm). Dedicated safety exclusion zones	Released ammonia must be routed to recovery systems, scrubbers, or designated safe open-air locations — passive ERS alone is insufficient	IMO MSC.1/Circ.1687 (Dec 2024); IGC Code (ammonia cargo)	Medium Low Pilot deployments only; no commercial port availability
Hydrogen	HP gas arms Covered in OCIMF 4th ed. as high-pressure gas arms	High-pressure rated connections (≥700 bar for vehicle-scale; lower for marine). Hydrogen-compatible seals and materials (no embrittlement). Advanced leak detection (H_2 is odourless and colourless). Explosion-proof electrical components in transfer zone	Continuous H_2 detection mandatory; purge-and-vent sequence before disconnection	ClassNK Guidelines v3.0; ISO/CD 24132 (in development)	Low Pilot scale only; no commercial port infrastructure available
	LH_2 cryogenic arms ISO/CD 24132 under development; no finalised standard yet	Vacuum-jacketed cryogenic arms (−253 °C). Ortho-to-para hydrogen conversion management. Vacuum integrity monitoring during transfer. Specialised ERS for cryogenic conditions	Extreme cooling hazard; vapour clouds invisible — optical/catalytic detectors required	ISO/CD 24132 (pending); ClassNK Guidelines v3.0	

Table 7-4 Comparison of alternative fuel transfer and bunkering infrastructure requirements

Table 7-4 compares the principal transfer-system requirements for the alternative fuels considered in this assessment. The comparison highlights significant differences in technology maturity, infrastructure requirements, operational complexity and commercial availability between the fuels. These differences have a direct influence on the suitability of each fuel for pilot-scale testing and demonstration activities at the Innovation Terminal.

Overall, the comparison demonstrates that transfer-system maturity and infrastructure requirements vary significantly between fuels. Biofuels and methanol can generally be supported through commercially available technologies and mobile deployment strategies, making them the most suitable fuels for early-stage testing. LNG may be feasible where a specific demonstration project justifies the additional complexity, while ammonia, compressed gaseous hydrogen and liquid hydrogen should be treated as future research pathways requiring dedicated transfer systems, enhanced safety controls and a clear operational justification.

These findings support a phased implementation strategy in which initial testing activities are based on truck-to-ship transfer and mobile or modular systems, while permanent shore-to-ship infrastructure is only considered if future demand and fuel-specific requirements justify additional investment.

7.4 Fuel storage requirements for pilot-scale testing

Storage requirements depend on the fuel type, test duration, vessel energy demand and whether the terminal is intended to provide fuel continuously or only for discrete test campaigns. For the first phase, large permanent storage tanks are not recommended. Instead, the terminal should prioritize small-volume, temporary or mobile storage arrangements, combined with clearly defined operating procedures and emergency response controls.

Conventional storage systems would include fixed tanks, bunding or secondary containment, instrumentation, fire protection, detection systems, transfer pumps, pipework and access controls. These systems can be suitable where long-term demand is confirmed, but they reduce layout flexibility and may introduce permitting and safety-distance constraints that are disproportionate for early-stage innovation activities.

Table 7-5 provides indicative storage and spatial implications for the alternative fuels assessed in this study. The values and observations should be considered planning-level guidance only, as the actual safety zones will depend on fuel quantity, storage conditions, transfer method, local regulations, site-specific risk assessments and emergency response requirements. For the Innovation Terminal, these values are primarily intended to illustrate the relative spatial implications of different fuel pathways and their potential compatibility with adjacent testing and innovation activities.

Fuel	Pilot storage	Estimated total area including safety zone	% of site used	Energy content	Typical autonomy (R&D vessel)	Key insight	Viability for this site
Biofuels	10 – 100 m^3	300 – 1,000 m^2	< 1%	High	2 – 10 days	Most efficient and simple; drop-in solution	No space or regulatory barriers; recommended as primary fuel Fully Viable
Methanol	20 – 200 m^3	800 – 2,500 m^2	< 3%	Medium	2 – 8 days	Requires larger volume; toxic handling needed	Space not a constraint; safety zone and permits required Viable
LNG/ Bio LNG	40 – 100 m^3	500 – 2,000 m^2	1 – 3%	High volumetric energy content compared with gaseous fuels	2 – 5 days	Mature pathway, but requires cryogenic storage, boil-off control and specialist transfer equipment.	Feasible only if linked to a confirmed user or demonstration program Conditional
Ammonia	50 – 500 m^3	5,000 – 30,000 m^2	5 – 30%	Medium–high	3 – 12 days	Energy density adequate; safety the critical constraint	Space sufficient; viability depends on local regulation and safety permitting Conditional
Hydrogen (gas)	1,000 - 10,000 m3	1,000 – 5,000 m^2	1- 5%	Low	2 – 12 hours	Only suitable for short tests; low energy density	Space viable; autonomy too low for operational vessels — suitable for R&D Lab use only
Hydrogen (liquid)	5 – 50 m^3	3,000 – 10,000 m^2	3 – 10%	High	2 – 8 days	Complex but viable at scale	Space sufficient; −253 °C infrastructure and high capex— viable only as long-term R&D investment High Complexity

Table 7-5 Assessment of Minimum storage needed for testing of fuels

The Table 7-5 highlights that the spatial requirements associated with safety zones may be more limiting than the physical footprint of the storage or transfer infrastructure itself. In particular, ammonia, compressed gaseous hydrogen, liquid hydrogen and LNG are likely to impose greater operational constraints than biofuels or methanol due to their toxicity, flammability or cryogenic characteristics. The large difference between compressed gaseous hydrogen and liquid hydrogen storage volumes reflects the much lower volumetric energy density of compressed gaseous hydrogen compared with cryogenic liquid hydrogen; however, liquid hydrogen introduces substantially greater technical complexity and capital cost.

The storage assessment reinforces the phased strategy. Biofuels and methanol can be accommodated with relatively compact pilot storage and manageable safety controls. Compressed gaseous hydrogen, liquid hydrogen and ammonia may be physically possible within the site area at pilot scale, but their safety and permitting implications are likely to be the controlling factor. LNG and liquid hydrogen introduce additional cryogenic complexity and are therefore less suitable for early implementation unless linked to a specific demonstration partner.

7.5 Safety distances and spatial implications

Safety distances are likely to be one of the main constraints on alternative-fuel testing at the Innovation Terminal. The relevant safety zones will depend on the fuel, quantity, storage condition, transfer method, release scenario, wind conditions, ignition sources, nearby occupied buildings, emergency access and applicable regulations. For this reason, all safety distances in this chapter should be treated as indicative only.

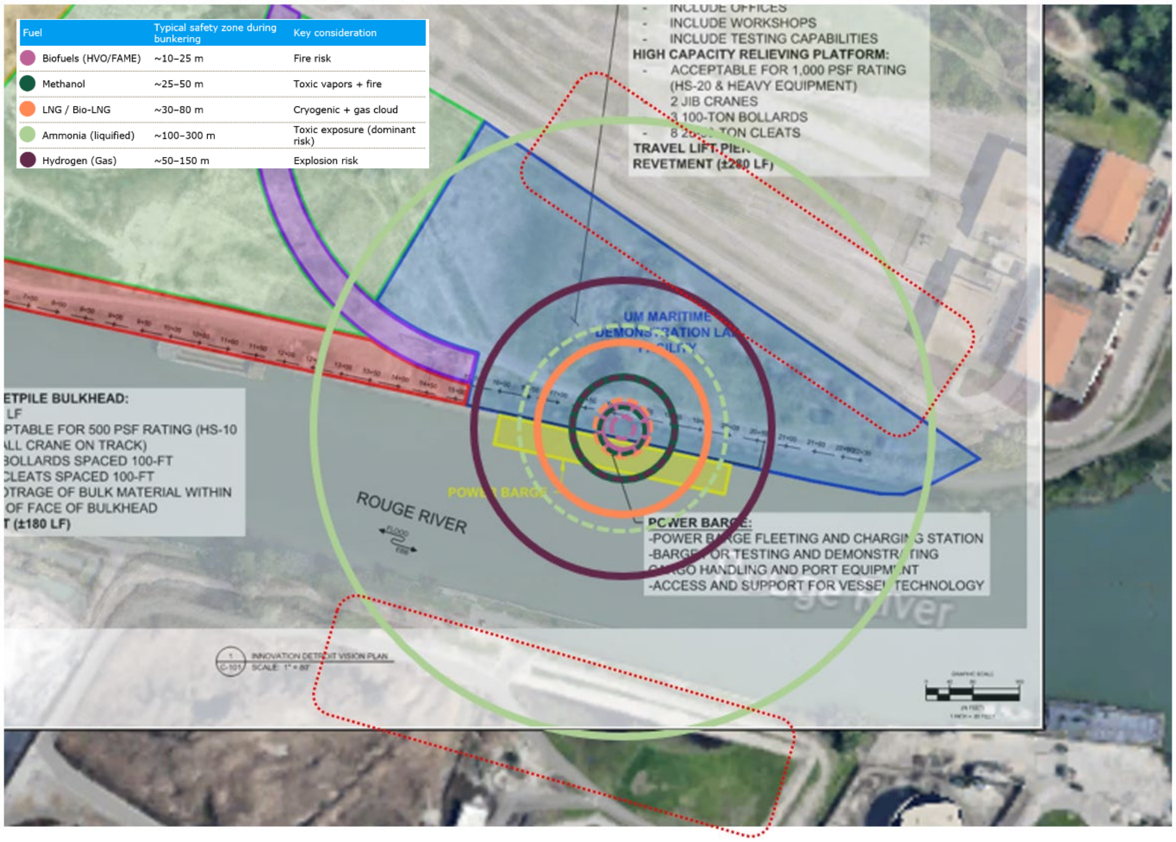
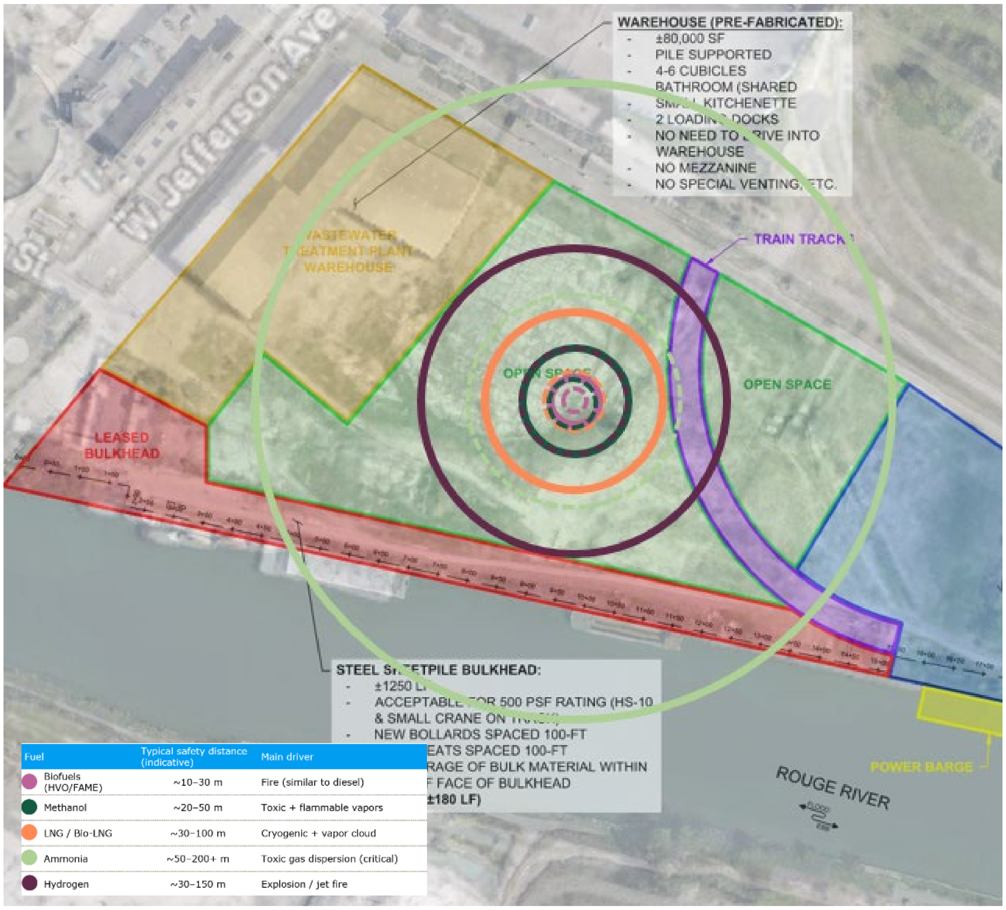


Figure 7-2 Indicative safety distances – Testing of alternative fuels Safety distance at fuel loading points

At the loading point (Figure 7-2), the principal planning issue is whether fuel transfer activities can be separated from laboratories, public access, routine quay operations and other simultaneous test activities. Liquid fuels such as biofuels and methanol are more compatible with compact terminal layouts, while LNG, ammonia, compressed gaseous hydrogen and liquid hydrogen require more stringent controls due to cryogenic, toxic or flammable hazards.



Fuel	Typical safety distance (indicative)	Main driver
Biofuels (HVO/FAME)	~10–30 m	Fire (similar to diesel)
Methanol	~20–50 m	Toxic + flammable vapors
LNG / Bio-LNG	~30–100 m	Cryogenic + vapor cloud
Ammonia	~50–200+ m	Toxic gas dispersion (critical)
Hydrogen	~30–150 m	Explosion / jet fire

Figure 7-3 Indicative safety distances – Storage tanks Safety distance at fuel storage

For storage areas (Figure 7-3), the safety zone rather than the tank footprint is likely to control the spatial requirement. Ammonia is expected to be the most challenging fuel from a site-planning perspective because toxic gas dispersion could extend beyond the immediate terminal area depending on quantity and release assumptions. Compressed gaseous hydrogen and LNG introduce explosion risks, while liquid hydrogen and LNG also introduce cryogenic hazards that require controlled layouts, ignition-source management and dedicated emergency response planning.

The implication for the Innovation Terminal is that alternative-fuel testing should not be located directly adjacent to personnel-intensive spaces unless the fuel, quantity and operating procedures are proven compatible through a formal safety assessment. If higher-risk fuels are retained as future options, the loading point and storage area should be located where exclusion zones can be managed without significantly disrupting quay access, vessel movements, emergency routes or adjacent innovation activities.

7.6 Suitability for the Innovation Terminal

Based on the assessment above, the most suitable near-term fuel pathways for the Innovation Terminal are biofuels and methanol. Biofuels provide a low-complexity entry point for fuel testing and can support demonstrations linked to drop-in or blended fuels. Methanol offers a more strategically relevant alternative-fuel pathway, with increasing commercial interest and manageable storage conditions compared with cryogenic or highly toxic fuels, but it still requires dedicated safety procedures, leak detection, ventilation and emergency response planning.

LNG and bio-LNG are technically mature and commercially established, but their cryogenic storage and transfer requirements make them less aligned with a flexible innovation-terminal concept unless a specific user or demonstration program is confirmed. Ammonia, compressed gaseous hydrogen and liquid hydrogen should be preserved as future research opportunities only. These fuels may be valuable for selected trials, but their safety, permitting, storage and emergency response requirements are too significant to justify fixed first-phase infrastructure without confirmed demand.

7.7 Recommendations for phased development

For Phase 1, the terminal should enable alternative-fuel readiness through flexible and low-regret infrastructure. This may include reserving an area for temporary fuel transfer operations, providing safe vehicle access for fuel delivery trucks, allowing for temporary exclusion zones, planning spill containment and drainage controls, and ensuring that the quay layout can accommodate mobile transfer skids, hoses, monitoring equipment and emergency response access. Permanent tanks, pipelines and marine loading arms should not be included in the base case unless supported by confirmed users and permitting requirements.

For Phase 2, fixed or semi-fixed alternative-fuel infrastructure could be considered if a specific fuel pathway, vessel user, operating frequency and business case are confirmed. The key triggers for advancing this investment should include confirmed demand, a completed safety case, local permitting acceptance, defined fuel quantities, emergency response planning, suitable separation distances, compatible quay and mooring arrangements, and confirmation that the infrastructure will not compromise the broader innovation function of the site.

In summary, alternative fuels should be incorporated into the Innovation Terminal as a future-proofing and controlled testing capability rather than as a first-phase commercial bunkering function. Biofuels and methanol are the most realistic near-term candidates for pilot-scale testing. LNG, ammonia, compressed gaseous hydrogen and liquid hydrogen should remain possible future options, but only under defined test campaigns or partnerships with sufficient safety controls, permitting support and operational justification. This approach preserves the terminal’s flexibility while allowing Port Detroit to participate in the maritime fuel transition as market demand and regulatory certainty increase.

8. Electrification of vessels – test of powering facilities

This chapter assesses the potential role of vessel electrification at the Innovation Terminal, with focus on powering facilities, charging concepts, Great Lakes relevance and planning implications. The assessment considers electrification as a testing and demonstration opportunity rather than as a first-phase commercial charging hub.

8.1 Characteristics – powering facilities for electrified vessels

Vessel electrification is increasingly relevant for short-route, predictable and high-frequency maritime operations, including ferries, harbor craft, workboats and tugboats. For the Innovation Terminal, the main opportunity is not to develop a full commercial charging hub in the first phase, but to provide a flexible testing environment for vessel charging, battery systems, shore-power interfaces, cable management solutions, Battery Energy Storage Systems (BESS) and retrofit-oriented electrification activities.

Battery-electric vessels are most suitable where operating profiles are predictable and charging can be planned around regular port calls. This makes ferries, tugboats and port service vessels useful reference cases for the Innovation Terminal. These vessel types typically operate over defined routes or within confined port areas, allowing battery capacity, charging duration and shore-side power requirements to be matched to the operating cycle.

Electric vessels are generally supplied from shore either through conventional shore-power connections, dedicated vessel chargers or higher-power charging towers. Depending on the vessel and operating profile, charging may be provided directly from the grid or supported by a BESS, which can reduce peak grid demand and provide greater flexibility where grid capacity is constrained.

A fixed charging tower is typically designed around a specific vessel geometry, berth position, charging interface, power demand and turnaround time. This can be appropriate for ferry terminals or dedicated tug berths, but it is less suitable for an innovation facility expected to host different vessels with varying dimensions, battery capacities, connection points and charging standards. The Innovation Terminal should therefore prioritize a mobile and adaptable charging concept during the first phase.

The feasibility of fast charging will depend strongly on available grid capacity, connection voltage, peak power demand, charging duration and the number of vessels that may need to charge simultaneously. If the grid capacity is limited, the terminal should avoid committing to high-power rapid charging as a base-case requirement. Instead, the first phase should focus on grid-readiness, BESS integration, mobile charging equipment, vessel battery testing, propulsion-conversion support and space reservation for future charging upgrades.

Figure 8-1 Example of shore-side charging concept for electric vessels

Source: https://www.baumueller.com/en/industries/shipbuilding/charging-systems

8.2 Examples of electric tugboats and ferries

Tugboats

Electric tugboats are a relevant reference case because they operate within ports and controlled waterways, often with predictable duty cycles and regular return-to-base charging opportunities. Current electric tug designs demonstrate that high bollard-pull harbor operations can be supported by battery systems, provided that charging power, berth availability and operating schedules are coordinated.

Reference examples include Svitzer Ingrid and Damen RSD Tug 2513 Electric

Indicative battery capacities for current electric tugboat examples range from approximately 1,800 kWh to 2,800 kWh, with bollard pull in the order of 70 tonnes. These values illustrate that electric tug charging can require substantial power, but also that the vessels are typically charged at dedicated berth locations with known operational patterns.

For the Innovation Terminal, these tugboat examples are most relevant as reference cases for testing charging interfaces, BESS-supported charging, battery retrofit packages and operational procedures rather than as direct design vessels for a fixed charging tower.

Figure 8-2 Examples of battery-electric tugboats

Source: https://workboat365.com/her-majesty-queen-mary-names-denmarks-first-electric-tug/ & https://medialibrary.damen.com/m/77f42872a6013e58/original/product-sheet-rsd-tug-2513-electric.pdf

Ferries

Fully electric ferries are becoming increasingly common on short, high-frequency routes where the charging location, turnaround time and vessel duty cycle are well defined. Ferry applications are therefore useful for understanding high-power charging requirements, automated connection systems and the role of grid upgrades or BESS in supporting rapid turnaround operations.

Reference example: high-capacity electric ferry applications

Large electric ferry projects can involve battery capacities well above those expected for small research or workboat applications. Such examples are useful for benchmarking future high-power charging requirements, but they should not define the first-phase design basis for the Innovation Terminal unless a specific ferry or vessel operator is confirmed.

Figure 8-3 Example of a battery-electric ferry application

Source: https://www.maritimedanmark.dk/forste-billeder-af-molslinjens-ny-el-hurtigfaerger

8.3 Potential on the Great Lakes

Tugboats

Tugboats are used daily throughout the Great Lakes to support docking, towing and maneuvering commercial vessels in ports, locks and confined waterways. Their operating profile makes them a potential candidate for electrification, particularly where vessels return regularly to a home berth and can be charged between assignments.

For Port Detroit, tugboat electrification is relevant because the Rouge River and Detroit River remain active working waterfront corridors where harbor craft and support vessels are essential to marine operations. The Innovation Terminal could support this transition by providing a controlled environment for testing charging equipment, battery retrofit concepts, operational procedures and shore-side power interfaces for port service vessels.

Figure 8-4 Great Lakes Towing Company service ports across the Great Lakes

Source: https://thegreatlakesgroup.com/the-great-lakes-towing-company

Figure 8-4 shows the ports across the Great Lakes where The Great Lakes Towing Company has an operational presence. The company serves more than 40 U.S. ports with tugboats, indicating a broad regional network of harbor tug activity. This network is relevant because tugboats often operate on local duty cycles and return to defined berths, making them potential candidates for future battery-electric or hybrid-electric retrofits. For the Innovation Terminal, this creates an opportunity to test charging interfaces, battery retrofit concepts and operational procedures for future electric harbor craft.

Ferries

Several ferry routes across the Great Lakes region have characteristics that make electrification technically relevant, particularly short crossings with predictable schedules. The Mackinac Island ferry conversion is an important regional example because it demonstrates that vessel electrification and shore-side charging upgrades are already being considered within the Great Lakes context.

The relevance for the Innovation Terminal is not necessarily to serve as a regular ferry charging terminal, but to support technology validation for short-route electric vessels, battery retrofits, charging interfaces and shore-power readiness. These activities align well with the terminal’s broader role as a test and demonstration platform.

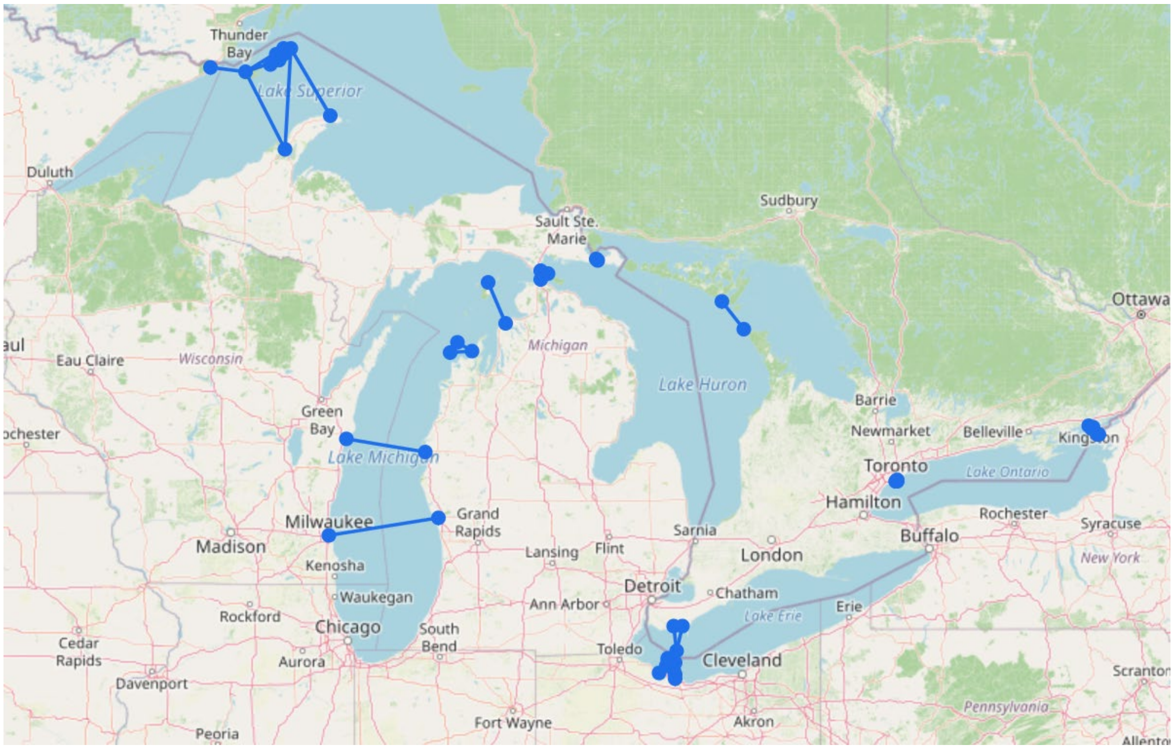


Figure 8-5 Great Lakes ferry routes with potential relevance for future electrification

Source: https://ferrygogo.com/ca/regions/great-lakes/

Figure 8-5 shows ferry operating areas across the Great Lakes region. Many ferry routes involve short, predictable crossings with regular return-to-terminal operations, making them potentially suitable for future battery-electric or hybrid-electric applications. For the Innovation Terminal, these routes provide useful reference cases for testing charging interfaces, battery systems, shore-power readiness and operational procedures for short-route electric vessels.

8.4 Charging concepts

Conventional vessel charging in ports is often provided through a fixed charging tower or dedicated shore-side connection point located at a specific berth. This arrangement can work well for vessels with predictable berth positions and standardized connection arrangements, such as ferries or dedicated tugboats.

For the Innovation Terminal, a fixed tower should not be the preferred first-phase solution because the site is expected to host different vessel types, geometries, charging sockets and battery capacities. A mobile charging arrangement is more appropriate because it can be adapted to different berth positions and test campaigns without creating a permanent obstruction on the quay.

Mobile charging concepts may include shore-side power sockets combined with mobile cable management systems (CMS), movable connection units, containerized power conversion equipment and, where needed, BESS modules. The shore-side electrical infrastructure can be designed to provide connection points along the quay, while the mobile CMS is deployed only when a vessel requires charging.

When not in use, mobile CMS units can be stored away from the quay edge, reducing interference with other research, lifting, vessel access or testing activities. However, one CMS may only be compatible with a specific cable type, voltage level or connector arrangement. Several CMS units may therefore be required if the terminal is intended to support a broad range of vessels and charging standards.

Connection points can be installed in trenches, service pits or protected quay-side socket locations, or provided through movable equipment positioned along the quay face. The preferred arrangement should be selected based on expected charging frequency, vessel berthing positions, cable reach, quay operations, maintenance access and the cost of installing electrical infrastructure in new versus existing terminal areas.

The main advantage of a mobile concept is that it preserves quay flexibility. The terminal can support charging tests while avoiding a permanent charging tower that may interfere with crane operations, vessel access, alternative-fuel testing, component handling or future layout changes. The trade-off is that higher flexibility may require additional CMS units, standardized operating procedures and careful coordination of charging equipment storage and deployment.

Figures 8-6 to 8-9 present reference examples of vessel charging and cable management arrangements. They illustrate the range of possible solutions, from dedicated berth-based charging to mobile or semi-mobile systems that can be adapted to different vessels and quay locations. For the Innovation Terminal, the key planning consideration is to preserve flexibility while enabling controlled charging tests and future upgrade options.

Figure 8-6 illustrates an example of a dedicated charging arrangement for an electric tugboat. The example shows how vessel charging can be integrated at a berth through a controlled cable management system and shore-side connection. For the Innovation Terminal, this type of arrangement is relevant as a reference for tugboat or workboat charging trials, but it should not be interpreted as the preferred first-phase solution unless a specific vessel, berth position and charging interface are confirmed.

Figure 8-6 Dedicated berth-based charging arrangement for the electric tugboat eWolf, Port of San Diego

Source: Photo courtesy of supplier Igus

Figure 8-7 shows a cable management system connected to trenched shore-side sockets. This concept allows electrical connection points to be integrated into the quay or terminal surface while keeping cable routing organized and protected during charging operations. For the Innovation Terminal, this arrangement could support flexible charging at defined berth positions.

Figure 8-7 Cable management system connected to trenched shore-side sockets

Source: Photo courtesy of supplier Igus

Figure 8-8 shows a cable management system connected to a mobile installation positioned along the quay face. Compared with fixed trenched sockets, this arrangement offers greater deployment flexibility and may be better suited to an innovation terminal where different vessels, berth positions and charging interfaces are expected. The concept could reduce permanent quay obstruction, but it would require space for equipment storage, safe deployment procedures and compatibility with the selected vessel charging standards.

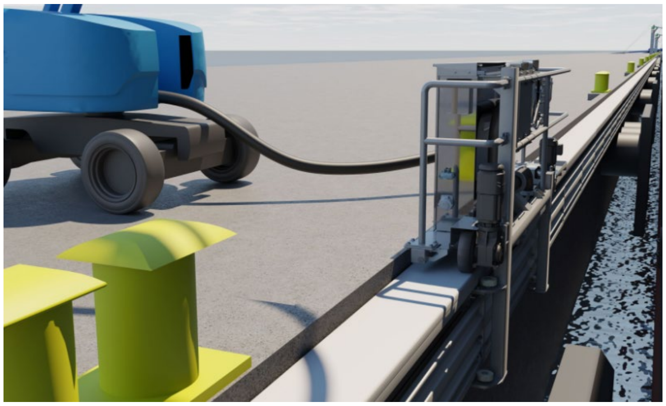


Figure 8-8 Cable management system connected to a mobile quay-side installation

Source: Photo courtesy of supplier Igus

Figure 8-9 shows an example of quay-side electrical infrastructure at Copenhagen Port. It illustrates how charging equipment and cable management can be integrated into an active port environment while preserving operational access. For the Innovation Terminal, this provides a useful reference for planning mobile or semi-mobile charging arrangements, protected connection points and clear cable routing along the quay.

Figure 8-9 Example of quay-side electrical charging infrastructure at Copenhagen Port

8.5 Impact on port planning

The recommended approach is to adopt mobile and flexible charging readiness for the first phase of the Innovation Terminal. This would allow the site to support electrification research and vessel-charging demonstrations without committing prematurely to a fixed charging tower or a single vessel interface. The concept also allows the quay to remain available for other innovation activities when charging is not taking place.

Design considerations

Key design considerations include available grid capacity, maximum charging power, expected charging duration, vessel battery capacity, berth position, connector type, cable handling method, BESS requirements, equipment storage, emergency access and compatibility with other quay activities. These parameters should be confirmed before selecting a fixed charging system or defining permanent electrical infrastructure.

Grid connection requirements are expected to be similar for both of the presented mobile concepts.

In the next phase, specific power requirements and design vessels should be identified to determine whether the terminal should provide only low-to-medium power testing capability, BESS-supported charging, or a future high-power charging connection. Standardization should be pursued where practical, but the layout should avoid assuming that all future vessels will use the same charging interface.

For Phase 1, the terminal should reserve space and utility corridors for mobile charging equipment, provide protected shore-side electrical connection points where practical, allow for future BESS placement and ensure that quay operations can accommodate temporary charging zones. For Phase 2, fixed high-power charging infrastructure should only be considered if a confirmed user, vessel type, charging frequency, battery capacity and grid connection requirement justify the investment.

Overall, the Innovation Terminal should be designed for electrical readiness rather than fixed high-power charging from the outset. The preferred first-phase approach is to provide protected shore-side connection points, utility corridors, space for mobile charging and cable management equipment, and optional BESS integration. Fixed high-power charging infrastructure should only be advanced in a later phase once vessel users, charging frequency, battery capacity, grid connection requirements and operating procedures are confirmed.

9. Development Plan

The development plan for the Innovation Terminal should be based on a phased implementation strategy. The purpose of phasing is to establish a practical and flexible first phase that can support near-term research, testing, retrofitting and demonstration activities, while preserving future options for more capital-intensive infrastructure if users, funding and technical requirements are confirmed.

Phase 1 should be understood as the base case development. It should provide the minimum viable terminal infrastructure needed to activate the site as an innovation platform, without prematurely committing to deep dredging, fixed high-power charging, permanent alternative-fuel infrastructure, large-vessel access or full intermodal terminal functions if a clear need for these investments is not defined. Phase 2 should be treated as a set of optional expansions that can be advanced only where confirmed demand, technical justification, permitting feasibility and funding support the investment.

This section of the report sets out the suggested development contents in the two phases, and how they are aligned, ensuring flexibility and optimized investments.

9.1 Development strategy

The recommended strategy is to avoid overbuilding the terminal before priority users, design vessels and operating requirements are confirmed. Instead, the first phase should focus on adaptable infrastructure that can support different research and demonstration activities with mobile equipment, modular systems and reserved utility corridors. This approach reduces early capital risk while keeping the site capable of evolving toward more specialized functions in later phases.

The phasing strategy should also distinguish between infrastructure that is required to activate the terminal and infrastructure that should be preserved as a future option. The base case should therefore include the lab, the new quay and the essential landside areas needed for vessel access, component handling, retrofitting, mobile charging and modular testing. More specialized elements, such as dredging to deeper levels, fixed alternative-fuel systems, permanent marine loading arms, floating dry dock facilities, a rail spur or fixed high-power charging, should only be advanced if clear triggers are met.

9.2 Phase 1 – base case development

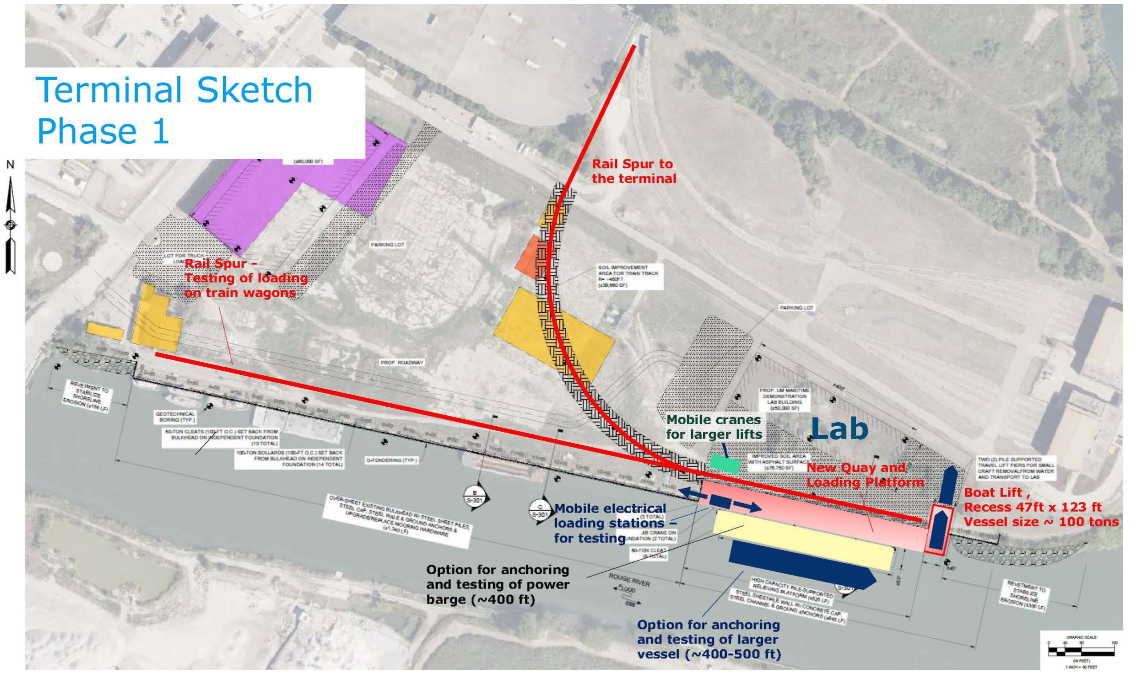


Figure 9-1 Terminal Sketch Phase 1

Phase 1 should establish the operational platform for the Innovation Terminal. It should be designed as a flexible base case rather than a reduced version of all future possibilities. These are recommended to include the following:

- Innovation lab and supporting landside facilities;
- new approximately 500–525 ft quay in front of the lab;
- quay apron and defined crane loading zones for mobile handling equipment;
- berthing capability for smaller demonstration vessels, workboats, barges and floating test platforms;
- recess or interface for a boatlift if vessel launch and recovery is retained as a first-phase function;
- laydown and retrofit areas for components, modules and temporary test equipment;
- truck access, circulation space and temporary equipment storage;
- containerized technology module laydown area;
- basic shore-side electrical readiness, including protected connection points where practical;
- reserved utility corridors for future power, data, charging and fuel-related upgrades;
- space allowance for mobile charging equipment, cable management systems and potential BESS modules;

- basic data and communications infrastructure to support testing, monitoring and digital maritime activities.

Phase 1 should support smaller research vessels, demonstration vessels, component handling, retrofit works, mobile vessel electrification trials, digital maritime technologies, autonomous or sensor-based testing, containerized systems and limited low-risk pilot-scale fuel activities where safety requirements can be managed. The phase should not assume full-depth dredging, permanent fuel tanks, fixed pipelines, fixed high-power charging towers, marine loading arms, dry dock infrastructure or full commercial container terminal equipment as base-case requirements.

A rail corridor may be preserved if it can be accommodated without compromising the quay layout, crane movements, safety zones or future vessel-handling arrangements. However, a rail spur should not be included as a mandatory Phase 1 installation unless a confirmed user requires rail-interface testing or intermodal demonstration activities.

9.3 Phase 2 – potential expansion

Phase 2 should be considered a set of possible infrastructure upgrades that can be implemented if the terminal secures users, funding and technical justification for more specialized operations.

Therefore, potential Phase 2 elements may include rehabilitation or reconstruction of the existing western quay, dredging to accommodate larger or deeper-draft vessels, longer berth availability, floating dry dock capability, fixed or semi-fixed alternative-fuel testing areas, dedicated fuel storage or transfer systems, larger safety-zone planning, a rail spur for intermodal demonstration, fixed high-power vessel charging, grid upgrades, expanded BESS capacity and dedicated container-handling equipment if repeated demand is confirmed.

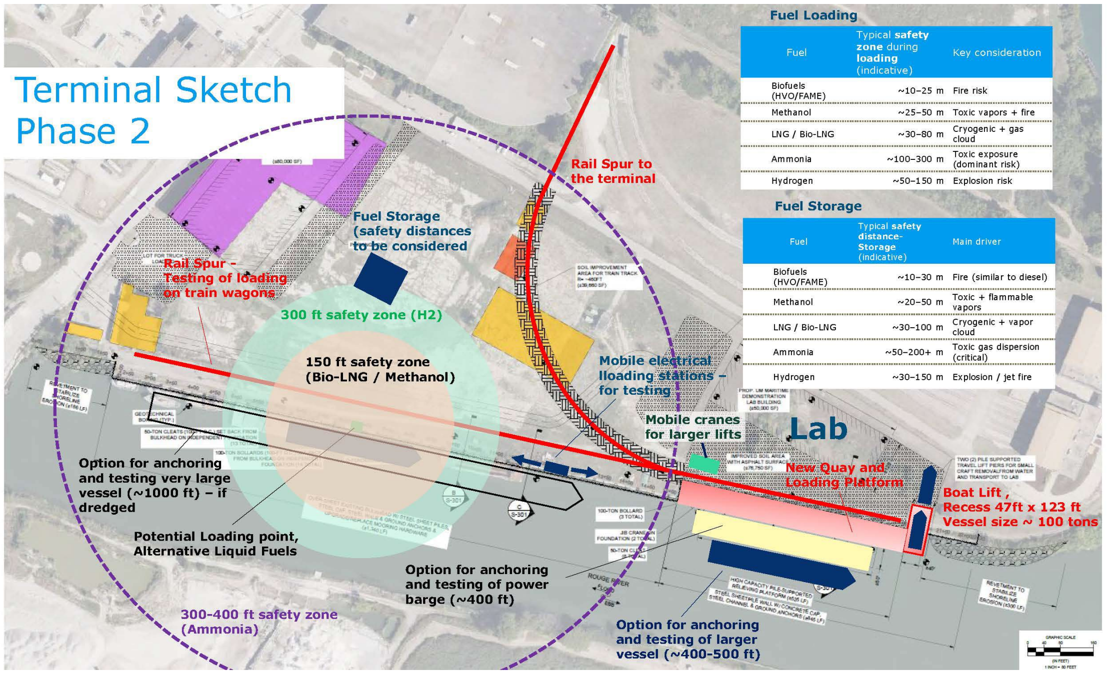


Figure 9-2 Terminal Sketch Phase 2

For alternative fuels, Phase 2 should preserve the possibility of more advanced testing, but only where the required safety case, separation distances, emergency response arrangements, permitting pathway and user demand are confirmed. Higher-complexity fuels such as ammonia, compressed gaseous hydrogen and liquid hydrogen should remain future research pathways unless a dedicated demonstration partner and project-specific safety case are established.

For electrification, Phase 2 may include fixed high-power charging infrastructure if vessel users, charging frequency, battery capacity, berth position and grid connection requirements are defined. Until these conditions are confirmed, the terminal should rely on mobile or semi-mobile charging readiness and reserved utility corridors rather than fixed charging towers.

For vessel access, dredging should be advanced only if a confirmed design vessel requires additional depth and if the associated quay wall, sediment management, permitting and maintenance dredging implications are acceptable. Larger-vessel access should therefore be treated as a trigger-based expansion, not as the default Phase 1 basis.

Should not rule it out, and it might be possible – but with some restrictions.

9.4 Future-proofing and interfaces between phases

Phase 1 should be designed so that Phase 2 can be implemented without major rework. This requires preserving corridors for future utilities, avoiding permanent obstructions in potential rail or charging alignments, locating early infrastructure so that future dredging or quay rehabilitation remains possible, and maintaining flexible quay and landside areas for future equipment, fuel and electrification functions.

Where cost-effective, the Phase 1 structural and utility design should allow future upgrades, including increased power capacity, additional data infrastructure, BESS integration, mobile crane loading zones, future fuel-transfer areas and possible connection to rehabilitated quay areas. However, future-proofing should not mean constructing all future infrastructure upfront. The objective is to avoid blocking later options while still maintaining a realistic and affordable base case.

The layout should also manage the interaction between different innovation activities. Alternative-fuel testing, vessel charging, crane operations, boatlift activities, containerized module handling, truck circulation and pedestrian access may all compete for space. The Phase 1 plan should therefore rely on flexible operating zones and temporary exclusion areas rather than fixed single-purpose areas wherever possible.

9.5 Summary development plan and decision triggers

Table 9-1 summarizes the recommended development logic for Phase 1 and Phase 2. The table distinguishes between base-case infrastructure that should be included to activate the Innovation Terminal and optional expansion elements that should be advanced only if supported by clear decision triggers.

Table 9-1 Summary development plan for Phase 1 and Phase 2

Function	Phase 1 base case	Phase 2 potential expansion	Decision trigger
Vessel access	Smaller demonstration vessels, workboats, barges and floating test platforms	Larger or deeper-draft vessels	Confirmed design vessel and operating draft
Quay infrastructure	New approximately 500–525 ft quay and flexible quay apron	Rehabilitation or reconstruction of existing western quay	Need for longer berth or larger vessel operations
Dredging	Avoid full-depth dredging unless required for selected vessels	Targeted or full-depth dredging if justified	Confirmed depth requirement, sediment strategy and permits
Handling and retrofits	Mobile crane, laydown area and possible boatlift interface	Floating dry dock or heavier dedicated handling systems	Repeated demand for larger or below-waterline retrofit works
Electrification	Mobile charging readiness, protected shore-side connections and BESS-ready space	Fixed high-power charging and grid upgrade	Confirmed vessel user, charging frequency and power demand

Alternative fuels	Temporary or mobile low-risk testing arrangements only	Fixed or semi-fixed fuel storage and transfer systems	Confirmed fuel pathway, safety case and permitting route
Containerized systems	Containerized modules, truck access and laydown area	Rail spur or dedicated intermodal handling equipment	Confirmed intermodal testing demand
Utilities and digital systems	Basic power, data and reserved utility corridors	Expanded power, data, emergency and monitoring systems	Confirmed user requirements and operational demand

The main decision triggers for Phase 2 should include confirmed user commitments, a defined design vessel, confirmed water-depth requirements, acceptable sediment and dredging strategy, structural feasibility of quay upgrades, grid capacity or upgrade pathway, alternative-fuel safety case, permitting feasibility, funding availability and evidence that the proposed investment will not compromise the flexible innovation function of the terminal.

Overall, the recommended development plan is to implement Phase 1 as a lower-regret innovation platform and preserve Phase 2 as a set of trigger-based expansion options. This approach allows Port Detroit to activate the site in the near term while maintaining flexibility for larger vessels, deeper dredging, alternative fuels, high-power charging, intermodal demonstrations and more specialized retrofit functions if market demand and funding mature.

10. Requirements for rehabilitation of quay structures and dredging works

This section builds on the phased development plan set out above and translates it into specific infrastructure requirements for the rehabilitation of the existing quay structures and the associated dredging works. The requirements are framed in the context of the current condition of the existing marine structures and the prevailing site conditions, including observed structural deterioration, existing bed levels, geotechnical constraints and the capacity limitations of the current quay to accommodate anticipated loads and vessels. This context is essential to determine which interventions are needed to activate the terminal under Phase 1 and which more extensive works should be reserved as Phase 2 options.

The requirements are organized around two distinct tiers. The first tier covers the Phase 1 works required to bring the existing quay structures back into safe and reliable service and to provide the minimum navigable depths needed to accommodate near-term research, testing, retrofitting and demonstration vessels. Informed by the current structural condition and site survey information, this includes targeted repair and strengthening of the existing quay walls, construction of the new quay section, and localized maintenance dredging to restore design depths in the berthing pocket and immediate approach areas. The second tier identifies the Phase 2 works that should be safeguarded through appropriate design provisions but not executed until clear triggers are met. These include deepening dredging to accommodate larger design vessels, further structural upgrades to support heavier deck loads or specialized equipment such as permanent marine loading arms and fixed high-power charging, and any additional quay extensions or modifications required for floating dry dock operations or expanded intermodal functions.

Before the terminal can be advanced into more detailed design, the existing quay wall systems, ground conditions, underwater conditions, water depths, sediment conditions and potential obstructions should be verified in greater detail. This will confirm whether the existing waterfront can be rehabilitated for continued maritime use or whether replacement, dredging or other enabling works will be required.

10.1 Quay Infrastructure

The quay infrastructure forms the primary marine-side interface of the port development and its design dictates the range of vessels, cargo types and handling operations that can be accommodated. The phased approach separates the delivery of a new, purpose-built quay at the southeastern end of the site in Phase 1 from the rehabilitation or reconstruction of the existing western quay in Phase 2. This sequencing allows the port to establish new operational capacity before undertaking disruptive works on legacy assets and provides an opportunity to validate design assumptions (loads, vessel calls, equipment types) before committing to the larger Phase 2 investment.

This section sets out the design basis, structural options, typical cross-sections and construction methodologies for both phases.

10.1.1 Phase 1: New Quay and Flexible Apron

The proposed southeastern quay is shown in the figure below, highlighted in blue.

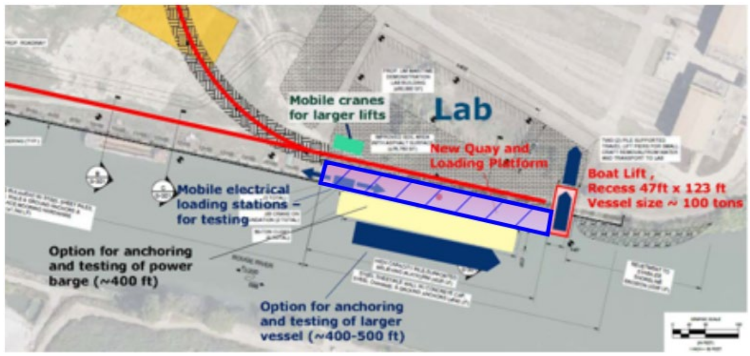


Figure 10-1 Figure Showing Location of Proposed New Quay (in blue)

10.1.1.1 Design Basis for New 500–525 ft Quay and Apron

The new quay is proposed as an approximately 500–525 ft continuous berthing face, designed to accommodate a range of vessels reflecting the port's evolving role. The following design assumptions are required to facilitate the proposed use for Phase 1, which includes materials handling, crane use, loading and off-loading vessels, vessel mooring and berthing:

- **Design vessel range:** vessels up to approximately 400-500ft LOA.
- **Berthing energy:** calculated in accordance with PIANC WG 33 / WG 145 guidance, with abnormal berthing factors applied for tug-assisted and unassisted maneuvers.
- **Uniform deck load:** minimum allowance for general circulation, e.g. trucks, across the deck and apron, with designated heavy-load zones to accommodate mobile cranes and project cargo.
- **Point loads:** mobile harbour crane outrigger loads.
- **Bollard capacity:** 80–100 t bollards, with additional heavy-duty bollards at quay ends.
- **Location of Berth Face:** aligned with the existing bulkhead located to the east of the site, creating a platform width governed to the setback distance between the two walls (approximately 50’). This creates a continuous berthing face once the two phases of construction are complete.
- **Design life:** 50 years minimum for the primary structure, with replaceable secondary elements (fenders, bollards, cathodic protection anodes) on shorter cycles.

Freeboard and levels: deck level set with allowance for sea level rise over the design life (typically +0.5 to +1.0 m above current design still water level, subject to local guidance).

Seismic and environmental loads: in accordance with applicable local codes; in particular currents, snow and ice loading assessed site-specifically.

<u>Existing Structure</u>

An assessment of the existing shoreline structure situated landward of the proposed new quay has been undertaken based on available reference material. The primary source of information is a drawing titled Inspection Observations, prepared by Foth Engineering, documenting a site inspection carried out in September 2025 and a Ramboll site visit (visual walkover only) in January 2026. It should be noted that available information on the existing structure is limited, no photographic records have been made available to date, and no direct information is available regarding subsurface conditions or fill materials behind the wall.

Existing structure description

The existing shoreline is retained by a steel sheet pile (SSP) bulkhead of varying section, comprising:

- PZ-38 sheet piles over approximately the first 50–75 ft of wall length; and
- PZ-27 sheet piles over the remaining length of the wall.

The bulkhead is understood to be tied back to H-pile anchor piles located behind the wall. Abandoned timber fender piles are also present at the mudline along the face of the structure.

Recorded conditions at time of inspection (September 2025)

Water depth along the face of the bulkhead ranged from approximately 2 ft to 5 ft.

Wall thickness measurements within the PZ-38 section (first 50–75 ft) indicate approximately 50% section loss at the mudline, associated with the presence of the H-pile anchors and abandoned timber fenders at that level.

The remaining length of PZ-27 wall exhibits approximately 20% section loss.

The overall condition of the bulkhead is assessed as Fair, on the basis of evidence of SSP section loss (largely 20% with a localized area of 50% at the mudline).

Subsurface conditions behind the wall, including backfill materials, presence of services (an electrical manhole is noted at chainage 19+50) groundwater regime and anchor system condition, are unknown based on the currently available information.

Implications for the Proposed New Quay Design

The condition of the existing bulkhead has several implications for the design and construction of the new quay:

The existing wall will remain in place behind the new quay and continue to function as a retaining element for the landside fill. The new platform design should not rely on the existing bulkhead for structural support of operational loads; new operational loads will be transferred to the new foundations.

The localized area of 50% section loss within the PZ-38 length represents a reduced-capacity zone and may warrant targeted rehabilitation (e.g. localized strengthening, or partial replacement) either as part of the Phase 1 works or as an early Phase 2 intervention.

The presence of H-pile anchors and abandoned timber fender piles at the mudline may constrain pile driving locations for the new quay and should be considered when developing the pile layout and construction methodology. Obstruction clearance may be required in some areas.

Unknown ground conditions behind the wall present a risk to design assumptions relating to lateral earth pressures, drainage, and the interaction between the retained fill and the new platform.

10.1.1.2 Structural Options and Construction Methodologies

Three principal structural typologies are considered viable for the new quay and these are set out below for comparison with the preferred solution put forward by Foth in the document 25D009_Innovation Detroit – Conceptual Development & Class 4 Cost Opinion. Selection should depend on geotechnical conditions, water depth, construction access, cost, environmental compliance/consent risk and local contractor capability.

Option A — Extended sheet pile wall cofferdam system (Combi King Pile / Sheet Pile System or steel sheet pile)

A cofferdam solution would provide a dry working platform by enclosing the required area with either a continuous sheet pile wall or a combi-wall comprising tubular king piles with intermediate sheet piles. The combi-wall arrangement offers higher bending capacity than a conventional sheet pile wall and is particularly well suited to locations requiring significant retained heights, or where future deepening of the adjacent dredged area may be envisaged. The wall would typically be anchored using tie-rods connected to a rear anchor wall or deadman, with a reinforced concrete capping beam at the top providing support for bollards, fenders and cast-in services. This arrangement delivers a robust, deep-draft-ready structure and, once the initial piles are driven, allows the majority of subsequent works to be carried out from the land side, reducing reliance on marine plant. Once enclosed and dewatered, the cofferdam would be backfilled with selected granular material placed in controlled lifts, incorporating appropriate drainage measures to manage groundwater and surface water. Services would be installed within buried ducts and corridors integrated into the backfill, allowing for future access and expansion consistent with the wider phased development strategy.

Option B — Suspended Deck on Piles (Open Piled Quay) – **Preferred**

A suspended reinforced concrete deck supported on vertical and raking steel tubular or concrete piles is suitable where soft founding conditions preclude economic gravity or sheet-pile solutions, or where minimizing disturbance to the existing seabed and hydraulic regime is important. The deck typically comprises precast beams with an in-situ topping slab, providing a durable working surface. This option offers good flexibility for services routing beneath the deck.

Option C — Gravity Caisson or Block Wall

Precast concrete caissons or mass-concrete blocks founded on a prepared rubble bed provide a robust, low-maintenance solution well suited to competent founding strata and locations where prefabrication and float-in installation are feasible. This option is attractive where local yard capacity exists but requires suitable bearing conditions and careful control of settlement.

A preliminary recommendation favors Option B, a **suspended deck design**, for the following reasons:

- With unknown ground conditions, the proposed solution presents the lowest risk due to existing ground obstructions, non-reliance on soft existing bed material (gravity walls) or potential requirement for removal due to settlement risk (combi-wall).
- Opportunity to introduce a revetment under as a means of assisting with stabilization of the existing bulkhead.
- Offers potential for under deck inspection of services (subject to freeboard being confirmed)
- Reduced impact on existing flow regime in the river
- The potential for adaptability to future dredging by incorporating an allowance into the pile design.

Risks associated with this solution include:

- Potential higher cost due to requirement for marine plant and weather sensitivity
- If the rock revetment is installed first, there may be difficulty in pile driving through rock armor (may be mitigated through the use of preinstalled temporary sockets)

This recommendation, as a reference design, a subject to geotechnical confirmation, given its balance of capital cost, adaptability to future deepening, and constructability from the land side.

10.1.1.3 New Quay – Suspended Deck Configuration

A potential structural configuration for the suspended deck quay comprises, from riverward to landward:

- Front row of piles (vertical and raking), driven riverward of, or through, the revetment toe to competent strata;
- Fender beam / edge beam supporting cell or cone fenders and bollards;
- Intermediate rows of piles, driven through pre-formed pockets in the revetment;
- Precast beams spanning between pile headstocks;
- In-situ reinforced concrete topping slab with cast-in ducts, drainage, and fixings;
- New rock revetment, remaining in place beneath the deck as shoreline protection, with locally regraded crest to provide clearance;
- New sheet piled bulkhead with ground anchors

- Transition slab and apron pavement connecting the suspended deck to the landside surfacing, with an articulated joint to accommodate differential movement.

Ancillary features include:

- Cell or cone fenders sized per PIANC berthing energy calculations, with high-friction panels;
- Bollards cast into the edge beam;

This matches the proposed section from Foth, shown in the extract below.

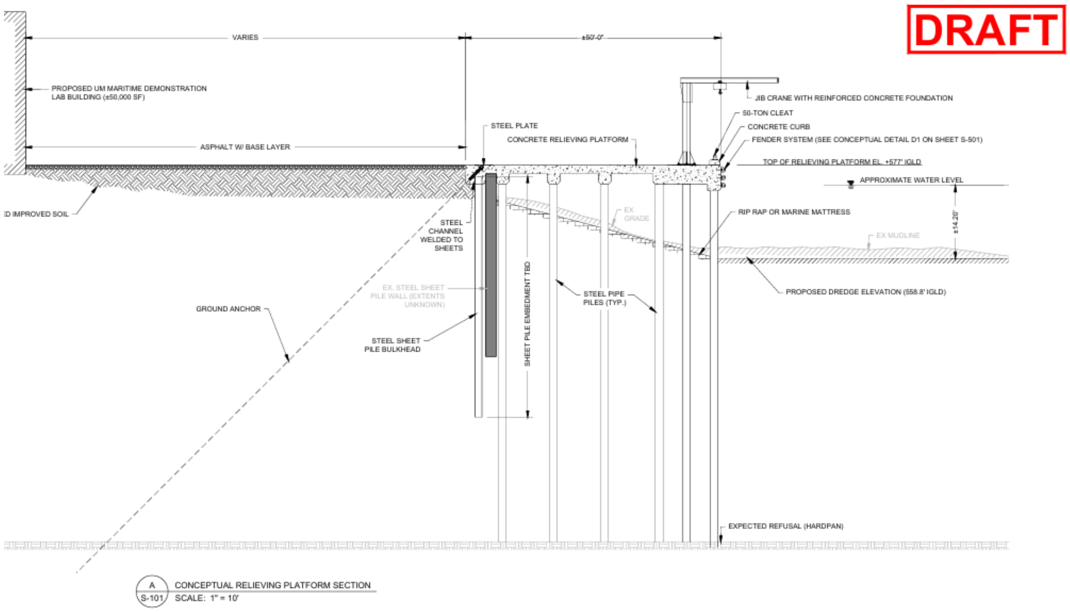


Figure 10-2 Figure Showing proposed relieving platform layout

Source: Ref Foth Memorandum Innovation Detroit – Conceptual Development & Class 4 Cost Opinion dated April 22 2026

The following additional considerations are proposed to optimize the design:

- Deck drainage collected through cast-in gullies discharging via controlled outlets, with provision for spill containment
- Opportunity for a specific piled crane loading platform within the relieving platform instead of designing for maximum load over the entire footprint
- Unknown ground conditions, depth of existing piles and other existing obstructions unknown
- Revetment under deck may require protection from vessel scour through appropriate sizing of the stone mattress

- Opportunity for the existing SSP to not be replaced as its function (as a retention structure and providing slope stability) can be done by the revetment slope.

10.1.1.4 Flexible Quay Apron Configuration and Load Capacities

The apron is proposed as a flexible, multi-use working platform rather than a single-purpose surface. Key design features could include:

- Minimum apron width: currently shown as approximately 50-60' from the rear quay edge to accommodate mobile crane operations, laydown, truck circulation and a rear service strip.
- Zoned loading: clearly demarcated heavy-load zones (e.g. for crane pads) with lighter-duty zones for general circulation.
- Reserved corridors: utility corridors reserved beneath the apron for future high-power cabling, alternative fuel lines, and data infrastructure.
- Modular tie-down points: cast-in anchor points at a regular grid to allow securing of containerized modules, temporary structures and cargo.
- Drainage and containment: graded surfaces with interceptor drainage, incorporating provision for spill containment.

This flexible layout is intended to defer commitment to fixed installations, supporting the phased and adaptable philosophy of the overall development.

<u>Boatlift Civil Infrastructure Requirements</u>

The boatlift is proposed for delivery in Phase 1, installed adjacent to, and just west of, the new piled suspended deck to provide integrated small vessel haul-out capability alongside the primary berth operations. The civil infrastructure requirements comprise a dedicated boatlift bay formed by parallel piled runway beams extending out from the shoreline into the water, and/or partially embedded within the shore, founded on driven steel piles coordinated with the adjacent suspended deck piling to allow efficient shared marine construction. The runway beams must be designed for the concentrated wheel loads of the boatlift under both travelling and lifting conditions, with appropriate freeboard above design water levels and sufficient clear width and submerged depth between the beams to accommodate the design vessel range. Interface with the adjacent suspended deck requires careful detailing of the shared edge, including differential movement, load transfer, and continuity of services and fendering.

Landward of the runway beams, a reinforced hardstanding area should be provided as the boatlift's rear travel path and vessel transfer and blocking area, with pavement design capable of supporting the boatlift's fully loaded axle loads and the point loads imposed by vessel keel blocks and support stands. Civil provisions should also include service connections at the interface (power, potable water, firewater, compressed air, and data), drainage with spill containment consistent with vessel maintenance activities, tie-down points for blocking and cradles, and clear demarcation of the boatlift operating envelope to segregate it from adjacent quay operations. Coordination with the adjacent suspended deck design, the rock revetment, and the reserved utility corridors is essential to ensure that the boatlift bay is delivered as an integrated element of the Phase 1 works rather than a standalone facility.

<u>Pavement recommendations</u>

Reinforced concrete (rigid pavement) is the most common solution for heavy-duty port aprons and is generally the preferred pavement type for the primary working areas of the quay apron. It offers excellent capacity for high point loads (e.g. mobile crane outriggers) strong resistance to fuel, oil and hydraulic fluid spillage, and a long design life of typically 40–50 years. It is stable under sustained static loads, provides a durable surface for cast-in anchor points, tie-downs and service access covers, and is compatible with heat and abrasion from crane tracks and steel-wheeled equipment. The main drawbacks are higher initial capital cost, longer construction and curing time, and more disruptive reinstatement after service trenching or reconfiguration. Typical construction comprises a reinforced concrete slab over a bound sub-base and a granular capping layer, with contraction and expansion joints at regular centers.

Heavy-duty asphalt (flexible pavement) may be appropriate for secondary areas of the apron such as truck circulation routes, lighter-duty laydown zones, and areas subject to more frequent reconfiguration. It has a lower initial capital cost than concrete, is faster to construct, allows earlier opening to traffic, and is easier to reinstate after service works. However, it is susceptible to rutting and deformation under sustained heavy point loads (particularly in warm weather), vulnerable to softening from fuel and oil spills, and has a shorter design life of typically 15–25 years with more frequent resurfacing. It is not suitable beneath crane outriggers and offers less resistance to abrasion from steel-wheeled or tracked equipment. Typical construction comprises asphalt (surface, binder and base courses) over a bound sub-base and a granular capping layer.

Heavy-duty interlocking concrete block paving (CBP) is widely used in container terminals and can be considered for heavy-duty static storage, laydown areas and container stacking zones. However, given the lower usage of this site, it is not considered appropriate and container areas may be surfaced with concrete instead.

For this development, the preliminary recommendation is:

- Reinforced concrete for the primary quay-edge working strip, heavy laydown zones, including container storage or crane outrigger locations, and reserved footprints for future fixed installations — reflecting the dominance of heavy point loads, sustained static loading, and durability requirements in these areas;
- Heavy-duty asphalt for truck circulation routes and lighter-duty peripheral areas — reflecting the value of lower capital cost and ease of reinstatement in these zones;

Final pavement zoning, thicknesses and specifications should be confirmed at detailed design stage, informed by geotechnical investigation, detailed operational load definition, and confirmation of the equipment fleet.

<u>Drainage Considerations</u>

Surface water drainage across the apron should be managed through a graded pavement surface directing runoff to a network of interceptor drains, gullies and collection channels arranged to suit the zoned pavement layout. Given the operational nature of the apron and the potential for contact with fuels, oils, hydraulic fluids and, in future, alternative fuel handling activities, the drainage system should incorporate oil/water separators (interceptors) and provision for spill containment ahead of any discharge, with isolation valves at key outfalls to allow containment in the event of a spill. Discharge of collected surface water to the adjacent river would require permitting and a compliance review under applicable federal, state and local regulations, and discharge water quality standards will need to be confirmed with the relevant regulatory authorities at an early stage of design. Depending on the outcome of that review, treatment measures beyond standard interception (for example, enhanced separation, filtration, or attenuation storage) may be required, and consideration should also be given to sustainable drainage measures such as attenuation and controlled discharge to manage peak flows. Drainage corridors and outfall locations should be coordinated with the reserved utility corridors and future fixed installations to avoid conflicts and to preserve flexibility for phased development.

10.1.2 Rehabilitation or Reconstruction of Existing Western Quay

10.1.2.1 Design Basis and Objectives

Phase 2 addresses the existing western quay, which is assumed to be an aging structure of uncertain residual capacity. In the phased development strategy, the western quay is positioned to accommodate larger vessel operations than those handled at the Phase 1 quay, together with a range of specialist functions including floating dry dock operations, alternative fuel vessel calls, intermodal (rail) interfaces, and high-power vessel charging.

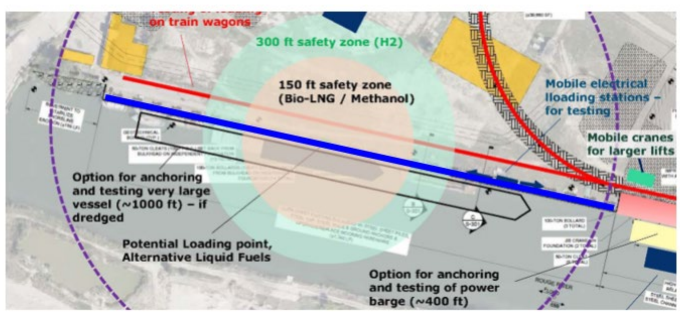


Figure 10-3 Figure Showing Location of Upgraded Western Quay (in blue)

The objectives for Phase 2 are to:

- Extend the useful life of the asset (possibly by a further 30–50 years);

- Upgrade capacity to accommodate larger vessels, with operating drafts of up to approximately 24 ft (7.3 m) potentially considered, assuming an indicative under-keel clearance of approximately 2 ft (0.6 m);
- Provide berth length, quay wall capacity, mooring arrangements and apron infrastructure suited to the expanded vessel envelope and functional demands;
- Integrate services, electrification and alternative fuel provisions in line with the port's phased strategy;
- Minimize disruption to ongoing operations during works.

Existing Structure

The following description of the existing western quay is based on the Foth survey of September 2025 and a Ramboll site visit (visual walkover only) in January 2026. The survey provides the current best available characterization of the structure and its condition and forms the basis for the preliminary design assumptions set out in this section. However, several significant information gaps remain, and a further, more comprehensive condition assessment is recommended prior to detailed design.

Existing structure description

The Foth survey indicates that the existing western quay is not a single, uniform structure but rather a composite of several structural forms along its length. The principal elements identified are:

Timber pile field — evenly spaced (approximately 600 ft): 12-inch diameter timber piles at regular spacing behind the existing bulkhead, supporting the apron and associated loads.

Timber pile field — unevenly spaced (approximately 600 ft): a further section of 12-inch diameter timber piles behind the bulkhead, but with irregular spacing, indicative of ad-hoc historical modifications, partial replacements, or original construction variability.

Steel pile-supported relieving platform (approximately 200 ft): a relieving platform of unknown width and configuration, supported on steel piles.

Existing bulkhead (steel sheet pile?): the frontal retaining element, with unknown embedment depth, tie-back configuration, and overall extents.

Concrete cope / capping beam: along the top of the bulkhead, integrating bollards and mooring furniture.

The width of the relieving platform varies, and the condition of all subsurface elements (timber piles, steel piles, relieving platform, bulkhead embedment, and any tie-back system) is unknown. It is also possible that backfill will be required in some areas where voids or settlement have developed behind the bulkhead.

Recorded conditions at time of inspection (September 2025)

The overall condition of the existing western quay is assessed as poor, based on the following observations from the September 2025 survey:

- Concrete cope spalling with exposed reinforcement: widespread spalling of the concrete cap, with exposed and section-reduced reinforcement. Notably, continuous spalling with exposed reinforcement and notably, section loss is recorded from Station 12+33 to Station 14+14 (a length of approximately 181 ft).
- Additional localized spalling: several further incidences of concrete cap spalling with exposed reinforcement recorded elsewhere along the quay.
- Damaged bollards: several instances of failed or damaged bollards, indicating reduced mooring capacity and potential safety concerns for current operations.
- Timber pile-supported relieving platforms: condition unknown; timber elements in a marine environment are subject to marine borer attack, decay in the tidal / splash zone, and mechanical damage, and cannot be assumed to retain their original capacity.

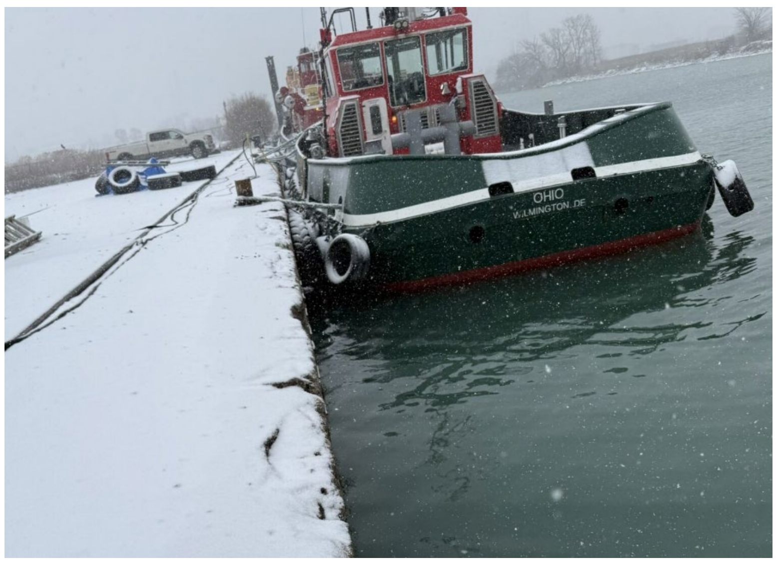


Figure 10-4 Photograph of existing vessels berthed on Western Quay *(Ramboll Site Visit Jan 2026)*

Implications for Design

The observed condition and information gaps have significant implications for the Phase 2 design and reinforce the rationale for the preferred structural approach (a new anchored steel bulkhead riverward of the existing structure, with localized relieving platforms - see below):

Structural capacity and reliability:

- The existing bulkhead cannot be relied upon to carry Phase 2 operational loads, given concerns on bulkhead condition, spalled cope with exposed reinforcement, and failed bollards. It should be treated as a secondary retaining element only, with new operational loads carried by the new bulkhead and associated anchor system.

- The existing timber and steel piles behind the wall cannot be relied upon to support new apron loads, particularly in heavy-load zones (mobile crane pads, mooring points for vessels and floating dry dock positions, rail spur). Ground strengthening, including localized relieving platforms on new piles, should be provided in these zones, independent of legacy foundations.
- The variable and partially unknown pile spacing and platform geometry means that legacy foundations should be assumed to provide no reliable contribution to the new design unless subsequently confirmed by targeted investigation.

Backfill and voids:

- Given the age and condition of the existing bulkhead, voids and settlement behind the wall should be anticipated, and provision made for backfill and grouting in affected areas as part of the Phase 2 works.
- Backfill placement between the existing and new bulkheads must be designed to avoid overloading or destabilizing the existing structure during construction.

Interaction with the new bulkhead:

- The new bulkhead should be designed independently of the existing structure, without relying on the existing bulkhead for anchorage, lateral support, or vertical load transfer.
- The anchor system for the new bulkhead must be designed to pass through or around the zone of existing timber piles, steel piles, and legacy bulkhead elements. Interference between new tie-rods and existing subsurface elements is likely and must be managed through targeted investigation and design coordination.
- Construction sequencing must recognize the poor condition of the existing bulkhead; vibration from piling, dewatering, or excavation could accelerate deterioration or trigger localized failure, and appropriate monitoring and control measures should be specified.

Operational risk prior to construction:

- The current condition (failed bollards, spalled cope, potential poor bulkhead/relieving platform condition) may constrain vessel operations at the existing quay prior to redevelopment. Interim operational restrictions and temporary mooring or fendering arrangements may be required until the new bulkhead is commissioned.
- Safety exclusion zones may be warranted in areas of the most severe deterioration (e.g., Sta 12+33 to Sta 14+14) pending the Phase 2 works.

Obstructions to future development:

- The existing pile field behind the bulkhead may present an obstruction to Phase 2 works such as piling and service trenches.
- These unknowns present a significant risk to both the design and construction of the new bulkhead, particularly with respect to pile driveability, anchor installation, and the ability to achieve the required embedment depths without refusal or damage to driving plant.

10.1.2.2 Upgrade/substitution of quay wall

The existing western quay is a composite structure in poor overall condition, with documented deterioration of the bulkhead, cope and mooring furniture, and with significant unknowns regarding the condition and configuration of subsurface elements. The condition assessment strongly supports the preferred Phase 2 approach of a new steel bulkhead riverward of the existing structure, with the existing bulkhead retained only as a secondary retaining element, localized relieving platforms provided in heavy-load zones, and provision made for backfill and grouting behind the existing wall. Further investigation is recommended to close identified information gaps and confirm the detailed design assumptions.

The form of the new steel bulkhead may include anchored or cantilevered options. The final design will depend on ground conditions and final confirmation of the loading conditions behind the wall.

The Foth proposal to replace with a new anchored SSP in front of existing and bollards on independent foundations is a reasonable approach, based on the information available at this time.

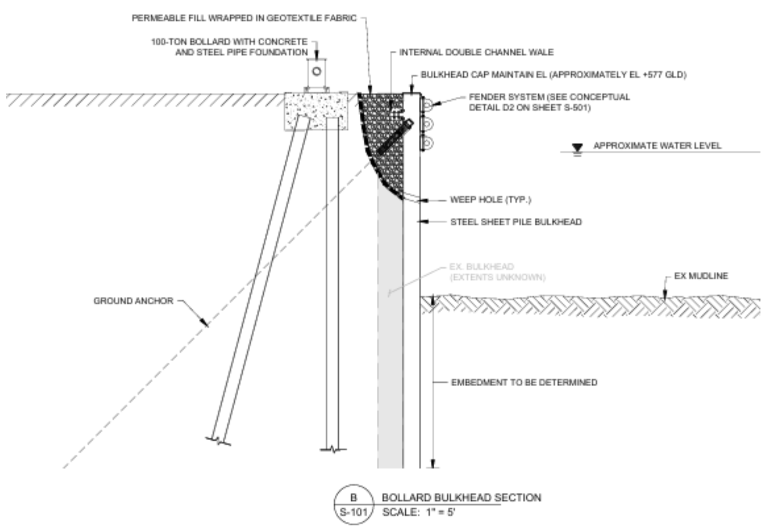


Figure 10-5 Figure Showing proposed bulkhead and bollard foundation layout

Source: Ref Foth Memorandum Innovation Detroit – Conceptual Development & Class 4 Cost Opinion dated April 22 2026

The following design issues should be addressed as this solution is developed:

Interaction Between New Bollard Foundations and the New Sheet Pile Wall

The new western quay will require new bollards sized for the expanded Phase 2 vessel envelope, including larger vessels, floating dry dock mooring loads, and any alternative fuel vessel calls. These bollards will be integrated into the new capping beam along the top of the new steel sheet pile (SSP) bulkhead, with their foundations located in close proximity to the SSP itself. Given the high mooring loads anticipated and the limited space available between the bollard foundations and the SSP, the structural interaction between the two elements must be carefully assessed during design.

Mooring loads applied to the new bollards will be transferred through the bollard foundations into the surrounding structure and ground. Depending on the foundation configuration adopted — whether the bollards are founded directly on the capping beam, on discrete pile groups, or on a shared reinforced concrete block — a portion of the mooring load may be transferred directly into the new SSP, either as horizontal thrust, vertical shear, or bending. Loading of the new SSP by the new bollard foundations may therefore be unavoidable, and this load path should be explicitly considered in the design rather than assumed away.

The design should assess the potential magnitude and distribution of these interaction loads under both operational and extreme mooring conditions, identify any zones where interaction is particularly acute (for example, at heavy-duty bollards serving floating dry dock or large vessel mooring positions), and specify appropriate structural provisions. Mitigation options include founding heavily loaded bollards on dedicated pile groups or localized relieving platforms independent of the SSP, providing isolation or articulation details between the bollard foundations and the SSP capping beam, or explicitly designing the SSP and its anchor system to accommodate the transferred loads. The selected approach should be developed in coordination with the design of any local relieving platform, e.g. for a mobile crane.

Opportunity for a Piled Crane Loading Platform

An important opportunity exists to optimize the design of the new bulkhead by decoupling heavy crane loads from the bulkhead itself. Mobile harbor cranes impose significant point loads through their outriggers, and designing the entire length of the bulkhead to accommodate the maximum crane loading in any position along the quay would result in a substantially heavier and more expensive structure than would otherwise be required.

Instead, a dedicated piled crane loading platform could be provided, either as a series of discrete pads at pre-determined crane operating positions, or as a continuous platform along a portion of the quay. The platform would be founded on its own piles, transferring crane outrigger loads directly to competent strata independently of the bulkhead. This approach offers several benefits:

- The new bulkhead can be designed for a lower, more uniform surcharge load, reducing steel section requirements and anchor capacity;
- Crane operating positions can be clearly defined and controlled, improving operational safety and predictability;

- The platform can be sized and located to suit the specific crane(s) selected, avoiding over-design elsewhere;

As noted above, the same principle can be extended to other heavy point loads, such as floating dry dock mooring points and heavy mooring bollards.

The layout and extent of the piled crane loading platform should be developed in parallel with confirmation of the crane specification and operational plan, to ensure that the platform is correctly sized and positioned. Coordination with the anchor system for the bulkhead is also required, to avoid conflicts between platform piles and tie-back arrangements.

<u>Apron Design, including Potential Rail Spur Behind the New Wall</u>

A potential rail spur is proposed on the landside apron behind the new western quay wall, providing intermodal connectivity to support the expanded functional role of the western quay (see Section 7). The introduction of rail loadings has several important implications for the design of the new SSP bulkhead and its associated infrastructure.

Rail loading introduces concentrated axle loads and dynamic effects that differ in character from typical apron surcharge loads. Depending on the rail spur alignment relative to the bulkhead, these loads may impose a significant surcharge on the active soil wedge behind the SSP, increasing lateral earth pressures on the wall and requiring corresponding increases in bulkhead section, anchor capacity, and embedment depth. Where the rail alignment passes within the influence zone of the bulkhead, the surcharge effect should be explicitly modelled in the earth pressure analysis, using appropriate dynamic amplification factors for the specified rail loading standard.

In addition, rail infrastructure is highly sensitive to differential settlement, and the interaction between the rail spur, the new SSP, and any localized relieving platforms must be carefully managed. Options to address this include providing ground improvement beneath the rail alignment; founding the rail spur on a dedicated piled platform where it passes close to the bulkhead, decoupling rail loads from the SSP and from any settlement of retained fill; or offsetting the rail alignment sufficiently from the bulkhead to remove it from the wall's influence zone. The selected approach should be developed in coordination with the design of the crane loading platform and other localized structural provisions, to ensure a consistent and cost-effective overall arrangement.

Early confirmation of the rail spur alignment, rail loading standard, and operational requirements is therefore essential, to allow the associated loads and settlement criteria to be incorporated into the bulkhead and apron design from the outset.

Otherwise, apron drainage and pavement considerations are as described for Phase 1 works.

Additional Infrastructure Requirements for Alternative Fuel Vessels

For safety reasons, the loading of alternative fuels is most appropriately located at the refurbished existing western quay (Scenario B), where the layout, standoff distances, and controlled operational environment can be developed to accommodate the specific hazards associated with these fuels. The introduction of alternative fuel vessels imposes a number of additional civil infrastructure requirements beyond those associated with conventional vessel operations, and these should be considered in the design of the new bulkhead, capping beam, and landside apron.

Fendering for alternative fuel vessels may need to be altered to minimize hull pressure during berthing and mooring, potentially requiring a shift from conventional cell or cone fenders to foam or pneumatic fenders, or to cone fenders with large distribution panels. These fender types generally require a greater depth of construction at the berthing face to accommodate the fender fixings, panels, and clearance envelopes, and this should be reflected in the design of the new capping beam and the setback of the bulkhead face. Mooring furniture may also need to be upgraded to quick-release hooks with integrated line monitoring, to allow rapid vessel release in the event of an emergency and to provide operational visibility of mooring line loads. Quick-release hooks are heavier and more complex than conventional bollards, and require larger foundation footprints, cabling for monitoring systems, and coordination with the localized relieving platforms provided at heavy mooring positions.

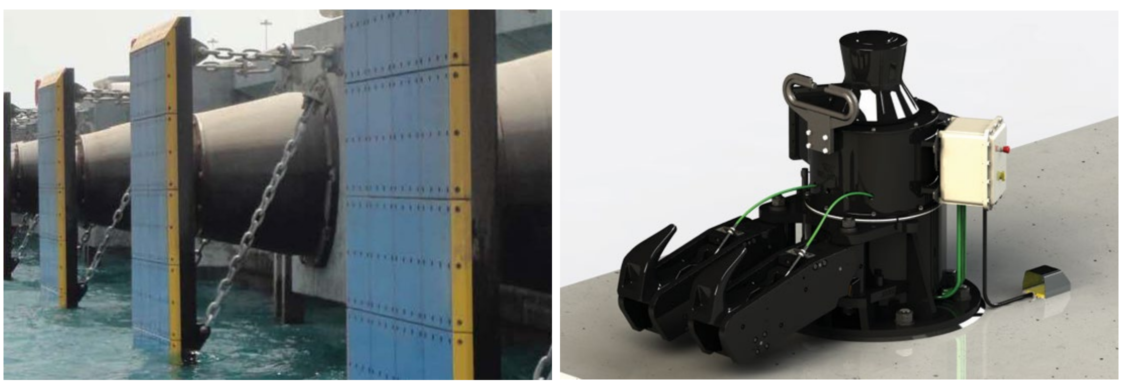


Figure 10-6 Examples of quayside equipment suitable for alternative fuel vessels © Trelleborg

Transfer of alternative fuel liquids between vessel and shore will require marine loading arms or fixed hoses, which are permanent installations requiring dedicated plinths, foundations, and utility connections at defined transfer positions along the quay. Loading arm foundations impose significant point loads and should be placed on localized piled platforms integrated with the bulkhead design. Pipeline infrastructure connecting the loading arms to the fuel storage tanks will also be required. Where these pipelines are routed above ground — which is often preferred for inspection, leak detection, and safety reasons — they will typically need to be carried on raised gantries or pipe bridges, with pedestrian bridges over or clear headroom provisions where they cross vehicular routes, to avoid obstructing site traffic and operational movements. The alignment and support arrangements for these gantries should be coordinated with the reserved utility corridors, the rail spur alignment, and the general apron circulation from the earliest stages of the Phase 2 design.

10.2 Western and Eastern Ends – Shoreline Revetment

10.2.1 Overview

In addition to the primary quay infrastructure works described above, the site includes two areas of existing shoreline at its extreme eastern and western extents that require dedicated shoreline protection works. Both areas comprise existing sloped shoreline rather than vertical quay walls, and both were inspected as part of the Foth survey of September 2025. Neither area is currently proposed to accommodate quayside infrastructure or vessel loading/unloading operations, and the works are therefore focused on shoreline stabilization and protection rather than berth development. It is recommended that these works are included in Phase 1 to provide protection to these vulnerable areas of the site against shoreline erosion.

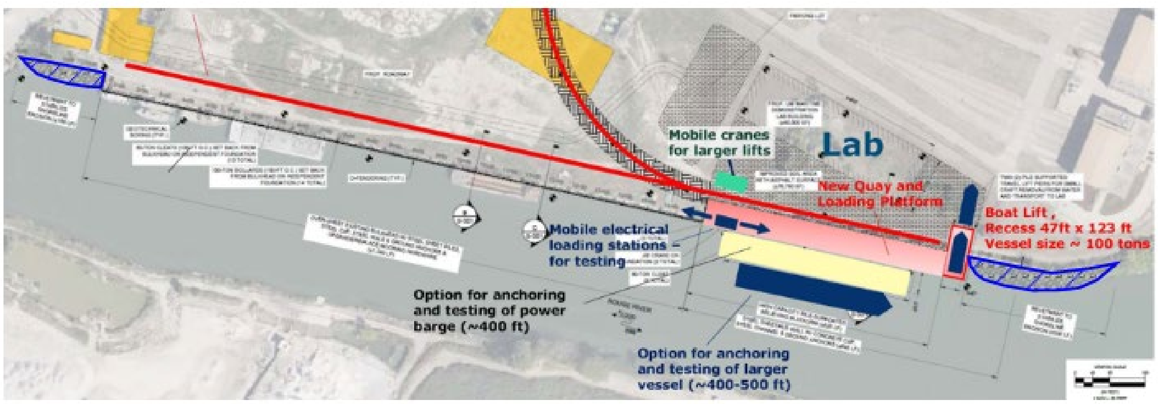


Figure 10-7 Figure showing areas requiring shoreline protection (in blue)

The proposed use of the areas immediately behind the rehabilitated shoreline is limited to general circulation, movement of materials, storage, and parking, consistent with the intent to reserve heavy operational functions for the Phase 1 and Phase 2 quay areas.

10.2.2 Eastern Extent

The eastern extent of the site comprises an existing sloped shoreline located adjacent to a bridge structure. The Foth survey identified the following key issues:

- Existing sinkholes in the ground surface behind the shoreline, indicative of subsurface erosion, void formation, or loss of fines through the existing slope protection;

- Evidence of active shoreline erosion, with associated risk of ongoing loss of ground and progressive undermining;

Further information gathered during a Ramboll site visit indicated

- Debris on the slope and foreshore;
- Proximity to the adjacent bridge, which introduces additional sensitivities regarding scour, hydraulic conditions, and the potential consequences of continued erosion for the bridge foundations and abutments.

Figure 10-8 Photos of revetment at Western end of the site (Ramboll site visit Jan 2026)

The overall condition of the eastern shoreline is assessed as poor. The presence of sinkholes in particular is a significant concern, as it indicates that erosion processes are not confined to the visible shoreline face but are also active in the subsurface, with implications for ground stability behind the shoreline.

10.2.3 Western Extent

The western extent of the site is located on the inner edge of a bend in the river. Although the inner bend is generally a lower-energy environment than the outer bank, the area is nevertheless subject to shoreline erosion, and the Foth survey identified the following key issues:

- Poorly placed rip-rap, which is not providing effective shoreline protection due to inadequate sizing, gradation, placement, or the absence of a suitable filter layer;
- Eroded shoreline behind and adjacent to the existing rip-rap, indicating that the current protection is not performing its intended function;

The overall condition of the western shoreline is also assessed as poor, with the existing rip-rap requiring replacement rather than repair to provide durable protection.

10.2.4 Proposed Works

The proposed works at both the eastern and western extents comprise rehabilitation of the existing shoreline as new engineered rock (stone) revetments. The revetments would be designed to provide durable, long-term shoreline protection consistent with the hydraulic conditions at each location, and would comprise the following typical elements:

- Regrading of the existing slope to a stable and constructible profile;
- Provision of a graded filter layer (typically a granular filter and/or geotextile) to prevent loss of fines from the retained ground;
- Placement of an underlayer of appropriately sized stone;
- Placement of a primary armor layer of engineered stone sized for the design hydraulic conditions (waves, currents, vessel wash, and ice where applicable);
- Toe protection at the base of the revetment to resist scour and provide a stable foundation for the armor layer;
- Crest detailing to tie in with the landside surface and to accommodate the intended surface use.
- At the eastern extent, the design must additionally address the existing sinkholes through appropriate ground investigation, void filling and grouting, and reinstatement of the retained ground behind the revetment. The proximity of the adjacent bridge requires coordination with the bridge owner and consideration of the interaction between the revetment works and the bridge foundations, including scour protection extending as necessary to protect the bridge interface.
- At the western extent, the design should account for the hydraulic conditions on the inner bend, including secondary currents and any localized scour patterns, and should ensure that the new revetment is properly keyed into adjacent shoreline features to prevent flanking erosion.

10.2.5 Proposed Use of Areas Behind the Revetments

Following rehabilitation, the areas immediately behind the new revetments are proposed to be used for:

- General storage of materials and equipment;
- Movement of materials and internal site circulation;
- Parking of vehicles and light plant.

No loading or unloading of cargo from vessels is proposed at either location, and no quayside infrastructure (bollards, fenders, mooring furniture, shore power, or bunkering) is proposed. This limits the operational demands on the revetments and the retained ground and allows the design to be optimized for shoreline protection and light-duty surface use rather than heavy operational loading.

10.2.6 Additional Considerations

Several additional considerations should be addressed during the design and delivery of the shoreline protection works:

- Existing vegetation clearance and ecological impact:
  - Both sites include existing vegetation that will require clearance ahead of the revetment works. The ecological impact of vegetation clearance should be formally assessed, in consultation with the relevant environmental authorities, and appropriate mitigation, replanting, or offset measures identified. Ecological assessment should also consider the aquatic habitat at the shoreline interface, particularly at the eastern extent given its proximity to the bridge.
- Unknown ground conditions:
  - Ground conditions behind and beneath the existing shoreline are not currently characterized at either location.
  - Both geotechnical stability and potential contamination should be investigated ahead of detailed design, comprising:
    - Boreholes and/or test pits to establish soil stratigraphy, strength parameters, and groundwater conditions;
    - Chemical testing of soil and groundwater samples to identify any contamination that may affect design, construction methodology, materials handling, or disposal of excavated material;
    - Specific investigation of the sinkholes at the eastern extent to establish their extent, cause, and any associated subsurface voids.
- Required ground surcharge during operation:
  - Although the proposed use is limited to storage, circulation and parking, the specific surcharge loads to be applied to the ground behind the revetments should be confirmed as part of the design brief. This includes stacking heights and unit weights for stored materials, axle loads for vehicles and light plant using the areas, and any localized heavy loads that may arise from occasional operations. The confirmed surcharge governs both the internal stability of the revetment and the design of any required ground improvement or surface treatment.

- Coordination with the adjacent bridge (eastern extent):
  - Design and construction at the eastern extent should be coordinated with the bridge owner from an early stage, to address interface issues including scour protection, hydraulic effects, construction access, and any restrictions on works within the bridge influence zone.

10.2.7 Summary

The eastern and western extents of the site both require dedicated shoreline protection works to address existing poor conditions, ongoing erosion, and (at the eastern extent) subsurface instability manifesting as sinkholes. The proposed solution at both locations is a new engineered rock revetment, with the retained areas used for general storage, circulation and parking only, and no quayside infrastructure proposed. Design development should be preceded by targeted ecological, geotechnical and contamination investigations, and by confirmation of the operational surcharge loads, with coordination with the adjacent bridge owner at the eastern extent.

10.3 Dredging

10.3.1 Overview

The dredging strategy for the port development is closely tied to the vessel scenarios the site is intended to accommodate across Phase 1 and Phase 2. The phased approach recognizes that dredging is a significant capital expense with associated environmental, permitting, and sediment management implications, and that it should therefore be deferred until operationally justified. The strategy is to minimize dredging in Phase 1 by working within existing water depths and selecting vessel operations accordingly, and to undertake targeted or full-depth dredging in Phase 2 only when required to unlock the larger vessel scenarios.

This section sets out the dredging basis, methodology options, and key additional considerations for both phases, and references the types of dredging equipment typically deployed in the Great Lakes region of the USA that may be used at this site.

3.2 Vessel Scenarios and Water Depth Requirements

The dredging requirements are driven by the vessel scenarios summarized below. Water depths are calculated on the basis of 1.1 × vessel draft, providing an approximate under-keel clearance allowance consistent with common practice for the design of berth pockets.

Scenario	Vessel Type	LOA (ft)	Draft (ft)	Water Depth (1.1 x Draft) (ft)
1A	Smaller demonstration vessels (Ribs, semi-autonomous)	20-35	3.5	4
1B	Larger vessels (research and Navy)	85	9	10
2	Very large vessels	1000	25	27.5

Water depths reported below are taken at the face of the steel sheet pile wall. Water depth is expected to increase with distance from the wall, and the dredging depths noted are therefore approximated from the depths at the concrete cap berth.

Scenario	Water Depth Required (ft)	Western Depth of Dredge – at concrete cap berth (ft)	Eastern Depth of Dredge – at SSP bulkhead (ft)
1A	4	0	0
1B	10	0	0
2	27.5	13.1 – 17.0	13.1 – 17.0

Scenarios 1A and 1B can be accommodated within existing water depths without dredging. Scenario 2 requires substantial dredging at both the western and eastern berths, with implications for structural design, sediment management, and permitting.

10.3.2 Phase 1: Minimized Dredging Strategy

Phase 1 is focused on establishing operational capability for Scenarios 1A and 1B without capital dredging, by working within existing water depths and selecting vessel operations accordingly.

10.3.2.1 Vessel Draft Assessment and Tidal Windows

Detailed assessment of the design vessel drafts should be undertaken during the early stages of Phase 1 design, confirming operating drafts under representative loading conditions and cross-checking against the current bathymetry at each berth. Given that the site is located in a river environment rather than a tidal marine setting, water level variation is primarily driven by seasonal river flows, lake level fluctuations, and operational water management rather than by astronomical tides. Operating windows should be established on the basis of forecast water levels, and vessel access procedures should account for periods of lower water when under-keel clearance may be reduced.

10.3.2.2 Selective Dredging for Priority Vessels

If specific priority vessels require greater draft than can be accommodated within the existing water depths, selective dredging of small, defined berth pockets may be considered as a targeted alternative to broader dredging works. Any such selective dredging should be limited in extent, justified by a specific operational need, and undertaken in a manner that does not preclude or complicate the larger Phase 2 dredging works. In practice, selective dredging in Phase 1 is expected to be avoided wherever possible in favor of accommodating vessel operations within existing depths.

10.3.2.3 Environmental and Permitting Considerations

Even where dredging is avoided in Phase 1, environmental and permitting considerations remain relevant, particularly where works to the quay or shoreline may disturb sediments or affect the aquatic environment. Early engagement with the relevant regulatory authorities is recommended to confirm the applicable permitting framework, baseline environmental data requirements, and any monitoring obligations that may apply during construction. Early sediment sampling and characterization is also recommended to inform the Phase 2 dredging strategy and to identify any contamination concerns.

10.3.3 Phase 2: Targeted or Full-Depth Dredging

Phase 2 dredging is required to unlock Scenario 2 vessel operations at the western and eastern berths, and involves substantial capital dredging with associated design, environmental, and consenting implications.

10.3.3.1 Justification Triggers and Vessel Demand Thresholds

As described in earlier sections of this report, Phase 2 dredging should be undertaken only when justified by confirmed vessel demand for Scenario 2 operations. Justification triggers should be defined during Phase 1 and may include: confirmed commercial agreements for larger vessel calls; confirmed strategic requirements from Navy, research, or other institutional users; or a defined threshold of aggregate demand across multiple vessel classes. Deferring dredging until these thresholds are met avoids premature capital expenditure and allows the environmental and permitting effort to be timed appropriately.

10.3.3.2 Dredging Methodology Options

A range of dredging methodologies is available for the Phase 2 works, with selection driven by sediment type, dredging depth, disposal method, environmental sensitivity, and site access. In the Great Lakes region of the USA, the following equipment types are commonly deployed and would be appropriate for consideration at this site:

- Mechanical dredgers, principally clamshell (bucket) dredges mounted on spud barges or crane barges, are widely used across the Great Lakes for berth deepening, maintenance dredging, and works in contaminated sediments. Clamshell dredging offers good control of the dredge footprint, minimal water entrainment (favorable for handling contaminated material), and the ability to load dredged material directly into scows for transport to disposal or dewatering facilities.
- Hydraulic dredgers, principally cutter suction dredges (CSDs), are used where larger volumes are to be moved and where sediment can be pumped through a floating pipeline to a nearby placement or dewatering site. CSDs are less commonly used than clamshells in the Great Lakes for constrained port works but may be appropriate for larger open-water dredging.
- Trailing suction hopper dredges (TSHDs) are generally not used in constrained Great Lakes port settings and are more typical of larger open-water or maintenance dredging projects.
- Environmental dredges — specialized mechanical dredges with enclosed buckets or precision hydraulic heads — are used where contamination is present and resuspension of sediments must be minimized. These are commonly deployed in Great Lakes remediation projects and may be relevant if contamination is confirmed at this site.

Clamshell mechanical dredging with scow transport is likely to be the reference methodology for this site, subject to confirmation of sediment characterization and disposal arrangements.

The dredging design must also address the stability of the dredge slope in front of the new bulkhead and existing structures. Slope stability analysis should confirm the maximum safe dredge depth and slope profile, taking into account soil conditions, retained heights, and any surcharge loads on the bank. Higher retained heights resulting from Phase 2 dredging will impose greater performance requirements on the new bulkhead, and the dredging and structural designs must be developed in an integrated manner.

10.3.4 Sediment Management and Disposal

Sediment management is a critical component of the Phase 2 dredging strategy. Key considerations include:

- Sediment characterization, comprising physical, chemical, and biological testing of representative samples across the dredge footprint, to establish suitability for various disposal or reuse options and to identify any contamination that may constrain handling.
- Contamination in dredged materials is a well-recognized concern in Great Lakes ports, given the industrial heritage of many locations. If contamination is identified, disposal options are typically restricted to confined disposal facilities (CDFs) or licensed upland disposal sites, with associated cost and logistical implications. Beneficial reuse (for example, in habitat creation or brownfield capping) may also be considered where sediment quality permits.
- Dewatering and handling provisions will be required if dredged material is to be transported by truck rather than scow, potentially requiring a temporary dewatering pad on site or at a nearby facility.
- Transport routes for scows or trucks should be identified early and coordinated with disposal site operators.
- Early sediment characterization — ideally undertaken during Phase 1 — is strongly recommended to inform the Phase 2 dredging cost estimate, methodology selection, and consenting pathway.
- Maintenance dredging requirements should also be anticipated as part of the long-term operational strategy. Sedimentation rates at the berth pocket should be estimated on the basis of local hydrodynamic conditions and any monitoring data available for adjacent facilities, and provision made in the operational budget for periodic maintenance dredging. The Phase 2 capital dredging design should facilitate future maintenance dredging by adopting stable slope profiles and avoiding features that would complicate re-entry of dredging plant.

10.3.5 Consenting Pathway

The Phase 2 dredging works will require consent under multiple regulatory frameworks, potentially including federal (US Army Corps of Engineers, US EPA), state, and local jurisdictions, as well as any tribal or interstate considerations relevant to the specific Great Lakes location. The consenting pathway is typically lengthy and data-intensive and should be initiated well in advance of the intended dredging program. Key steps include:

- Baseline environmental studies, covering sediment quality, benthic ecology, fisheries, and water quality;
- Impact assessment, addressing turbidity, contamination, habitat disturbance, and cumulative effects;
- Consultation with regulatory authorities and stakeholders, including any tribal, community, or environmental groups;
- Preparation and submission of permit applications, with supporting technical documentation;
- Response to regulator queries and conditions, potentially including design modifications or additional monitoring obligations.

Early engagement with the US Army Corps of Engineers and the relevant state environmental agency is strongly recommended, and the consenting timeline should be reflected in the overall Phase 2 delivery program.

10.3.6 Summary and Recommendations

Phase 1 should be delivered without capital dredging, accommodating Scenarios 1A and 1B within existing water depths and deferring dredging until Phase 2 operational demand is confirmed.

Phase 2 dredging should be triggered by confirmed demand for Scenario 2 operations, with reference to a clamshell mechanical dredging methodology consistent with common Great Lakes practice.

Early sediment characterization should be undertaken during Phase 1 to inform the Phase 2 dredging cost, methodology, and consenting strategy, and to identify any contamination concerns that may constrain disposal options.

Dredge slope stability and its implications for bulkhead performance must be addressed through integrated dredging and structural design.

Consenting effort for Phase 2 dredging should begin well in advance of the intended dredging program, given the typically lengthy and data-intensive nature of Great Lakes dredging approvals.

10.4 Electrification, Utilities and Digital Services – Civil Infrastructure Considerations

10.4.1 Phase 1

10.4.1.1 Charging Readiness and Shore Connections

Phase 1 electrification is focused on establishing a flexible, low-commitment civil foundation for future vessel charging and shore power operations, without committing to specific electrical technologies or vessel classes at this stage. The intent is to ensure that the civil provisions installed in Phase 1 — ducts, trenches, foundations, reserved footprints, and access arrangements — do not become a constraint on Phase 2 development, and that the port can respond to early charging demand using mobile and modular equipment without disruptive retrofit works.

To support the deployment of mobile or containerised charging equipment at nominated locations along the Phase 1 quay, hardstanding areas of appropriate size and load-bearing capacity should be provided at strategic points, together with truck access routes suitable for delivery and repositioning of containerised units. The civil provisions should anticipate typical containerised charger footprints and weights, and should include tie-down points, drainage, and clearance envelopes. Cable routes from this hardstanding to the quay face should be pre-installed as ducts or trenches to avoid the need for surface cabling during operation.

Protected shore-side connection points should be provided at regular intervals along the Phase 1 quay, with the associated civil works comprising weatherproof cabinets or pits, cast-in ducts through the quay structure, cable pull-pits, and foundations for above-ground equipment. Duct sizing should anticipate future upgrade to higher-power circuits, and spacing should allow flexible connection to a range of vessel sizes and manifold positions. Coordination with the quay structural design is essential to ensure that ducts and cast-in items are incorporated at construction rather than retrofitted.

A reserved footprint for a future Battery Energy Storage System (BESS) should be identified within the Phase 1 apron layout, with civil provisions including a prepared ground slab or reserved area of enhanced ground-bearing capacity, drainage, fire separation clearances from adjacent facilities, cable ducts routed to the shore-side connection points and to the future grid connection, and vehicular access for delivery and maintenance of containerised BESS units. Reserving and civilly preparing the space in Phase 1 avoids the significant cost and operational disruption of retrofitting these provisions in Phase 2.

All civil provisions should be developed in accordance with applicable safety and industry standards governing separation distances, containment, fire protection, and interaction with adjacent services. Early confirmation of the applicable standards framework is recommended to ensure that duct routing, cabinet locations, and BESS reservations remain compliant as the design develops.

10.4.2 Other Baseline Utilities and Reserved Corridors

Similarly, Phase 1 provision of other utilities should be focused on delivering the baseline services required for initial operations while reserving sufficient physical capacity within the site layout to accommodate the expanded demands of Phase 2 without disruptive retrofit works. The civil emphasis is on establishing well-planned, accessible corridors and connection points that can be progressively developed as demand grows.

A data and communications backbone should be established in Phase 1, providing fibre and copper connectivity between the operational areas, gate, quay, and any containerised modules or shore-side connection points. Civil provisions include dedicated data ducts (separated from power services), communications cabinets with reserved capacity, and pull-pits sized for future cable additions. The backbone should be designed to support progressive expansion for CCTV, SCADA, monitoring, and access control systems in Phase 2.

Reserved utility corridor planning is the most important civil provision in Phase 1, as it determines the ease and cost of Phase 2 expansion. Corridors should be identified across the site with sufficient width, depth, and separation to accommodate Phase 1 and future power, data, water, firewater, alternative fuel, and monitoring services. Reserved corridors should be documented on the composite utilities plan, protected from encroachment by other infrastructure, and where practical partially pre-installed with empty ducts and chambers to avoid future excavation across finished surfaces.

10.4.3 Phase 2

10.4.3.1 Fixed High-Power Charging and Grid Upgrade

Phase 2 electrification transitions from the flexible, mobile-based arrangement of Phase 1 to fixed, high-power charging infrastructure, requiring more substantial civil works to support permanent equipment installations, upgraded grid connections, and integrated BESS deployment. The civil scope should be developed to leverage the reserved footprints and duct provisions established in Phase 1, minimising rework.

Installation of fixed high-power chargers along the western quay will require dedicated equipment foundations, cable trenches connecting to the site distribution network, and protective enclosures or barriers. Foundation design should account for the loads, vibration, and interface with the underlying quay structure, and locations should be coordinated with vessel berthing arrangements, crane operating positions, and other quayside equipment. The trenching provisions provided in Phase 1 should be extended and completed in Phase 2 to provide the flexible cable routing required for high-power charging.

A grid connection upgrade may be required to support the increased electrical demand of Phase 2 operations, and the associated civil works may include a substation or transformer compound with prepared foundations, secure fencing, drainage, fire separation, and vehicular access; new cable routes from the point of grid connection to the site distribution and BESS locations; and any works required within the utility provider's easements. The substation footprint should be identified and reserved at concept design stage to allow coordination with other landside developments.

Deployment of the Battery Energy Storage System within the footprint reserved in Phase 1 will require completion of the civil works to a state suitable for permanent installation, including final ground slab, containment, drainage, cable terminations, fire suppression provisions, and access. Coordination between the BESS civil works, the grid upgrade, and the charging infrastructure is essential to ensure a consistent overall arrangement.

Coordination with the utility provider is critical to the civil scope of Phase 2, particularly in defining the physical point of grid connection, the extent of works within utility easements, the location and configuration of any new substation, and the sequencing of civil works to align with utility programme milestones. Given typical utility lead times, this coordination should begin during the latter stages of Phase 1 delivery to avoid programme delays to the Phase 2 civil works.

10.4.3.2 Expansion of Other Utilities and Monitoring

Enhanced data infrastructure in Phase 2 should provide the higher bandwidth, redundancy, and coverage required to support expanded operations. Civil works include additional fibre routes (using the reserved corridors established in Phase 1), additional communications cabinets, and connection points at all new operational areas. Redundant routing between key nodes should be provided to improve resilience.

Emergency response systems — including firewater distribution, fire hydrants, emergency lighting, alarm systems, and emergency communications — should be extended and enhanced in Phase 2 to reflect the expanded operational footprint and the introduction of higher-risk activities such as alternative fuel handling and high-power charging. Civil provisions include firewater mains and hydrants along the western quay, foundations for emergency equipment, and reserved routing for future upgrades. Design should be developed in coordination with the applicable safety and regulatory frameworks.

Monitoring, SCADA and digital twin integration in Phase 2 could build on the data backbone to provide comprehensive operational visibility across the site. Opportunities for these should be explored. Civil provisions would include cable routing and mounting points for structural monitoring instrumentation (on the quays, revetments, and other key assets), CCTV and access control installations, environmental monitoring stations, and central control facilities. The instrumentation strategy should be developed early in Phase 2 to ensure that mounting provisions and cable routes are incorporated during construction rather than retrofitted.

10.5 Information Requirements

10.5.1 Overview

The recommendations set out in this report are based on the best information currently available, principally the Foth survey of September/October 2025 and a site visit by Ramboll in January 2026, supplemented by publicly available site data and professional judgement. However, a number of significant information gaps exist across the site, and these gaps introduce uncertainty into the design assumptions and recommendations presented in the preceding sections. To progress the project into detailed design with confidence, and to avoid the risk of costly rework or unexpected site conditions during construction, a targeted programme of surveys and investigations should be undertaken during the next phase of the project.

This section consolidates the information gaps identified across the report and provides a checklist of the surveys and investigations recommended to close them.

10.5.2 Information Gaps and Limitations

The following information gaps and limitations have been identified and should be acknowledged in the ongoing design process:

- No underwater photographs available: the underwater portion of the existing bulkhead, the pile toes, the seabed profile at the wall face, and any scour or undermining could not be visually documented during the September 2025 survey.

- Restricted access: some areas of the existing quay could not be inspected at the time of the survey, and their condition is therefore unknown.
- Limited bathymetric data: water depths recorded at the time of inspection ranged from 10.5 ft to 14.6 ft, providing only a snapshot of the seabed profile at the time of survey. Longer-term bathymetric trends, scour patterns, sedimentation rates, and toe conditions are not established.
- Unknown bulkhead extents: the horizontal and vertical extents of the existing bulkhead, including embedment depth and any tie-back system, have not been established.
- Unknown condition of subsurface elements: the timber piles, the steel piles of the relieving platform, the bulkhead embedment, and any tie-back system have not been directly assessed.
- Unknown geometry of the relieving platform: the width of the existing relieving platform varies along its length and is not fully documented.
- Unknown ground conditions: subsurface conditions across the site — including soil stratigraphy, strength parameters, groundwater levels, and rock levels — are not currently characterised to a level sufficient for detailed design of the new bulkhead, piled quay, revetments, or ground improvement works.
- Unknown obstructions: legacy tie-rods, deadmen, abandoned utilities, buried debris, and remnants of earlier structures may be present but are undocumented, presenting risk to piling and anchor installation.
- Unknown sediment quality: the physical, chemical, and biological quality of sediments within the potential dredge footprint is not established, and contamination cannot be ruled out.
- Unknown existing bollard foundations: the configuration and extents of the existing bollard foundations along the western quay are undocumented.
- Unknown existing utility locations: the alignment and condition of existing site utilities have not been fully mapped.
- Ecological baseline data: vegetation, aquatic habitat, and species presence at the shoreline protection areas and dredge footprint have not been assessed.
- Sinkhole extents at the eastern shoreline: the extent, depth, and cause of the sinkholes identified at the eastern extent are not established.
- Existing bridge interface (eastern extent): the foundation and scour condition of the adjacent bridge, and any restrictions on works within its influence zone, are not documented.

10.5.3 Recommended Surveys and Investigations

To close the information gaps identified above and confirm the design assumptions underpinning this report, the following surveys and investigations are recommended prior to detailed design. Investigations should be scoped and phased to inform each stage of design development, with priority given to those items on the critical path for Phase 1 delivery.

- Underwater inspection of the existing western quay by diver or ROV, with comprehensive photographic and video records, covering the full length of the bulkhead, the seabed profile at the toe, any exposed pile elements, and evidence of scour or undermining – this may have already been completed by Foth.
- Access improvements to enable inspection of areas of the existing quay that were inaccessible during the September 2025 survey.
- Bathymetric survey across the full site footprint, including berth pockets, approach areas, and shoreline protection zones, to establish the current seabed profile and identify scour patterns, sedimentation trends, and toe conditions.
- Topographic survey of the landside areas, coordinated with the bathymetric survey to provide a continuous site model.
- Geophysical investigation, including sub-bottom profiling and magnetometer survey, to establish bulkhead embedment depth, identify tie-back systems, locate buried obstructions, and characterise sub-seabed stratigraphy.
- Geotechnical investigation comprising boreholes and cone penetration tests (CPT) along the alignments of the new bulkhead, piled quay, revetments, ground improvement zones, and heavy equipment foundations, extended to sufficient depth below anticipated pile toe levels to characterise founding strata.
- Intrusive investigation to confirm the configuration and condition of the existing bulkhead embedment, tie-back system, timber piles, steel piles of the relieving platform, and existing bollard foundations.
- Material testing of the existing structures (supplementing work already undertaken by Foth)
- Sediment characterisation across the potential dredge footprint, comprising physical, chemical, and biological testing of representative samples, to inform dredging methodology, disposal options, and permitting.
- Contamination investigation of landside soils and groundwater at the shoreline protection areas and other zones of proposed excavation or ground improvement, to identify any contamination that may affect design, construction methodology, materials handling, or disposal.
- Ecological survey covering vegetation, aquatic habitat, and species presence at the shoreline protection areas, dredge footprint, and any other areas of proposed disturbance, to inform ecological impact assessment and permitting.
- Sinkhole investigation at the eastern shoreline, comprising targeted boreholes, geophysical survey, and inspection to establish the extent, depth, and cause of the sinkholes and any associated subsurface voids.
- Bridge interface assessment at the eastern extent, undertaken in coordination with the bridge owner, to establish foundation conditions, scour risk, and any restrictions on adjacent works.
- Utility survey to map the alignment, depth, and condition of existing site utilities, including any redundant services that may present obstructions.

- Hydrodynamic and metocean data review, covering water level variation, currents, waves, ice conditions (where relevant), and vessel wash effects, to inform design of the quay, revetments, and berth pocket.
- Structural re-assessment of the existing quay based on the updated survey and investigation data, to confirm its residual capacity in its retained secondary role behind the new bulkhead, or the decision may be taken to ignore any contribution made.
- Navigation and manoeuvring study to confirm approach, turning, and passing clearances for the expanded Phase 2 vessel envelope, and to inform tug support requirements.

10.5.4 Recommended Approach

To manage the investigation programme effectively, the following approach is recommended:

- Prioritise investigations on the critical path for Phase 1 design, particularly geotechnical, bathymetric, and underwater inspection works;
- Undertake early sediment characterisation during Phase 1 to inform Phase 2 dredging planning and permitting well in advance of works;
- Coordinate investigations across disciplines to avoid duplication and to allow shared use of marine plant and access arrangements;
- Engage regulatory authorities early to confirm baseline data requirements for permitting, so that investigations can be scoped to meet both design and consenting needs;
- Document all investigation outputs in a central project data register to support consistent use across design disciplines and future phases.

10.6 Conclusions and Recommendations

The infrastructure options developed in this report provide a phased, adaptable pathway for the redevelopment of the port site, enabling early operational capability under Phase 1 while preserving flexibility to accommodate expanded vessel operations, alternative fuel handling, floating dry dock capability, intermodal connectivity, and high-power vessel charging under Phase 2. The principal conclusions of the assessment are as follows.

- Existing shoreline structures. The condition of the existing shoreline structures along the site frontage is generally assessed as Poor to Fair, based on a review of the Foth inspection observations (Ref: Drg Inspection Observations Sheet 1 of 1, dated 10 October 2025, and Drg Demo Plan C-102, dated 15 October 2025). Documented defects include steel sheet pile section loss, widespread concrete cope spalling with exposed reinforcement, failed bollards, and timber and steel pile-supported relieving platforms of unknown condition. The observed deterioration is consistent with an aging composite structure that has exceeded its serviceable life for the operational demands anticipated under Phase 2.

- Need for wall upgrade and substitution. The Foth proposals recommend the upgrade and substitution of the existing wall for the entire frontage (Ref: Foth Memorandum Innovation Detroit – Conceptual Development & Class 4 Cost Opinion, dated 22 April

2026). Ramboll agrees with this conclusion, and this report has developed a number of additional considerations relevant to the design and delivery of the new wall, including the interaction between the new bulkhead and legacy bollard foundations, the surcharge implications of the potential rail spur, the opportunity for a piled crane loading platform, and the additional infrastructure requirements associated with alternative fuel vessel operations.

- Relieving platform at the eastern end. At the proposed relieving platform at the eastern end of the site, the need for additional sheet piling may be removed if the underlying slope is incorporated into the slope stability of the structure and appropriate load restrictions are implemented on the platform. This offers a potential cost and constructability benefit and should be developed further during the next design stage, subject to confirmation of ground conditions and operational surcharge requirements.
- Dredging. The Foth proposals recommend that no dredging is required. Ramboll's view is that dredging may in fact be required, depending on the final decision on the maximum design vessel (informed by the business case) and the corresponding required water depth at the quay. Under the larger vessel scenario (Scenario 2), significant dredging in front of the quay would be needed to achieve adequate under-keel clearance. Further considerations relevant to the dredging decision include:
    - Sediments are most likely contaminated, given the industrial heritage of the location, which would significantly influence dredging methodology, disposal options, and cost;
    - Ground conditions are unknown, and dredging will have a significant impact on wall stability and, therefore, on the required structural design of the new bulkhead;
    - Maintenance dredging may be required on an ongoing basis, depending on the existing sedimentation regime of the river, which could add significant operational expenditure (OPEX) to the project over its lifetime.
- Alternative fuels. The business case also refers to the opportunity for alternative fuels to be tested at the facility. Should vessels handling such materials be accommodated, the required marine furniture will differ from that used for conventional vessels, including changes to fendering (potentially foam, pneumatic, or panelled cone fenders to reduce hull pressure), mooring furniture (quick-release hooks with line monitoring), and the introduction of fixed loading arms, plinths, pipelines, and gantries with associated safety separation distances.

Based on the conclusions above, the following recommendations are made to progress the project through the next phases:

- Progress the design of a new wall across the entire frontage, adopting a new anchored steel sheet pile bulkhead as the reference structural form for the western quay;

- Develop the eastern relieving platform option further to test the feasibility of removing the additional sheet piling by incorporating the underlying slope into the slope stability design, subject to defined load restrictions;
- Undertake the surveys and investigations identified above to close the significant information gaps affecting design confidence, particularly in relation to ground conditions, existing structure configuration, and sediment quality;
- Confirm the dredging strategy on the basis of the selected design vessel and the outcome of sediment characterization, integrating dredging design with structural design of the new bulkhead;
- Establish reserved provisions in Phase 1 for the Phase 2 infrastructure requirements identified in this report;
- Engage regulatory authorities and the utility provider early, given the long lead times typically associated with dredging permits, environmental approvals, and grid connection upgrades.

11. Funding options and strategies

11.1 Funding Strategy Overview

The Innovation Terminal is likely to require a layered funding strategy because the capital program combines several different project drivers: contaminated sediment management, navigational dredging, quay and upland infrastructure, energy transition infrastructure, research and demonstration facilities, and academic or industry-led technology validation. No single funding source is expected to align with all of these elements. The most effective approach will likely be to separate the program into fundable components, match each component to the most appropriate state, federal, academic, private, or philanthropic source, and maintain a phased capital plan that allows early work to proceed while larger grant or cost-share opportunities are pursued.

11.2 Sediment, Dredging, and Environmental Remediation Funding

Sediments within the channel and adjacent berth areas are considered to be impacted by historical industrial, port, and urban waterfront uses. As a result, any dredging program should be evaluated not only as a navigation improvement, but also as a potential sediment remediation or sediment management project. This distinction is important because maintenance or development dredging that involves impacted sediment may create additional sampling, permitting, handling, treatment, disposal, and long-term liability considerations, but it may also allow the Port to access environmental restoration funding sources that would not typically be available for conventional port dredging.

The Great Lakes Legacy Act (GLLA), implemented through the U.S. Environmental Protection Agency's Great Lakes National Program Office, should be evaluated as a priority funding pathway if sediment characterization confirms contamination that is contributing to environmental impairment within the Detroit River Area of Concern. GLLA funding is intended to accelerate contaminated sediment remediation in Great Lakes Areas of Concern and can support projects that advance cleanup, beneficial-use impairment removal, habitat restoration, and waterfront revitalization. A GLLA-supported project would likely require a non-federal sponsor, a defined sediment remedy, early coordination with EPA and state regulators, and a credible implementation schedule. If applicable, the Port should frame dredging as a combined navigation, remediation, habitat, and redevelopment project rather than a stand-alone capital dredging activity.

A couple additional notes on GLLA funding:

- Typically, covers about half to two-thirds of eligible project costs while requiring a non-federal match of at least 35 percent.
- Non federal match can be cash and/or in kind contributions from states, tribes, local governments, port authorities, NGOs, and private/industrial partners can all count toward the non federal share if properly documented.

- GLLA funds are often used for dredging, dewatering and disposal of contaminated sediment.
- Recent dredging in the Rouge River Old Channel was completed under this program.

Next steps for pursuing environmental funding related to sediment and dredging include completing a targeted sediment investigation, comparing results to regulatory and disposal criteria, identifying whether dredging would remove or isolate legacy contamination, and coordinating with EPA, the Michigan Department of Environment, Great Lakes, and Energy, and other stakeholders to determine whether the project could be positioned for GLLA, Great Lakes Restoration Initiative, or complementary state environmental funding. Early technical scoping should also distinguish between material that may be suitable for confined disposal, treatment, beneficial reuse, or upland landfill disposal, as funding eligibility and project cost can vary significantly depending on the selected sediment management strategy.

11.3 Port, Freight, and Infrastructure Funding

Typical port-development funding sources should be pursued for quay construction, berth improvements, apron construction, utility corridors, freight-supportive upland improvements, intermodal access, berth deepening that is not otherwise eligible as remediation, and equipment that improves port efficiency or safety. The U.S. Department of Transportation's Maritime Administration Port Infrastructure Development Program is the most directly aligned federal grant program for port capital projects, particularly where the project improves the safety, reliability, or efficiency of goods movement within or around a port. Other federal transportation programs, including multimodal freight grant programs and low-interest federal credit assistance, may also be applicable depending on the final project scope, public benefits, revenue structure, and benefit-cost analysis.

State and regional infrastructure funding should also be evaluated, including Michigan port, freight, economic development, brownfield, environmental infrastructure, and resilience programs. State-backed loans, revolving funds, municipal bonds, tax increment financing, brownfield redevelopment authorities, public-private infrastructure contributions, and local match programs may be useful either as stand-alone funding sources or as required non-federal match for federal grants. The Port should build the capital plan so that local or state sources can be used strategically as match for larger federal awards rather than consumed on early work that lacks leverage.

11.4 Academic, Research, and Demonstration Funding

Because the Innovation Terminal is intended to support research, testing, demonstration, and technology validation, academic and research-oriented funding should be treated as a distinct funding pathway. University-led or consortium-based proposals may be able to support portions of planning, design, instrumentation, data systems, pilot equipment, workforce development, testing protocols, environmental monitoring, and technology demonstration costs. These funds are unlikely to pay for all core civil works, but they can meaningfully reduce the cost of specialized systems that support electrification, alternative fuels, vessel retrofits, digital port operations, emissions measurement, autonomous or remote operations, and applied maritime innovation.

In addition to the established collaboration with University of Michigan, potential sources include National Science Foundation research and engineering programs, U.S. Department of Energy maritime innovation and clean-energy demonstration programs, ARPA-E opportunities, university research grants, state university-industry partnership programs, philanthropic climate and freshwater initiatives, and industry-sponsored research agreements. The strongest candidates will likely be projects that combine physical infrastructure with measurable research outcomes, such as shore-power demonstrations, battery energy storage integration, low-carbon fuel handling protocols, emissions reductions, digital twin development, water-quality monitoring, sediment beneficial-use evaluation, or resilient port operations. Partnering with universities, national laboratories, equipment suppliers, vessel operators, and technology developers can improve competitiveness and allow research funds to support instruments, equipment, pilot systems, and data platforms that would otherwise be carried as project capital costs.

11.5 EPA Identified Funding Opportunities for Ports and Near-Port Communities

A current port-related funding matrix is maintained by EPA as part of their Port Initiative program (EPA Ports Initiative funding opportunities matrix). EPA notes that the matrix lists current and recent funding opportunities for port facilities and near-port communities to reduce emissions, improve environmental performance, and increase efficiency. The following currently open/applicable funding sources are listed on the matrix and appear most relevant for Port Detroit's Innovation Terminal.

- Economic Development Administration Planning Program & Local Technical Assistance Program: This program is listed as open with applications accepted on an ongoing basis. This could support early-stage planning, economic development strategy, resilience planning, green infrastructure concepts, and technical assistance tied to the Innovation Terminal's role in maritime innovation, clean energy, and job creation.
  - *Applicability*: Strong fit for planning, feasibility refinement, economic impact analysis, implementation strategy, grant packaging, and partnership development.
- Economic Development Administration Public Works and Economic Adjustment Assistance Programs: This program is listed as open with applications accepted on an ongoing basis until a new notice of funding opportunity is published, with individual awards ranging from $100,000 to $30 million. This program could support infrastructure and facility work that advances economic development in distressed communities.
  - *Applicability*: Potentially relevant for terminal infrastructure, utility corridors, innovation facilities, public waterfront industrial redevelopment, and infrastructure that supports job creation, private investment, and maritime-sector growth.

The EPA Ports Initiative provides a central resource for funding, best practices, clean-air strategies, port-community collaboration, technical tools, and grant-related resources for ports and near-port communities. It is a useful source for identifying applicable funding opportunities and maintaining awareness of future port-specific environmental funding.

11.6 Additional Funding Options to Consider

- **DOE and energy-transition demonstrations:** Potentially applicable to battery energy storage, shore power, vessel charging, alternative-fuel pilot systems, microgrid integration, and applied decarbonization research.
- **Brownfield and site redevelopment programs:** Applicable where upland contamination, industrial legacy conditions, demolition, environmental due diligence, or site preparation must be addressed before terminal redevelopment.
- **Resilience and climate-adaptation funding:** Potentially applicable to shoreline protection, flood resilience, stormwater upgrades, utility hardening, and adaptive infrastructure that protects port operations.
- **Economic development and workforce funding:** Applicable to job creation, maritime workforce training, technical education partnerships, and innovation-economy development tied to the terminal program.
- **Private-sector and equipment-vendor participation:** Equipment manufacturers, vessel operators, technology developers, and fuel suppliers may contribute funding, in-kind equipment, pilot systems, operating commitments in exchange for demonstration access, data rights, or early market validation.
- **Philanthropic and foundation support:** Freshwater, Great Lakes, climate, environmental justice, and regional economic development foundations may support planning, community engagement, monitoring, education, and early implementation elements that are not readily funded through conventional port grants.
- **Public-private partnership or lease-backed financing:** If future users can be identified, the Port could structure selected improvements around leases, user fees, concession agreements, or shared-use infrastructure contributions to reduce the public capital burden.

11.7 Recommended Funding Approach

The recommended approach is to organize funding around discrete, defensible project packages. Package 1 would focus on sediment characterization, environmental due diligence, and regulatory coordination so the Port can determine whether GLLA, GLRI, state environmental, or brownfield funding is available. Package 2 would focus on Phase 1 port infrastructure, including the new quay, apron, utility corridors, and flexible terminal improvements, with MARAD and state port-development funding as the primary targets. Package 3 would focus on research and demonstration systems, including electrification readiness, instrumentation, data platforms, and pilot equipment, with academic, DOE, NSF, ARPA-E, vendor, and industry-partner funding as the primary targets. Package 4 whould preserve Phase 2 expansion options, including deeper dredging, western quay rehabilitation, fixed charging, alternative-fuel systems, and larger-vessel access, but defer major commitments until user demand, sediment strategy, permitting, cost-sharing, and grant eligibility are better defined.

This funding strategy should be revisited after completion of the sediment investigation, refinement of the Phase 1 capital cost estimate, and confirmation of likely terminal users. The Port should maintain a funding matrix that tracks each capital element, likely funding source, sponsor or applicant, match requirement, eligibility risk, anticipated application schedule, and dependencies. This will allow the project team to pursue multiple funding streams in parallel while avoiding scope overlap, double counting of match, or commitments that limit future grant eligibility.