Mærsk Mc-Kinney Møller Center
for Zero Carbon Shipping

Methanol Ship Design and Operations

Operational Experience from Early Adopters

Onboard and vessel technologies, October 2026

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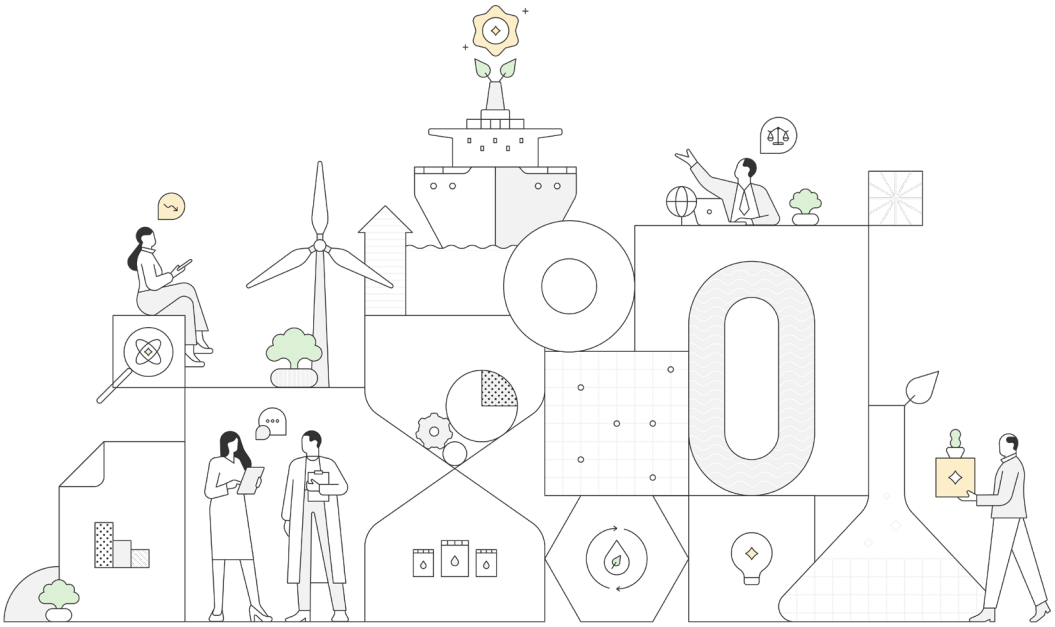
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Executive summary

Methanol is one of the few alternative fuel pathways in operational use today. A group of first movers has accumulated experience of running methanol-fueled vessels in commercial service, and that experience has so far remained largely inside the organizations that acquired it.

Consolidating these experiences, this report's findings draw on interviews, workshops and written contributions from vessel operators, shipyards, engine and equipment manufacturers, ports and terminals that have designed, commissioned, crewed, operated and bunkered methanol-fueled vessels through to 2025. Their central finding is that methanol can be operated safely and effectively in commercial service, and that vessel operations proceeded without fundamental barriers where systems, procedures and crew competence were aligned. That alignment begins in preparation, design, and training and continues into operation, system integration, safety, regulatory approval, and bunkering.

Early design decisions set the operating burden for the vessel's life. For retrofits, two factors decide which vessels were candidates at all: whether a methanol dual-fuel retrofit kit existed for the installed main engine, and whether tank volume and fuel-system spaces could be accommodated without undermining structure, arrangement or commercial efficiency. Kits were available for only a limited number of main engines still in production and four-stroke auxiliary conversion was largely unavailable, so methanol was implemented on the main engine with auxiliaries left on conventional fuel. Newbuilds carried no such constraint and could integrate tanks, cofferdams, hazardous areas and bunkering arrangements within a single design concept. The same fuel therefore produced materially different design outcomes depending on the route taken.

Operators built vessel-specific training on top of the mandatory courses. Mandatory training provided the foundation, while operators added practical instructions tied to their own vessels, covering alarm interpretation, automation logic and hazard recognition. Retaining that competence proved harder than building it, particularly where methanol use was intermittent.

Operational success depended on system integration. Complexity concentrated at the interfaces between fuel supply, automation and safety systems. Many of the faults reported in service originated in automation logic, sensor signals, and sequences that stopped while waiting on interlock and permissive conditions.

Safety performance came from layers acting together. It was the combined outcome of engineered safeguards, automation, detection systems, procedures, risk management controls, emergency preparedness, and competent crews. Incidents were minor, arising during maintenance, confined-space entry and configuration changes, with procedures and human factors being the common theme of causality.

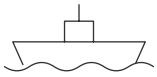
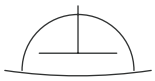
Regulatory interpretation varied across class societies, flag states and jurisdictions. The current International Maritime Organization (IMO) framework functioned as a workable interim basis for the first projects, and it left substantial room for interpretation during design and approval. One respondent described taking the same arrangement to two class societies and receiving two different answers. The consistent request was for clearer definitions and more standardized interpretation.

Bunkering became routine where readiness had been built. Port calls proceeded much as they did for conventional vessels once familiarity was established. First-of-a-kind bunkering operations required extensive coordination between operators, suppliers, ports, regulators and emergency responders, and procedures converged as experience accumulated. Success continued to depend on local readiness and on the competence of everyone at the quay.

The first movers have established that methanol works in commercial service. The next step is to implement methanol consistently across more vessels and more ports and to enable crews and shore teams to operate and manage the required systems.

Summary findings

Methanol has moved from concept to operational reality. The table sets out the main finding of each section and the audience it was written for. The sections are designed to be self-contained, and together they provide a connected view of how methanol systems are implemented and managed in practice.

Section	Main finding	Audience
 2 Vessel Design and Retrofit considerations	Engine kit availability and tank space are the binding constraints.	– Naval architects – Newbuild and retrofit project managers
 3 Training and capability development	Additional training beyond minimum requirements improved competence.	– Manning and crewing managers – Superintendents – Fleet operations – Seafarers
 4 Technical operations in service	Operational success depends largely on system integration.	– Superintendents – Senior engineers – Technical managers
 5 Safety and regulatory learnings	Safety is achieved through layered protection.	– Health, Safety, Environment and Quality and staff – Masters and chief engineers – Operations and technical managers
 5.8 Regulatory experience and evolving guidance (with supporting material at 6.11)	Regulatory frameworks are largely functional but continue to mature.	– Policymakers – Class societies – Flag states
 6 Cargo, port and bunkering operations	Bunkering has become increasingly routine, but readiness remains essential.	– Port and bunkering operations – Chartering and operations – Terminal and supplier partners

01 Introduction

Shipping decarbonization is entering a phase of practical implementation with multiple alternative fuel pathways. However, shipowners are adopting cautious and case-specific fuel strategies to balance compliance, operational flexibility, and commercial risk. Within this context of uncertainty, a limited number of fuel pathways have progressed beyond concept into operational use. Among these, methanol has emerged as one of the most prominent, already being applied in practice.

Methanol offers a credible route to lower lifecycle greenhouse gas emissions where low-carbon methanol production is available. Despite this progress, there remains limited public information on how methanol performs in day-to-day operation and what is needed for it to be managed effectively in service.

This report addresses that question from the perspective of operational practice. It is intended for shipowners, managers, charterers, ports, regulators, and other stakeholders moving from concept evaluation to implementation. It draws on direct experience from first movers across the value chain – vessel operators, shipyards, original equipment manufacturers (OEMs) and ports who have commissioned, operated, and supported methanol-fueled vessels in service. The analysis spans areas such as vessel design, training and competence, operational performance, maintenance, safety management, emergency response, and the port and bunkering interface. A central premise of this report is that the most useful lessons come from execution — how systems behave in practice, how crews interpret and respond to them, and how procedures evolve over time. These insights determine whether a fuel is not only technically feasible, but operationally reliable in commercial service.

This report follows the transition from concept to operation:

Section 2 covers vessel design and retrofit, from the choice between retrofit and newbuild through tank location and cargo capacity, fuel flexibility, hazardous zoning and bunkering arrangements, to commissioning and handover.

Section 3 covers training and capability development: what mandatory courses provided, what respondents built on top of them, how crew and shore staff readiness was assessed, and where gaps remained.

Section 4 covers technical operations in service — engine and fuel-system behavior, auxiliary, automation and leak-detection systems, and the effect of methanol on maintenance regimes, spares and shore support.

Section 5 covers safety and regulatory learnings, from safety-management changes, personal protective equipment (PPE), gas detection and emergency preparedness through incident experience and insurance, to inspection in service and the state of regulatory guidance.

Section 6 covers the vessel–port interface: voyage planning and trade deployment, port and terminal readiness, permitting and pre-arrival coordination, bunkering operations, venting, cargo operations during bunkering, sampling, and spill response.

Section 7 draws the findings together and sets out what they imply for organizations preparing to adopt methanol.

Readers may approach this report either sequentially or by focusing on sections most relevant to their role.

Methodology

This report was developed through structured engagement with organizations holding direct experience of methanol-fueled vessels — organizations involved in the design, construction, operation, maintenance, technical support and bunkering of those vessels. Participation spanned the value chain: vessel operators, shipyards, engine and equipment manufacturers, ports and terminals, and other stakeholders supporting methanol projects in service. Contributions covered both newbuild and retrofit projects, and both vessels in commercial trade and the shoreside organizations supporting them.

Input was gathered through interviews, workshops, review meetings and written contributions. Interviews followed a common thematic frame — design and retrofit, training and competence, technical operations, maintenance, safety management, emergency response, and the port and bunkering interface — so that experience from different parts of the value chain could be compared theme by theme. In total, the study drew on over 35 interviews involving over 50 participants from 9 organizations. Workshops and review meetings were used to test emerging findings with contributors and to resolve points on which accounts differed. Written contributions supplied supporting detail on specific systems, procedures and events. The evidence base for this report closes at the end of 2025, and the findings describe first-mover methanol practice as it stood at that point.

Contributions were aggregated and anonymized. The Center synthesized them to identify recurring themes, points of divergence, and the practical lessons that first-mover projects reported. The findings are therefore the Center's interpretation of the collective account and are not attributable to any single participating organization.

Contributions

This project was a collaboration between the MMMCZCS and our partners: A.P.Møller Mærsk, V-Ships, Xpress Feeders, NYK, Port of Gothenburg, Port of Rotterdam, Everllence, Tsuneishi Shipyard, Hyundai Heavy Industries. Additionally, the project was reviewed by DNV, Seaspan and The Global Methanol Alliance (formerly The Methanol Institute).

Participants:

MAERSK

V-Ships

X-PRESS FEEDERS

NYK LINE NIPPON YUSEN KAISHA

PORT OF GOTHENBURG

Port of Rotterdam

Everllence

TSUNEISHI

HD HYUNDAI HEAVY INDUSTRIES

Reviewers:

DNV

seaspan

The Global Methanol Alliance

A note on terms

This report uses respondents for the organizations that contributed to the project and the individuals who spoke on their behalf, referred to collectively and without attribution to any one of them. Where the report states that respondents reported, described or highlighted something, it refers to that aggregated account. Respondents were not a survey panel, so the term identifies the source of a statement rather than a measured proportion of any population.

First mover describes the same organizations in a different aspect — their position among the earliest to design, build, operate or bunker methanol-fueled vessels — and is used of their projects, vessels, practice and experience rather than of their statements. Where the report names a segment — vessel operators, shipyards, engine and equipment manufacturers, ports and terminals — it does so because the experience described belonged to that part of the value chain.

Limitations

The findings rest on self-reported operational experience rather than on measured or independently verified performance data. Vessel types, engine configurations, fuel-system arrangements and operating profiles differed between respondents, and practice described on one vessel did not necessarily transfer to another.

Because the population of methanol first movers was small, coverage was uneven across the themes. Some points rest on accounts that converged across many respondents; others reflect the experience of a single project, and the report states which. Expressions such as consistently, several or one respondent describe the pattern of what was reported, not a count, and no frequency should be inferred from them.

Methanol-fueled shipping remains an evolving field. Technologies, operating practices, regulatory frameworks and industry experience continue to develop, and several of the constraints respondents described were already being addressed as the report was prepared. The report should therefore be read as a snapshot of first-mover experience at the time the project was conducted.

02 Vessel design and retrofit

For retrofit projects, engine kit availability and tank space were the primary constraints on feasibility. Early design choices for first movers had significant implications for maintenance, accessibility, bunkering arrangements, emergency response, and how safely crews could access, inspect and intervene in methanol systems. Respondents consistently highlighted the importance of considering operational realities during newbuilding and retrofit decisions.



Respondents described both newbuild and retrofit projects as vessel-specific integration programs requiring methanol systems to be adapted to the vessel design, operating profile, capacity management, yard capability, and organizational readiness. These conditions defined what was technically feasible, commercially acceptable, and operationally practical before detailed work on vessel design began.

Practical considerations for successful methanol vessel design included the trade-off between tank capacity and cargo capacity, stability, hazardous spaces, bunkering layout, access, and long-term maintenance. Additionally, methanol fuel system pipe routing and associated lines across the vessel affected pressure loss, space use, detector placement, ventilation behavior, and maintainability. Bunkering-station location affected hose handling, safety zones, cargo activity, and compatibility with local transfer practice.

This section focuses on how these design decisions were made in practice by first movers, highlighting the trade-offs, constraints, and integration challenges that emerged when methanol systems were implemented on real, commercially trading vessels.

2.1 Strategic design decisions: Retrofit versus newbuild

The choice between retrofit and newbuild remained one of the largest strategic decisions in methanol implementation. Across respondents this was driven by vessel age, capital availability, lead time, engine compatibility, regulatory timing, yard capability, and wider fleet strategy. However, in one case, a company described its first retrofit explicitly as a "proof of concept" intended to demonstrate that methanol retrofit was technically feasible.

Respondents described the considerations in Table 1 as shaping the choice. Engine compatibility and layout feasibility were singled out as the hardest and most decisive; the remainder set the commercial and practical boundaries around them.

Table 1: Decision filters applied to retrofit versus newbuild

Filter	What respondents assessed	Reported basis for the decision
Remaining vessel life	Trading years left after conversion	Business case held where 10–12 years remained
Time to operation	Delivery window	Retrofit ~3–6 months; Newbuilds ~24–36 months
Engine compatibility	Whether a methanol dual-fuel retrofit kit existed for the installed main engine	One of the hardest filters: only a limited number of modern main engines in production had commercially available kits; four-stroke auxiliary conversion was limited or unavailable
Layout feasibility	Whether tank volume and fuel-system spaces fit without undermining structural integrity, arrangement logic, or commercial efficiency	Decisive filter; drove the tank location study in 2.2
Yard capability	In-house engineering, hazardous-area competence, crane capacity, welding and materials control	Crane capacity around 150 tonnes governed module subdivision; fabrication, subdivision and lifting plans reviewed as part of cost and schedule evaluation
Off-hire exposure	Earnings foregone or replacement tonnage chartered during conversion	A real loss even where spare tonnage existed, since the vessel could not be deployed or sold while unavailable
Fuel availability and technology timing	Bunkering access and the pace of change in fuel supply, regulation and technology	Retrofit described as making sense only where supported by a clear multi-year plan
Fleet and regulatory strategy	Fleet renewal plans, compliance pressure, contract access	Newbuild favored where tonnage was needed anyway; retrofit used as a targeted compliance response, or as a proof of concept

A common consensus was that retrofitting business cases only made sense where a vessel still had significant years (10–12 years) ahead of it. A key difference between retrofits and newbuilds was the timeline involved. Retrofits were often seen as the shorter route into operation, with expected delivery windows around 3-6 months, while newbuilding programs were more commonly associated with 24-36 months. However, respondents were also clear that retrofits remained highly complex and demanded coordinated engineering effort, careful project planning, and tolerance for off-hire periods.

Newbuilds gave vessel designers freedom to integrate methanol-related design elements such as tanks, cofferdams, hazardous areas, fuel preparation spaces, venting arrangements, bunkering stations, and cargo layout within one integrated design concept. Companies planning fleet renewal or requiring additional tonnage therefore often favored newbuilds, with methanol integration following naturally from that broader decision.

Retrofits had to work inside an existing hull, machinery arrangement, and cargo layout. That meant methanol tank volume had to be created within available space, often requiring trade-offs involving cargo capacity, fuel endurance, or vessel arrangement.

Piping had to route around existing systems, hazardous spaces had to be introduced within pre-existing operational boundaries, and fuel preparation areas had to be fitted into configurations that had never originally been designed for them. Respondents believed this constrained the design space early in the design process.

Some respondents framed retrofit as especially relevant where the vessel segment offered unusually strong leverage for emissions reduction. One operator specifically pointed to Panamax and Kamsarmax bulk carriers because of their fleet share and the scale of emissions that could be addressed if methanol retrofitting could be made workable in those classes.

When selecting a vessel for retrofit, engine compatibility was one of the hardest filters because only a limited number of modern main engines still in production had commercially available methanol dual-fuel retrofit kits. Retrofitting the main engine also usually required major changes to the surrounding control, safety, and automation systems developed through an extensive hazard identification (HAZID) study, often followed by a hazard and operability (HAZOP) study, that engine manufacturers conduct with classification societies before releasing a new-fuel engine to market. At the time of the projects reviewed, four-stroke auxiliary genset conversion options were more limited and, in many cases, unavailable lacking a viable conversion pathway, or commercially unattractive, which reinforced the pattern of focusing methanol implementation primarily on the main engine. Layout feasibility formed another decisive filter, because methanol tanks and fuel-system spaces had to fit without undermining structural integrity, arrangement logic, or commercial efficiency.

Vessel off-service time impacted the retrofit business case significantly. Respondents explained that when a vessel was taken out of service for retrofit, the operator had to either accept reduced earnings or charter a replacement vessel of comparable size to preserve service continuity. Even where spare tonnage existed, off-hire remained a real loss because the vessel could not be deployed elsewhere or sold while unavailable. Fuel availability and technology timing also influenced the retrofit decision. Respondents described methanol retrofit as something that only made sense when supported by a clear multi-year plan, especially in a market where fuel availability, regulation, and technology continued to evolve. Some companies also saw retrofit as a targeted response to regulatory pressure where rapid compliance improvement could improve competitiveness or contract access, provided the vessel still had enough remaining life to justify the effort.

2.2 Tank location and cargo capacity

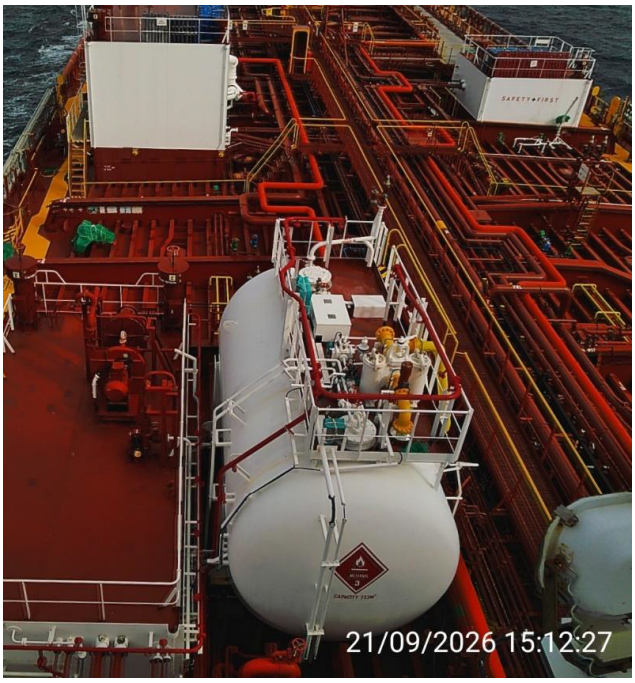
Methanol's lower energy density was one of the most consequential design issues because it directly impacted required tank volume, endurance, and cargo capacity. Respondents actively managed tank sizing from voyage demand and operating profile. One operator said explicitly that methanol tank capacity had been designed to support a single round voyage. For longer trades such as Asia–Europe, respondents explained that the preferred approach was to rely on a multi-port bunkering strategy.

Methanol tank location on board was evaluated against vessel-specific constraints including cargo impact, available space, hazardous-area requirements, trim and stability considerations, and bunkering arrangements. Locations considered in different projects included positions forward of accommodation, in cross-deck structures between hatch covers, under the upper deck, and inside the cargo hold. In one newbuild container-vessel project, the operator compared the implications of various configurations and ultimately placed the methanol tank inside the cargo hold as the most workable solution. Another operator also placed the tank in the cargo region specifically to minimize cargo loss, while positioning the fuel preparation room outside the accommodation block to simplify routing and reduce retrofit complexity. Other options, including use of existing fuel-tank spaces or upper-deck positions, were also assessed but failed to avoid deadweight loss while preserving conventional endurance and were therefore disregarded.

Many operators also adapted partial operations on methanol as the practical design basis. This allowed tank volumes to remain manageable while retaining conventional marine fuels as backup fuel. In practice, this approach depended on reliable bunkering access to methanol. One operator secured methanol supply in Rotterdam a year in advance. Another described vessel operation at approximately 50% methanol and 50% conventional marine fuels. By reducing endurance margins and avoiding excessive fuel storage, operators were able to manage the tank volume constraint without major impact on cargo intake.

The relationship between tank capacity and cargo intake impact was not a standard ratio. Cargo intake impact depended on vessel type, trade, and loading profile. One operator reported a loss of only 8 twenty-foot equivalent units (TEU) on a feeder vessel that still retained approximately 950 TEU after retrofit and considered that acceptable. Several respondents also stressed that nominal slot loss did not necessarily translate into the same reduction in cargo carried because many container trades were constrained by weight rather than slot count. Locating methanol tanks low in the vessel also improved stability and partially offset cargo penalties.

On-deck methanol storage tank. Image provided by NYK.



2.3 Fuel flexibility

Respondents were clear that current methanol vessel designs and retrofit packages were optimized specifically for methanol and offered only limited flexibility for later retrofit to other alternative fuels. Tank systems and fuel-supply arrangements were designed for methanol and other low-flashpoint liquid fuels, but would require substantial modification for fuels such as ammonia, liquefied natural gas (LNG), or hydrogen, which require fundamentally different storage and handling conditions.

Some respondents did acknowledge that certain liquid fuels, particularly other alcohols such as ethanol, could theoretically be used with limited changes to piping and pump systems. In practice, however, those options were not considered commercially or operationally relevant for the vessels under discussion. For any additional fuel requiring its own dedicated injection equipment, physical space around the engine was a key limitation, as space around each cylinder was very limited, making installation of a third parallel injection system extremely difficult. Carrying more than two fuels onboard would require dedicated storage, handling and injection arrangements for each fuel, increasing space requirements, reducing available cargo capacity, and adding substantial system complexity. Gas turbines were a theoretical route to broader fuel flexibility but were not considered viable for marine service because of efficiency limitations outside narrow operating ranges. The dominant conclusion across the interviews was that these vessels were fundamentally designed around methanol, and any future transition to a fundamentally different fuel — such as ammonia, LNG, or hydrogen — would require substantial redesign and reconstruction, whereas a transition to a closely related fuel such as ethanol was regarded as a comparatively minor adaptation.

2.4 Vessel design learnings

2.4.1 Key integration considerations, tank engineering, and coatings

One of the strongest design themes across the interviews was that methanol fuel tank design was shaped by fuel properties as well as by tank coating requirements. Inorganic zinc silicate was identified as the standard coating system across the projects reviewed. Uncoated tanks were investigated through corrosion testing but were not adopted. Stainless-steel tanks were also considered because they would remove coating requirements but were rejected due to high costs. Other coating systems were reviewed but not regarded as sufficiently proven or were associated with long-term performance concerns. In some projects, an enhanced coating arrangement was used by adding a phenolic epoxy layer over zinc silicate, and respondents reported good outcomes where application quality was high.

None of the respondents in this study used or evaluated uncoated tanks, with all reporting zinc silicate coating or stainless steel as the only options considered. External feedback received during their review process suggested that uncoated (black steel) tanks may already be viable and in use in some contexts. If confirmed, this could remove the need to relocate structural reinforcement outside the tank to accommodate coating applications, reducing both the cofferdam space penalty and the coating-related material and labor costs described elsewhere in this section — and warrants further investigation.

On-deck methanol storage tank. Image provided by NYK.



Respondents emphasized that long-term paint performance depended on surface preparation quality, accurate control of coating thickness, proper curing, and established arrangements for coating inspection, maintenance, and repair. These requirements also influenced tank design directly as zinc silicate was difficult to apply well on highly complex geometry and warranted simplified tank internals. Some considered corrugated bulkheads to reduce the number of internal stiffeners and inaccessible coating surfaces. Others explored moving structural supports out of the tank to facilitate coating. In several projects, the dependence between coating and structure influenced the move toward fewer, larger, and simpler tanks, especially where vessel size allowed that approach.

Tank arrangement was also a central early design decision. In container vessels, respondents described the move toward larger cubic tank geometries within the double hull, effectively creating a tanker-like section inside the vessel. Since methanol is stored as a liquid at ambient temperature and pressure, most projects did not see a need for LNG-style independent gas containment such as Type A, B, or C tanks. Type C tanks were studied in some cases, especially for retrofit or deck-mounted concepts, but for larger vessels they were rejected because they were space inefficient and commercially weak against cargo trade-off.

Respondents evaluated maximum feasible tank volume, the resulting impact on vessel deadweight and cargo capacity, structural impact, and the choice of tank containment concept — for example, integral tanks versus independent Type A, B, or C tanks — driven primarily by methanol's ambient-liquid storage properties and by retrofit or regulatory constraints. While methanol fuel systems remained relatively immature and more expensive, respondents anticipated wider adoption would help simplify design and reduce costs over time. Material compatibility extended beyond the tanks and included methanol-compatible pipes, valves, seals, gaskets, and other wetted components. Fuel transfer pump selection was an important design issue. Several projects preferred top-entry long-shaft electric or hydraulic-driven deep well pumps because they eliminated bottom penetrations, flanges, and gaskets, reducing leak risks and avoiding flooding scenarios that would be particularly difficult to recover from in methanol service. Leak recovery was considered more important than leak probability itself, because of vapor and toxicity restrictions on immediate crew intervention. Electric submerged pumps familiar from LNG service were regarded as unsuitable in some cases because methanol did not provide similar cooling to the pumps.

> The structure could not sustain the weight of the methanol hose, confirming that methanol designs could not simply inherit LNG bunkering-station conventions without careful review.

Safety considerations related to toxicity, flammability, double piping, ventilation, inerting, firefighting, gas detection, alarm systems, and isolation arrangements were integrated into vessel design from the beginning. The bunkering station was also described as a key integration point. One operator reported that the accepted bunkering station specification was not fully rule-compliant, because the support structure had been sized for lighter, rigid cryogenic LNG hoses rather than the heavier, flexible ambient-temperature hoses methanol requires — the structure could not sustain the weight of the methanol hose, confirming that methanol designs could not simply inherit LNG bunkering-station conventions without careful review.

2.4.2 Cofferdams and heat transfer

Cofferdam segregation between methanol tanks and adjacent tanks is a class-mandated safety requirement, with reduced conductive and radiative heat transfer as a useful secondary benefit of the dead space it creates. Respondents also managed heat-transfer risk through arrangement — keeping methanol tanks away from heated tanks or hot spaces wherever the layout allowed — as good practice layered on top of that mandatory segregation. Respondents also referred to the use of insulation on one or both boundaries, or within the cofferdam, where required.

To ensure effective application of zinc silicate coatings, structural members were often moved out of the methanol tank and into the surrounding cofferdams, which increased their size. Reported cofferdam widths ranged from approximately 640 mm in some cases to between 1,000 mm and 1,500 mm in others, particularly where inspection access, rescue, piping, or routing requirements required a wider space.

From a safety perspective, respondents regarded double-hull arrangements with cofferdams as advantageous. When a methanol tank is fully surrounded by a cofferdam, some fire-protection expectations may be simplified. By contrast, single-hull arrangements without cofferdams typically attracted more demanding fire-protection and hazard-management measures. Where cofferdam segregation was in place, adjacent ballast tanks were considered in some projects as an additional thermal and physical barrier, with their suitability depending on vessel type, stability, volume, and layout.

Operationally, cofferdams introduced their own requirements. Cofferdams were generally not mechanically ventilated continuously during normal operation. Temporary ventilation was commonly provided before entry. Where ventilation was provided, it was typically a non-permanent arrangement used ahead of entry — both to clear any flammable vapor and, just as importantly, to address the risk of oxygen depletion from local corrosion inside the confined space, which some respondents regarded as the more critical hazard given how quickly it can become life-threatening. Associated lines such as vent and sounding pipes often passed through cofferdams. Structural members could obstruct airflow and create local stagnation zones, which meant that cofferdam ventilation was not simply a fan-sizing question. Some respondents also referred to continuous temperature monitoring of methanol tanks, especially where high ambient temperature or heated adjacent spaces made heat ingress a realistic concern. Drainage and leak-collection arrangements in cofferdams were practical safety features, intended to catch methanol and prevent environmental spread in the event of leakage.

While cofferdams were structurally simple, robust, and familiar to classification societies, they consumed space, increased construction complexity, and created narrow confined spaces that were difficult to access, inspect, ventilate, and maintain. Emerging sandwich-panel and composite double-barrier arrangements were assessed as possible future alternatives, with the attraction of reduced thickness and improved space efficiency but were still immature concepts because of unresolved questions around fire safety, leak detection, leakage through both barriers, inspection after installation, and class and flag acceptance. Hence, under current conditions, cofferdams remained the only proven solution.

On-deck methanol storage tank. Image provided by NYK.



2.4.3 Nitrogen systems

Nitrogen generator systems were required for fuel-line purging in both newbuild and retrofit cases, driven by a combination of engine manufacturer specifications (such as MAN Energy Solutions' ME-LGIM[3] requirement for two separate nitrogen supplies at a minimum of 8 bar and 95% purity), low-flashpoint fuel notations issued by classification societies, and the functional goals for inerting, purging, and leak mitigation in the International Code of Safety for Ships using Gases or Other Low-Flashpoint Fuels (IGF Code)[6]. Respondents consistently identified nitrogen as the most practical inert gas solution, as flue gas was generally disregarded due to hydrocarbon contamination risk and operational uncertainty, and nitrogen systems were therefore adopted as the standard medium for both tank inerting and piping purging.

Respondents sized nitrogen generator capacity and buffer storage around routine purging demand, the most frequent and time-critical nitrogen consumption event. Calculations included the possibility of simultaneous purging of multiple consumers, such as the main engine and auxiliaries, within a defined time window, with both generator capacity and buffer storage derived from the number and frequency of possible purge events. A practical rule-of-thumb used was to size the system around 40-50% above this maximum expected purging demand. Full-tank inerting or purging is a separate, larger-volume operation, typically met through extended generator run-time or supplementary equipment sized independently of this routine margin. Gas-freeing subsequently requires replacement of the inert atmosphere with air and verification of safe conditions.

Tank inerting requirements also formed part of the design basis. Calculations involved tank volume, target oxygen concentration typically below 8%, required inerting time, leakage allowance, mixing efficiency, and environmental conditions. Some also referred to lower oxygen levels around 3% as a control threshold at which automatic nitrogen shut-off might occur. Emergency nitrogen bottles were deployed as backup support for the generator. In some configurations, the generator effectively acted as the means of replenishing these cylinders rather than feeding the whole system directly all the time.

Practical operating limitations with nitrogen generators involved reduced purging and inerting efficiency in very cold climates, and this influenced their design capacity. Nitrogen systems were thus implemented conservatively and integrated tightly with gas detection, ventilation, and emergency shutdown logic.

2.4.4 Gas detection, ventilation systems, and pressure relief valve (PRV) design

Methanol gas detection and ventilation required a fundamentally different design approach from LNG because of the way methanol behaved in a release scenario. Methanol tended to form liquid pools and evaporate gradually, resulting in slow dispersion of vapor rather than rapid flashing. This created a key detection challenge as vapor could be removed by ventilation before it accumulated to a level detectable by conventional fixed gas detectors. In one project, respondents reported that methanol vapor released in a confined or structurally complex space could take a prolonged period to reach a remote detector location, depending on geometry and leak position. This behavior reduced the effectiveness of conventional point-type gas detection and required deployment of sampling-based gas detection systems, where vapor was drawn through sampling lines to remote detection units. This also avoided placing sensors inside difficult or inaccessible spaces and reduced the need for crew entry for maintenance while improving detection reliability in low-dispersion environments. In some cases, this approach required alternative design approval, since guideline interpretations of the continuous-detection requirement were written with point-type sensors in mind rather than the sampling-based method deployed here.

Ventilation design was developed together with the detection philosophy. Low-level methanol leaks were addressed by adopting a two-stage ventilation approach, especially in spaces like fuel preparation rooms, with lower air-change rates during normal operation and automatic increase to higher ventilation rates upon gas detection or pre-defined alarm conditions.

> In one project, respondents reported that methanol vapor released in a confined or structurally complex space could take a prolonged period to reach a remote detector location, depending on geometry and leak position.

Pressure-relief valve outlet design introduced additional operational challenges. Respondents reported that vapor was drawn into engine-room ventilation intakes both from designated vent lines during intentional purging operations, such as after bunkering or before maintenance, and separately when a pressure-relief valve (PRV) lifted during an overpressure event. In response, respondents relocated vent outlets to remote deck positions, arranged for ventilation systems to shut down or divert automatically whenever a PRV lifted or a vent line discharged, and added gas detection in engine-room spaces to trigger isolation and shutdown if vapor ingress occurred. Some were also evaluating increased vent height and vapor treatment systems as further mitigation.

The design learnings reported across the projects are summarized in Table 2, with the operational consequence attached to each.

Table 2: Key vessel design learnings

Design area	What first movers decided	Operational consequence
Tank coating	Inorganic zinc silicate as the standard system, and in practice the only option yards would warranty; phenolic epoxy over zinc silicate where an enhanced arrangement was used; stainless steel rejected on cost; uncoated tanks investigated but not adopted	Coating quality depends on surface preparation, thickness control, curing, and an inspection and repair regime for the life of the tank
Tank internals and structure	Simplified internals; corrugated bulkheads considered; structural members moved out of the tank into the cofferdam	Fewer inaccessible coating surfaces inside the tank, at the cost of wider cofferdams
Tank arrangement	Fewer, larger, simpler tanks; larger cubic geometries within the double hull; integral tanks rather than LNG-style Type A, B or C containment	Follows from ambient-temperature liquid storage; Type C rejected on larger vessels as space-inefficient and commercially weak against cargo trade-off
Fuel transfer pumps	Top-entry long-shaft electric or hydraulic deep well pumps preferred; LNG-style electric submerged pumps regarded as unsuitable where methanol did not provide equivalent cooling	Eliminates bottom penetrations, flanges and gaskets, and the flooding scenarios hardest to recover from under vapor and toxicity restrictions
Cofferdams	Class-mandated segregation, widths of ~640 mm up to 1,000–1,500 mm; drainage and leak collection; non-permanent ventilation ahead of entry	Reduced heat transfer as a secondary benefit and simpler fire-protection expectations, against space consumed and confined spaces that are hard to enter and inspect
Nitrogen system	Nitrogen as the standard inert medium; capacity sized on routine purging demand plus 40–50%; emergency bottles as backup	Flue gas disregarded on contamination risk; reduced efficiency in very cold climates factored into design capacity
Gas detection	Sampling-based detection in place of conventional point-type sensors, in some cases requiring alternative design approval	Answers methanol's pooling and slow-evaporation behavior, and removes sensors from spaces the crew would otherwise have to enter to maintain them
Ventilation	Two-stage arrangement: lower air-change rate in normal operation, automatic increase on detection or alarm	Preserves the ability to detect a low-level leak that a continuously high rate would dilute below detectable concentration
PRV outlets and vent lines	Vent outlets relocated to remote deck positions; ventilation shut down or diverted automatically on PRV lift or vent discharge; engine-room gas detection added	Response to vapor drawn into engine-room ventilation intakes during purging and overpressure events; increased vent height and vapor treatment under evaluation

2.5 Hazardous zones, bunkering design, and cargo operations

Hazardous zones are an inherent feature of methanol-fueled vessels, and the design objective across projects was to minimize their extent and operational impact while maintaining compliance with the IGF Code, methanol interim guidelines, and class requirements. Using a predominantly risk-based approach, projects began with regulatory default hazardous zones defined around potential release points, and additional dispersion or ventilation studies were applied selectively where required, particularly for first-of-a-kind vessels or specific operational scenarios. For retrofit projects, existing studies from comparable methanol newbuilds were often considered sufficiently representative, and additional computational fluid dynamics analysis was not always required.

Methanol fuel preparation room. Image provided by NYK.



Fuel preparation rooms, methanol supply systems, and associated piping were physically segregated in dedicated hazardous compartments structurally separated from engine room, cargo spaces, and accommodation. Respondents explicitly stated that preserving the engine room as a non-hazardous space was the basic objective/requirement to avoid extensive use of explosion-proof equipment and maintain conventional machinery operations. Where boundaries with non-hazardous areas could not be avoided, designers applied double-wall piping, secondary containment, ventilation, gas detection, and automatic isolation as an integrated protection system. Double-wall piping provided monitored containment, while ventilation and detection were arranged to prevent vapor accumulation and enable early identification of leaks, with isolation logic limiting ingress and escalation.

Hazardous-zone influenced vessel layout, for example, the arrangement of accommodation, pressure–vacuum valve location, and freefall lifeboat access to ensure safe crew escape routes. Additionally, vent exhaust and air-intake openings were separated to limit hazardous-zone footprint and prevent recirculation of discharged vapors. Containment philosophy extended to leak management. Drain tanks, where installed, were typically sized for small local leak scenarios involving pumps, valves, and drip trays. Some vessels did not include dedicated methanol drain tanks and instead relied on compartmental containment and operational procedures. Methanol-contaminated bilge water could not be processed through conventional oily water separators and instead required segregated sumps, dedicated collection tanks, or methanol-specific monitoring systems.

Bunkering-system design drew heavily on tanker practice, benchmarked against LNG, liquefied petroleum gas (LPG), and product-tanker operations. In the absence of a dedicated methanol standard, companies developed internal specifications to ensure compatibility and safe operation. Manifold arrangements were intentionally configured to resemble product-tanker layouts, facilitating ship-to-ship transfer without hose crossovers. Closed-loop vapor-return systems were commonly adopted so that displaced tank vapors could be returned to the supplying vessel or facility.

Bunkering stations were positioned to avoid conflicts with cargo-handling equipment, accommodation openings, and hazardous-area restrictions. Flow capacity was determined by operational targets and practical transfer limitations. In one case, a target bunkering duration of approximately twelve hours for a vessel carrying 16,000 m^3 of methanol required a transfer rate of around 1,600 m^3/h, resulting in a configuration of two parallel eight-inch liquid hoses and a single vapor-return line.

The operational impact of hazardous zones on cargo handling was generally limited as hazardous zones were fully contained within methanol service spaces below the cargo deck. In newbuilds, where equipment such as vent masts extended near cargo areas, additional safeguards including gas detection, alarms, marking, and operational procedures were implemented. Operational impacts were typically confined to specific activities such as bunkering, venting, or maintenance and were managed through planning, permit systems, and crew procedures.

2.6 Retrofit learnings

2.6.1 Main barriers

Once a retrofit pathway had been identified, accommodating methanol systems within the existing vessel remained a significant challenge. Respondents highlighted trade-offs involving fuel-tank volume, cargo capacity, vessel layout, structural constraints, and integration with existing systems. Reuse of existing fuel tanks was also challenging because of segregation, piping, coating and material-compatibility requirements.

> Operators acted in practice as "system integrators" because a fully mature turnkey solution was not available yet.

Methanol retrofit is a highly complex integration exercise, requiring coordination of new fuel systems with existing machinery, automation, safety arrangements, and structural modifications. Shipyard capability constituted another barrier.

Respondents therefore repeatedly described operators as acting in practice as "system integrators", coordinating class, engine makers, fuel-system vendors, coating suppliers, automation providers, and yard teams because a fully mature turnkey solution was not available yet. Off-hire cost and lost service revenue reinforced the need for careful vessel selection, yard selection, and early risk mitigation.

2.6.2 Gaps and suggestions to improve the Interim Guidelines

Respondents aimed to comply with the International Maritime Organization's (IMO) Interim Guidelines for the safety of ships using methyl/ethyl alcohol as fuel (MSC.1/Circ.1621)[1] as closely as possible but also identified areas where the framework remained insufficiently practical or explicit. In some projects, alternative design approval was needed because the technically preferred solution did not align neatly with literal interpretation of the guidelines.

> Alternative design approvals were frequently used to reconcile practical safety outcomes with prescriptive requirements.

Two specific gaps were identified where the Interim Guidelines' literal requirements worked against practical safety outcomes. First, respondents considered sampling-based detection more effective than point-type detection for specific project arrangements and pursued alternative design approval for its use.

Second, the Interim Guidelines specify at least 30 air changes per hour in fuel preparation spaces. In specific projects, respondents concluded through risk assessment and supporting studies that a lower normal ventilation rate, combined with increased ventilation following detection, would improve early leak detectability. This alternative arrangement required approval. A further suggestion was that the guidelines should specify an expected height for pooled liquid following a leak, to support consistent detection and response design across projects.

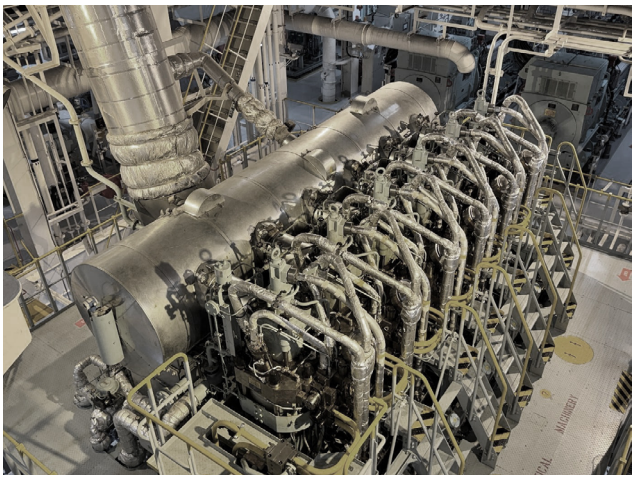
One specific suggestion was that thermal-imaging capability deserved more explicit recognition because methanol flames are difficult to detect visually in service. Several respondents also indicated that some parts of the current framework still inherited too much LNG logic, especially where methanol release, evaporation, and fire behavior differ materially.

2.6.3 Equipment, system integration and modification

Respondents experienced relatively limited impact on conventional engine-room machinery from methanol retrofitting, with most modifications concentrated on safety systems, controls, and methanol-specific support equipment. Components such as turbochargers and oil-mist detectors generally did not require resizing or replacement unless required by the engine OEM. OEMs generally defined methanol-retrofit requirements for the main engine during retrofit planning and execution, while operators played a central role in system integration, implementation, commissioning, and operational-readiness activities.

The most important engine-related changes were functional, involving upgrading of the engine safety and control architecture to enable methanol operation and integration of the vessel's wider alarm, monitoring, and control systems with methanol-related signals. These changes introduced additional components, piping, and controls around the engine, which in turn created new spatial and arrangement constraints.

Methanol dual-fuel engine. Image provided by NYK.



One respondent described a specific case where the methanol valve train had to be placed above the centerline of the main engine exhaust manifold. This proved particularly challenging on container vessels, where available space near deck level was limited, illustrating how system requirements directly influenced engine-room arrangement.

Respondents also highlighted software integration as an important and underestimated part of the retrofit. Methanol alarms had to be integrated into the vessel's existing automation, monitoring, and emergency shutdown logic in a coherent way. At the engine-room level, compliance with MSC.1/Circ.1621 and class expectations drove the addition of protection measures including double barriers around methanol systems, alcohol-resistant foam protection for relevant engine-room levels, and methanol gas detection around the main engine.

Auxiliary engines were generally left on conventional marine fuels as retrofit projects discussed were focused on main-engine methanol integration only. Respondents also said that base electrical loads usually remained within generator capacity and that additional load came mainly from methanol support systems. One further effect that had to be assessed case by case was the impact of lower exhaust-gas temperature and available heat during methanol operation. This could reduce steam production and waste-heat recovery output, affecting exhaust-gas boilers, waste-heat recovery systems, and steam turbines dependent on recovered exhaust energy.

2.6.4 Electrical load, power supply, and redundancy requirements

Methanol retrofit had limited effect on electrical-certification requirements. Existing IP ratings generally stayed the same, and only new equipment inside hazardous spaces needed to satisfy Ex requirements. Within the engine room, no major new Ex-rated equipment was generally required. Fuel-preparation rooms and other dedicated hazardous spaces were handled separately.

Methanol dual-fuel engine. Image provided by V-Ships.



At the same time, one retrofit yard reported a measurable increase in electrical load — around 100 kW — associated with methanol-related additions, including the main control console, extension alarms, additional bridge indications, and especially the nitrogen generator. Respondents noted that the increased load was driven above all by methanol support systems, particularly nitrogen generation and compressor demand.

The logic of emergency power support also remained specific. Methanol was treated as a secondary fuel, so no new emergency-bus or emergency-generator provision was generally made for continued methanol operation. The vessel was expected to fall back safely to the primary fuel (conventional marine fuel) if the methanol operation failed. However, some safety-critical methanol systems — including alcohol-resistant foam systems, gas detectors, and methanol-related leakage detection — were supplied from emergency power sources.

Redundancy was primarily applied to safety-critical and monitoring functions, while primary-fuel fallback provided an independent means of maintaining vessel operability following methanol-system shutdowns. Respondents noted, for example, that duplicate methanol pumps offered limited value because the methanol system had to be shut down, isolated, and purged before maintenance, so one pump could not simply take over seamlessly in all cases. By contrast, redundancy was clearer around ventilation, detection, monitoring, and other safety and control functions.

2.6.5 Retrofit execution and yard planning

The feasibility of a methanol retrofit depended heavily on yard readiness, coordination, and quality control. Crane capacity was identified as a foundational yard constraint because it determined how tanks, fuel-preparation rooms, and other large modules were subdivided, lifted, and installed. Capacities around 150 tonnes were cited in the interviews, depending on yard and configuration. Yards were therefore expected to submit fabrication, subdivision, and lifting plans aligned to actual crane capability, and these were reviewed as part of both cost and schedule evaluation.

Prefabricated tank installation was a way to reduce off-hire and limit intrusive steel cutting. On vessel types with sufficiently large hatch openings — especially some container vessels and bulk carriers — a prefabricated methanol tank could in principle be lowered into the hold using a floating crane. That was described as much less practical on vessels with smaller openings, such as tankers or some ro-ro designs.

In-house design capability at the yard was treated as a major advantage. Respondents said that while many yards could execute conventional steel repair, methanol projects required engineering teams that understand hazardous-area implications, class dialogue, and systems across mechanical, electrical, and control facets. Where engineering was outsourced, operators examined the competence and experience of the external design company carefully. Use of stainless steel required contamination control, material segregation,

qualified personnel, and dedicated work areas. Double-wall piping installation was singled out as one of the most difficult parts of retrofit execution, demanding skilled and specifically qualified welders.

One vessel-management company described maintaining a dedicated site team of naval architects, electrical and machinery specialists who worked closely with the yard's quality-control organization throughout the project. Structural modifications were prepared in prefabricated blocks, with assembly procedures reviewed jointly by design and site teams before installation. Welding control received particular emphasis because of thickness transitions and plate thicknesses reportedly reaching up to 100 mm in some areas. In that context, one operator required phased array ultrasonic testing to detect flaws, explicitly as an operator requirement above ordinary yard practice.

Another takeaway was the importance of accurate knowledge of the actual as-built condition. Several respondents said that 3D scanning of the main engine and surrounding spaces was essential as drawings alone were considered unreliable because vessels often diverged from drawings after years of modifications. The 3D model was a common reference point for clash detection (identification of physical conflicts between new and existing equipment), routing, and coordination between organizations responsible for concept design and detailed engineering.

System integration and commissioning were repeatedly described as among the most difficult stages of methanol retrofit and required handling as a set of connected vendor deliveries. A methanol retrofit typically involved the engine maker, fuel-supply system provider, automation supplier, integrated automation system, gas detection vendor, ventilation supplier, pump and valve makers, tank manufacturer, and coating supplier. All of these had to align around one emergency-shutdown philosophy and a consistent cause-and-effect matrix defining shutdown triggers, interlocks, alarm consequences, and actions across control and safety systems.

Respondents described monitoring and alarm integration as a weakness, especially where OEM systems, yard systems, and vessel systems had to communicate across multiple platforms. One respondent described an emerging best practice in which all relevant OEM software was brought together in a simulated or virtual environment before commissioning, so that communication and logic issues could be exposed before physical commissioning began onboard.

Responsibility allocation was another important theme. Formal responsible, accountable, supporting, consulted, informed (RASCI) matrices were not always used, either because they were not part of normal project culture or because turnkey yard contracts were assumed to define ownership implicitly. In practice, however, respondents repeatedly said that a more explicit RASCI approach would have been useful, especially in first-of-a-kind projects. One respondent gave a concrete example where an incorrectly designed and installed stripping-pump suction pipe was corrected quickly because the responsible party was identifiable immediately through such a matrix.

Finally, respondents described bunkering-system execution as a key retrofit-planning topic. In the absence of a global standard, methanol bunker stations were designed by adapting LNG, LPG, and product-tanker practice while respecting retrofit constraints, hazardous areas, and preserving existing deck fittings or deck arrangements where possible. Closed-loop vapor return was treated as a central principle. Flow rates, hose sizes, isolation valves, breakaway couplings, gas detection, instrumentation, interlocks, and hazardous-area-rated equipment were then integrated to support safe transfer within the limits of the existing vessel.

The retrofit execution phase extends beyond physical installation. System integration, testing, commissioning, and handover readiness were critical to ensuring that individual supplier systems functioned as a coherent operational platform.

The retrofit learnings reported across the projects are summarized in Table 3.

Table 3: Key retrofit learnings

Retrofit area	Constraint reported	What it required
Engine compatibility	Limited availability of methanol dual-fuel retrofit kits; auxiliary conversion largely unavailable	Methanol implementation focused on the main engine, with auxiliaries left on conventional marine fuels
Engine-room arrangement	New components, piping and controls around the engine; in one case the methanol valve train had to sit above the centerline of the exhaust manifold	Spatial coordination early in design, particularly on container vessels with limited space near deck level
Software and automation	Methanol alarms had to enter existing automation, monitoring and emergency-shutdown logic coherently	Software integration treated as a first-order workstream rather than a commissioning detail; respondents described it as consistently underestimated
Electrical load and power	~100 kW added, driven by nitrogen generation and compressor demand; methanol treated as secondary fuel	No new emergency-bus provision for continued methanol operation; safety-critical items — foam system, gas and leak detection — supplied from emergency power
Redundancy	Duplicate methanol pumps of limited value, since the system must be shut down, isolated and purged before maintenance	Redundancy concentrated on ventilation, detection, monitoring and control; primary-fuel fallback carries operability
Yard capability	Crane capacity around 150 tonnes governed how tanks and fuel-preparation rooms were subdivided and lifted	Fabrication, subdivision and lifting plans submitted against actual crane capability and reviewed in cost and schedule evaluation
Yard engineering	Conventional steel repair capability was not sufficient	In-house teams competent in hazardous-area implications, class dialogue, and mechanical, electrical and control systems; external design houses examined closely
Materials and welding	Stainless steel contamination control; plate thicknesses up to 100 mm at transitions; double-wall piping the most difficult installation task	Segregated work areas, qualified welders, and in one case Phased Array Ultrasonic Testing required above ordinary yard practice
As-built accuracy	Drawings unreliable after years of modification	3D scanning of the main engine and surrounding spaces as the shared reference for clash detection, routing and coordination

Vendor integration	Engine maker, fuel-supply, automation, detection, ventilation, pump, valve, tank and coating suppliers delivering in parallel	One emergency-shutdown philosophy and one cause-and-effect matrix across all deliveries; OEM software brought together in a simulated environment before physical commissioning
Responsibility allocation	RASCI matrices often absent, ownership assumed to follow turnkey contracts	Respondents concluded an explicit RASCI approach would have helped, particularly in first-of-a-kind projects
Bunkering station	No global methanol standard	Adaptation of LNG, LPG and product-tanker practice within retrofit constraints, hazardous areas, and existing deck arrangements, with closed-loop vapor return as the central principle



2.7 Commissioning and handover readiness

Respondents reported that commissioning methanol-fueled newbuilds involved additional complexity beyond conventional marine fuel vessels. A recurring challenge lay in the relative immaturity and integration complexity of methanol systems during early operation, particularly in first-mover projects. Early-life issues were commonly reported in injection equipment, auxiliary-engine injectors, high-pressure supply arrangements, and solenoid valves, some of which only became apparent after commissioning. Crew and shore-side familiarity with methanol systems was also identified as a recurring challenge during commissioning, particularly in early projects where practical operating experience was limited. Respondents noted that many of these challenges reduced as equipment designs, commissioning practices, and operational experience matured.

System integration was identified as one of the most demanding aspects. Methanol operation depended on seamless interactions between engines, fuel systems, compressors, purging arrangements, automation, and safety systems. Gaps in understanding of these systems led to repeated issues at both yard and site-office level. Processes such as flushing, purging, and fuel changeover depended on tightly coordinated interaction between multiple supplier systems. In practice, weaknesses between these system interfaces — particularly in signal alignment, sequencing logic, and responsibility boundaries — were a recurring source of operational issues during commissioning. Some vessels also revealed design weaknesses during trials, including pressure build-up in return lines during repeated purging and safety-valve releases on deck, highlighting verification gaps prior to delivery.

Crew competence and commissioning-team composition were critical success factors. Methanol systems introduced new operating modes, alarms, and safety requirements, while crews and shore-based personnel assigned to newbuilds often had limited dual-fuel experience. Several operators addressed this by deploying crews and relevant shore-based personnel well before delivery and involving them directly in commissioning (sea-trials) and initial bunkering to build familiarity and refine onboard procedures. Respondents emphasized the importance of including personnel with prior methanol or tanker experience who could apply independent judgement and identify system risks during handover.

Acceptance testing required thorough verification of methanol-specific systems, including tightness testing, purging sequences, valve function, double-wall leak detection, and automated control logic. Where delivery schedules were compressed, incomplete testing led to deficiencies becoming visible only during initial service.

Methanol newbuilds also required closer early-life operational follow-up. Particular attention was given to planned maintenance system (PMS) configuration, spare-parts planning, and mid-term inspection expectations, as component reliability and maintenance intervals — especially for injection systems — continued to evolve. Overall, newbuild takeover was described as more time-consuming and more integration-intensive than for conventional vessels.

These integration difficulties were also apparent in service; see Section 4, Technical operations in service.

The design parameters reported across the projects are shown in Appendix A.

03 Training and capability development

Additional training beyond minimum requirements improved competence. Successful methanol operation depended heavily on competent and trained personnel. Operators had to build vessel-specific practical training on top of mandatory training, particularly around alarm interpretation, automation logic, and hazard recognition that generic courses often did not adequately cover.



Training emerged across the interviews as one of the decisive enablers of operational readiness and safe methanol implementation. The commissioning and handover phase highlighted that successful methanol operation depended on system performance as well as on the ability of crews and shore-based personnel to understand, operate, and maintain those systems effectively. Due to methanol's hazard profile and a more automation-heavy engine platform, formal compliance with mandatory training requirements alone did not create operational readiness. Some first movers built broader training systems around the then-available regulatory framework, combining formal fuel-specific certification, company-specific familiarization, OEM engine training, simulator and practical exercises, onboard mentoring, and continued reinforcement after delivery.

Respondents also stated that training served several requirements simultaneously, including ensuring regulatory compliance, creating fuel-specific hazard awareness, and ensuring correct understanding of actual vessel systems and alarms, and control logics. As one respondent put it,

> The purpose of training was to reduce fear of an unfamiliar fuel without reducing caution.

Training also helped build the technical confidence needed to interpret automation behavior and respond to faults or shutdowns. Finally, effective training bridged ship and shore so that crew, superintendents, HSEQ staff, and operational managers were aligned on preparing and operating on methanol.

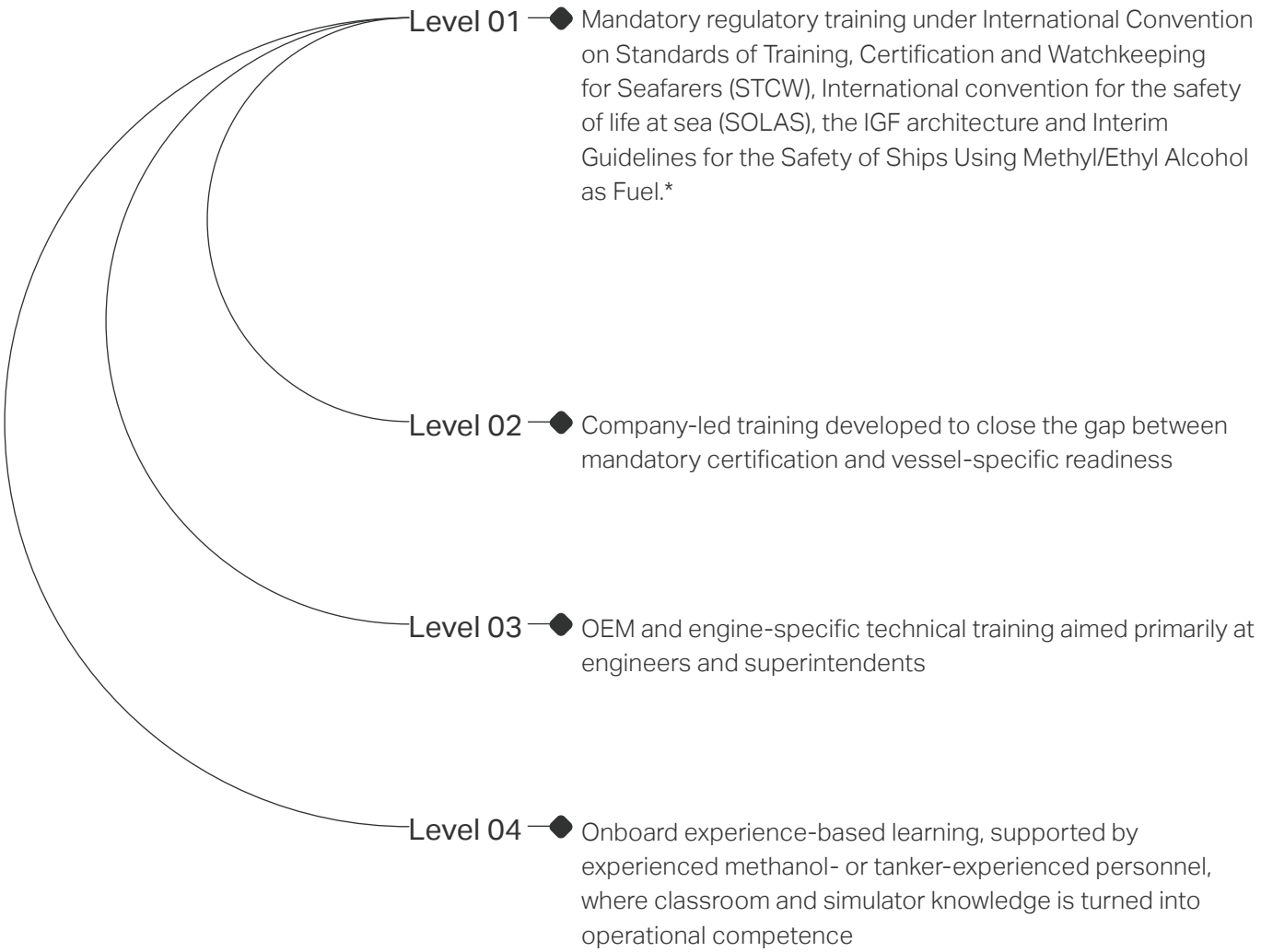
This section focuses on how methanol competence is developed and sustained in practice, including training effectiveness, skill retention, and operational readiness beyond formal certification requirements.

Maintenance of methanol fuel-system equipment during inspection and overhaul. Image provided by A.P.Møller Mærsk.



3.1 Current structure of methanol training

The structure of methanol training is best understood as layered, combining mandatory regulatory requirements with additional company and OEM-led programs to bridge the gap between certification and operational readiness. Across interviews, four main levels were identified:



* The IGF Code does not yet contain a dedicated methanol chapter. MSC.1/Circ.1621[1] provides the principal IMO design and approval guidance for ships using methyl/ethyl alcohol as fuel, with alternative designs requiring demonstration of equivalent safety under the applicable SOLAS approval process.

Respondents agreed that methanol competence could not be delivered through one course alone and required accumulation across these stages.

As of 2026, methanol training remained governed by the IMO interim guidance on training for seafarers serving on ships powered by alternative fuels and new technologies (STCW.7/Circ.25)[2] and did not have fully codified international requirements. These guidelines provided a competency-based framework for alternative fuels, including methanol, but they had not yet been incorporated into the mandatory STCW competence tables in the same way as LNG under the IGF Code. Similarly, the IGF Code itself still did not contain dedicated methanol chapters, and methanol requirements were addressed through MSC.1/Circ.1621 and the alternative design approval process. In practice, training was mandatory but detailed content, depth, and quality of training still varied between operators and providers. Within this framework, mandatory training formed the baseline layer on which all additional competence-building activities were structured.

3.1.1 Mandatory training

Mandatory training was primarily governed by the IMO framework, with additional requirements from class, flag, and port authorities often becoming operationally mandatory in practice. Respondents referred mainly to STCW, SOLAS, IGF provisions, and methanol Interim Guidelines.

A key development was the IMO interim training framework, comprising the generic guidance in STCW.7/Circ.25[2] and the subsequent methanol-specific Interim Guidelines on Training for Seafarers on Ships Using Methyl/Ethyl Alcohol as Fuel (STCW.7/Circ.26). The guidance provides a framework for administration-approved training aligned with STCW principles and defines competence areas including fuel-specific hazards, operational procedures, emergency response, equipment handling, and vessel-specific familiarization.

Methanol safety expectations were applied through MSC.1/Circ.1621, which, although formally interim, was treated as mandatory in practice through the alternative design approval process. Training content included competence in managing methanol's low flash point, toxicity, and invisible flame behavior, as well as fuel-system operation, ventilation and inerting systems, emergency shutdown, and methanol-specific drills.

Mandatory training covered all personnel with safety duties related to methanol systems. Basic STCW V/3 training applied to officers and ratings involved in operations such as bunkering, monitoring, and watchkeeping, while advanced training applied to those with direct operational responsibility, including the Master where responsible for fuel operations, the Chief Engineer, the Second Engineer, engine officers directly operating the methanol system, and officers in charge of bunkering. All crew underwent vessel-specific familiarization prior to sailing. Respondents adopted different training strategies, ranging from full-crew methanol training to role-based approaches in which mandatory methanol training was limited to personnel with methanol-related duties, while other crew members received vessel-specific familiarization only.

Because methanol training was not yet embedded in main STCW competence tables, no global refresher cycle had been established. Respondents reported internal refresher intervals of two to three years, based on skill decay and evolving operational experience. They also noted that extended periods without methanol use reduced familiarity with procedures and system behavior.

Additional requirements from classification societies and industry bodies, while not IMO law, effectively formed part of the mandatory framework for approval. These typically addressed bunkering operations, methanol-specific firefighting and detection, hazardous-zone management, fuel preparation room operations, and vessel-specific familiarization and drills, reinforcing competence beyond baseline certification.

3.1.2 Additional training beyond the mandatory baseline

Multiple respondents said operational readiness required more than mandatory training. Because methanol-fueled vessels remained relatively rare and global standards were still developing, companies could not rely entirely on external training provision and had to build competence internally. Respondents also raised concerns that formal approval of a training provider did not always guarantee instructor competence, and that this could create a risk of inconsistent or inaccurate technical explanation.

Operators explicitly regarded generic IGF or LNG-oriented courses as insufficient for methanol, not because they lacked value but because they remained too generic, too LNG-focused, and too distant from the actual vessel systems that crews would later operate. Operators repeatedly pointed to a gap in relation to vessel-specific understanding, hazard interpretation, and system behavior. Respondents also noted that incorrect assumptions imported from LNG or conventional-fuel operations could lead to inappropriate operating practices if not addressed through additional training and familiarization. They also noted that crew were not always able to relate lower explosive limit (LEL) alarm thresholds to actual hazardous conditions or to distinguish clearly between toxicity-driven and flammability-driven risks in enclosed or inerted spaces.

Crews from containership, bulk carrier, and passenger backgrounds lacked the tanker-style liquid cargo discipline needed for methanol and therefore required additional upskilling in hazard awareness, hazard management and control, leak management, atmosphere monitoring, and procedural rigor. One respondent captured the psychological dimension very clearly, saying that one of the biggest benefits of training was that methanol started to feel “not so scary” once its behavior and controls were understood properly.

Several companies therefore built in-house methanol training programs that included methanol-specific familiarization, system-drawing reviews, office-based preparation, vessel-level procedure walkthroughs, and company-developed material around actual methanol operations. In some cases, companies coordinated with flag administrations during early Certificate of Proficiency processing to secure dispensations while the first crews were being trained and certificated. One vessel operator relied mainly on an initial external course and onboard knowledge transfer from the first trained crews, illustrating that building non-mandatory methanol competence remained far from standardized.

3.2 Training content

Training content and delivery methods varied across organizations, reflecting approaches to building operational competence that were not standardized.

3.2.1 Company-developed training content

Respondents used a variety of additional training models generally resting on three linked components:

01

External methanol training from specialist providers

02

Internal company- and vessel-specific preparation

03

Onboard mentoring by experienced methanol or tanker personnel

These elements were collectively designed to develop practical competence beyond regulatory training requirements.

A common external model described was a one-week methanol course designed specifically around operational and safety needs and, in some cases, co-developed between the shipping company and the training provider so that the content could evolve with operational experience. Respondents described three main blocks within this structure.

- The first block was a two-day basic course introducing methanol's physical and chemical properties, its hazards, and the safety mindset required when handling a fuel that behaves differently from conventional bunkers. The key objective of this block was to build familiarity with methanol behavior and hazards. Emphasis was placed on fire fighting, due to invisible flames, because this was entirely unfamiliar to many crews.

- The second block was a two-day advanced module focused on technical and operational aspects of methanol as a marine fuel. This typically included structured walkthroughs of systems, process-flow logic, and operation under both normal and abnormal conditions. Until methanol-specific simulators become widely available, some centers relied heavily on drawings, flowcharts, and operational scenarios to build the cognitive understanding needed for safe operation.

- The third block was a one-day methanol firefighting module, described as the most impactful part of the program. Crews were exposed to invisible flame conditions, heat-detection tools, specialized PPE, and realistic extinguishing practice. This created what one respondent called the required "muscle memory" for methanol firefighting, and several companies emphasized that methanol firefighting must be methanol-specific and practical to make the hazard sufficiently real.

This structure reflected a deliberate progression from basic familiarity to system-level understanding and finally to practical response capability.

In addition to such external training, some companies also built internal company-specific programs to ensure that crews understood not only methanol as a fuel, but also the actual procedures and expectations of their own vessels. This internal content often covered the safety management system (SMS), company-specific bunkering

Maintenance of methanol fuel-system equipment during inspection and overhaul. Image provided by A.P.Møller Mærsk.



procedures, methanol emergency roles, vessel-specific fuel arrangements, and the behavioral expectations needed to raise non-tanker crews toward "tanker standards." Because bunkering is one of the most sensitive operations, some companies also created simulation-based bunkering training to compensate for the absence of real-life bunkering practice before crew joined methanol vessels. A few operators also adjusted training content deliberately, adding focused modules on engine room systems control logic, auxiliary-engine behavior, crew coordination, and methanol-specific operational risks while removing non-essential mechanical basics that did not add value for already experienced personnel.

3.2.2 Vessel-specific training

Vessel-specific training answered the gap set out in 3.1.2. Respondents therefore described it as essential for developing familiarity with the installed fuel system, alarm philosophy, operating procedures, interlocks, and emergency-response arrangements before the vessel entered service.

To close that gap, many companies created company- and vessel-specific training covering methanol vessel layout, bunkering arrangement, operational philosophy, vessel-specific fuel-handling procedures, methanol risk assessments, alarm logic and interlocks, and manufacturer-specific procedures. The strongest gap appeared in the area of system-level understanding. Engineers repeatedly reported difficulty locating consolidated explanations of alarm cause-and-effect, safety interlocks, automatic fallback logic to conventional marine fuels (typically very-low-sulfur fuel oil (VLSFO) and marine gas oil (MGO)), and the way the installed system behaves under fault or changeover conditions. Troubleshooting therefore often depended on onboard experience or informal internal guidance instead of structured, vessel-specific understanding acquired before joining.

One vessel operator argued strongly that a detailed methanol fuel system manual should be considered essential onboard because it gives the crew much of the knowledge needed to improve operation. The same respondent also proposed that shipyards should take a more active role in knowledge transfer, given their central role in the actual vessel configuration. However, other respondents noted that, particularly in early methanol projects, operational knowledge and practical solutions were often developed by owners and operators as experience with methanol systems matured.

3.2.3 OEM and engine-specific training

For engineers and technical superintendents, OEM training went far beyond IGF and general STCW competence. Its purpose was to create personnel who could operate, diagnose, and maintain methanol dual-fuel engines correctly and safely.

Training was divided explicitly into a first "pre-dual-fuel" week and a second methanol-specific week. OEM respondents described the teaching method as a "building blocks" progression, in which subsystems were taught sequentially and then reassembled into a complete system picture because experience had shown that the whole system could not be learned effectively all at once.

Week one focused on the electronically controlled engine platform, including fuel supply, hydraulics, electrical and electronic logic, sensors, software architecture, and baseline engine operations. Respondents repeatedly felt that this phase was a prerequisite, because trainees first needed to understand the underlying dual-fuel engine concept, control philosophy, and system interactions before moving to methanol-specific behavior and operating procedures.

Week two then moved into methanol-specific topics, including liquid methanol injection, pilot-fuel support, engine performance and efficiency, the interaction between rail pressure, fuel temperature and combustion stability, protective interlocks, nitrogen purging, leak detection, emergency shutdown, and mode transitions with fallback to primary fuel.

> A substantial share of the reported dual-fuel issues arose on the fuel-supply side rather than within the engine itself, and respondents emphasized fuel-system behavior and diagnostics.

A very large share of operational issues originate in the fuel supply system, and training is weighted accordingly. A substantial share of the reported dual-fuel issues arose on the fuel-supply side rather than within the engine itself, and respondents emphasized fuel-system behavior and diagnostics.

The training content itself was highly technical. Engineers worked through the engine-control architecture, injection timing, exhaust-valve actuation, scavenge-air control, cylinder-pressure monitoring, sensor and transmitter networks, software-derived values and correction factors, and supply-system behavior under conditions such as contamination introduced by inadequate tank or pipeline cleanliness, cavitation, or poor pressure control.

Other technically important content included electrical and electronic diagnostics from the measurement point to controls, interpretation of alarm hierarchies and permissive logic, pilot-fuel conditioning and its impact on ignition stability, recognition of partial leaks, blocked sniffer lines, false alarms, and confirmed release, detailed methanol injector handling, and detailed troubleshooting designed to prevent trial-and-error part-swapping.

Respondents also noted areas where OEM training could be further strengthened. Operational scenarios such as leak response, fault isolation under time pressure, and gas-freeing or maintenance preparation were in some cases described at a conceptual level rather than extensively practiced. In several instances, operators sought additional clarification on methanol-specific automation logic or supplemented available materials with shipboard instructions to support practical application.

One practical point raised in the interviews concerned purging and gas-freeing of methanol tanks. Several operators indicated that current arrangements and documentation did not always fully support these activities in practice. Fixed gas-freeing lines may not be included in all designs, sampling points may present operational challenges, and complete stripping of tanks may not always be achievable, leaving residual volumes and complicating dry-dock preparation. In some cases, ship and shore teams developed supplementary procedures to support these operations based on operational experience.

Respondents also noted that, in one training approach, completion depended on achieving a defined level of simulator engagement, with approximately 70% of exercises tracked through learning analytics. While this did not constitute a formal examination, it provided a structured threshold for demonstrating familiarity with system behavior.

3.2.4 Simulators versus hands-on training

Delivery methods were as important as training content, particularly for the technical material described in 3.2.3. Respondents emphasized that simulator-based training helped build understanding whereas hands-on work built operational competence, confidence, and the ability to respond under stress. Simulators, especially digital twins, were valuable because methanol dual-fuel engines depended heavily on electrical systems, hydraulic systems, software logic, alarms, interlocks, and automated state transitions. The simulator environment described by OEMs was cloud-based

and gave each trainee access to an individual instance of the actual control software on their own laptop, ensuring that trainees could directly interact with the same logic used onboard.

Simulators were especially useful for alarm interpretation, operating sequence logic, restart and changeover behavior, control-system operation, fault tracing, and safe rehearsal of scenarios too risky to reproduce on an operating vessel. This reflected the fact that methanol operation relied heavily on system logic and automation behavior, which are best understood through simulated interaction rather than passive instruction.

At the same time, some elements of methanol training like invisible-flame firefighting, hose handling, physical emergency response, mechanical maintenance competence, large-injector handling, and working in actual vessel spaces required hands-on training. One OEM described the intended balance during the second week training as approximately one-third theory, one-third simulation, and one-third mechanical hands-on work.

Vessel operators also valued simulator-based training particularly for bunkering operations training. Because methanol bunkering simulators were initially unavailable, some first movers developed augmented reality-based bunkering tools to teach sequencing, emergency shutdown (ESD) logic, communication, and emergency response before the crew experienced a real bunkering operation. Respondents also noted that while simulator access sometimes remained available for up to two weeks after the course, post-course access was underused unless the company actively supported continued learning.

3.2.5 Onboard training

According to many respondents, onboard training was the stage where the crew learned what methanol systems looked like, sounded like, and felt like in operation. Methanol handling was progressively learned through real system interaction, troubleshooting events, bunkering operations, watchkeeping, observation of alarms and system response, and supervision by more experienced personnel. This was especially important for crews from containership, bulk, and passenger sectors, who did not bring chemical or methanol cargo experience.

Methanol bunkering. Image provided by Xpress Feeders.



Some companies deliberately placed ex methanol tanker officers and engineers onboard to mentor others. These personnel functioned as live trainers who supervised bunkering, corrected mistakes, demonstrated practical methods, and helped crews move from caution to confidence. Respondents attributed limited methanol incidents to effective onboard mentoring. OEM made the same point from the technical side: if trainees did not operate the dual-fuel engine soon after completing the training, knowledge decayed quickly, especially where automation logic and alarm interpretation were central to the learning.

3.2.6 Train-the-trainer

Respondents recognized that methanol-fueled operations required trainers who genuinely understood the fuel, the systems, and the operating behavior of methanol dual-fuel vessels. Hence, vessel operators built internal expertise by deliberately using methanol-experienced or tanker-experienced personnel as trainers and mentors. They also co-developed training content with external providers and used feedback from vessels to improve both internal and external teaching material.

OEMs addressed the same challenge by keeping training under tight in-house control. Respondents said instructors were usually engineers, trained internally over months, exposed to real engines, and certified by senior specialists. OEMs did not favor open delegation of dual-fuel training because of the risk of technical inaccuracy. They also maintained tight update loops because engine and control-system configurations continued to evolve. In practice, operators tended to solve the train-the-trainer problem through operational experience transfer, whereas OEMs solved it through technical control and formal instructor development.

3.3 Crew and shore staff readiness

3.3.1 Crew selection and profile

Respondents described a deliberate, performance-driven process for selecting crews for methanol vessels. The personnel sent to methanol vessels were typically already recognized as high performers who exceeded minimum competence matrices. Experience with dangerous liquid cargoes was treated as particularly valuable. Strong preference was given to tanker-experienced personnel, especially to those with methanol-carrier backgrounds, because they already brought hazard awareness, risk-mitigation experience, procedural compliance, chemical-handling awareness, and well-developed practical skills in atmosphere control and liquid-fuel containment. Even so, respondents noted that methanol is not a traditional marine fuel, and tanker-experienced personnel still required methanol-specific familiarization alongside their existing backgrounds.

Container, bulk, and passenger-vessel crews were not excluded, but respondents said they generally required additional familiarization with methanol-specific procedures, chemical handling, permit-to-work practices, PPE requirements, and bunkering operations. OEMs described their own trainee profiles somewhat differently. Their courses were usually attended by chief engineers, second engineers, third engineers in progression, electrical officers, and technical superintendents. One OEM respondent specifically highlighted the importance of retaining and training electrical officers, noting that modern dual-fuel systems were becoming increasingly dependent on electrical control and logic at the same time that some operators were reducing those roles onboard. Successful methanol trainees were also described in behavioral terms: curious, willing to admit what they did not understand, prepared to repeat simulations until they grasped the system, and technically engaged rather than passive.

3.3.2 Crew reluctance and feedback

Respondents did not report resistance to methanol as such. The more consistent picture was one of initial apprehension, especially regarding invisible flame, followed by growing confidence through training. Several operators said they deliberately used training to ensure that crews joined the vessel "not scared but confident".

Several companies actually reported high demand from crew to serve on methanol-fueled vessels, in some cases supported by bonuses reflecting the extra responsibility associated with dual-fuel operation. In those organizations, the challenge was selection, not reluctance. OEMs observed a somewhat different issue. What they saw most often was not fear of methanol itself, but insufficient preparation, low engagement, or inability to handle the technical demands of modern dual-fuel systems. Some trainees reportedly arrived without knowing which vessel they would join or why they had been sent to training. Respondents also highlighted the need to correct LNG-derived assumptions (3.1.2). In practice that correction happened during vessel and engine-specific training. Despite these challenges, feedback across respondents was overwhelmingly positive. Live methanol firefighting and direct explanation of system logic were repeatedly described as transformative.

Crew competence and confidence were identified as critical to sustaining dual-fuel capability. Respondents stressed that preservation of methanol competence was as important as preservation of hardware: unfamiliar crews could default to primary fuel operation even when methanol was available. Early crews were often highly motivated, particularly where methanol operation was linked to professional pride and decarbonization goals. At the same time, crew were unsatisfied where they maintained readiness but operated for extended periods without using the system, limiting practical experience.

3.3.3 Training shore-based teams

Respondents repeatedly stressed that methanol readiness had to extend beyond the ship to shore-based personnel, including superintendents, HSEQ personnel, safety staff, operations support, and technical managers. Shore teams had to answer safety-critical questions, support bunkering coordination, communicate with class and flag, assess incidents, and give instructions to the vessel. They therefore needed to share the same technical and safety language as the crew. Several companies sent shore personnel to the same methanol courses as shipboard staff and deliberately brought ex methanol tanker personnel into shore positions to act as knowledge carriers.

OEM respondents went even further, saying that training shore-based personnel was strategically necessary, not optional. Vessel superintendents needed to be able to interpret data, support troubleshooting, and maintain standards across the fleet. OEMs therefore often trained shore personnel through the same platform and simulator pathways used for seagoing engineers.



3.4 Gaps and recommended improvements

3.4.1 Main training gaps

Respondents identified recurring training gaps in the following areas:

- Detection and alarm interpretation. This included confusion in gas-detection interpretation, especially between parts per million-based exposure tracking and LEL-based explosion risk; weak understanding of alarm logic, particularly where methanol systems revert automatically to primary fuel; and persistence of incorrect LNG-based assumptions (3.1.2).
- Electrical and automation baseline. Poor baseline competence in electrical, hydraulic, and automation systems; declining technical baseline in some trainee groups.
- Troubleshooting discipline. Weak troubleshooting discipline, including blind part-swapping instead of root-cause diagnosis; inadequate preparation for real leak detection and fault isolation under time pressure.
- Provider and pre-course consistency. Inconsistent quality across external training providers; insufficient preparation of trainees before course attendance, including gaps in basic theoretical understanding.

One of the most important human-factor observations from the vessel operator side is that future risk might arise from complacency rather than fear of the fuel despite the high initial caution. Several respondents compared this with earlier LNG experience and warned that methanol could later become normalized in ways that reduce vigilance unless companies actively reinforced operational rigor.

A structured gap-to-competency mapping, including corresponding training interventions, is summarized in Appendix B, Gap-to-training matrix parameters reported by first movers, to support development of targeted methanol training programs.

3.4.2 Recommendations for strengthening methanol upskilling

Respondents proposed a coherent set of measures to strengthen readiness for methanol-fueled vessel operation. Training should include methanol-specific and practical firefighting, realistic hazard demonstration, equipment-specific explanation, and clear instruction in thermal detection and alcohol-resistant foam use. A more standardized methanol-specific IGF supplement would help reduce inconsistency between providers, and several respondents viewed a two-year refresher cycle as more appropriate than a five-year cycle to maintain competence, reinforce operational discipline, and sustain familiarity with methanol systems.

Container, bulk, and passenger crews required additional support to develop tanker-like liquid-cargo handling rigor. Embedding experienced tanker or methanol personnel onboard during early operations was repeatedly described as highly effective. Respondents also felt that crews would benefit from stronger explanation of the wider strategic rationale for methanol adoption, including the role of regulatory change and greenhouse gas reduction.

On the technical side, engineers needed stronger foundations in electrical and hydraulic principles, automation logic, signal interpretation, and systematic troubleshooting. Simulation could be used more aggressively to teach root-cause analysis. Methanol readiness could also extend to ports, terminals, flag administrations, class societies, pilots, and port state control inspectors, with joint exercises and broader awareness work improving simultaneous cargo and bunkering readiness.

Finally, respondents repeatedly stressed the value of better trainee preparation prior to training attendance. A mandatory pre-learning package covering methanol basics, relevant vessel systems, and core safety principles was presented as a straightforward and high-impact improvement.

04 Technical operations in service

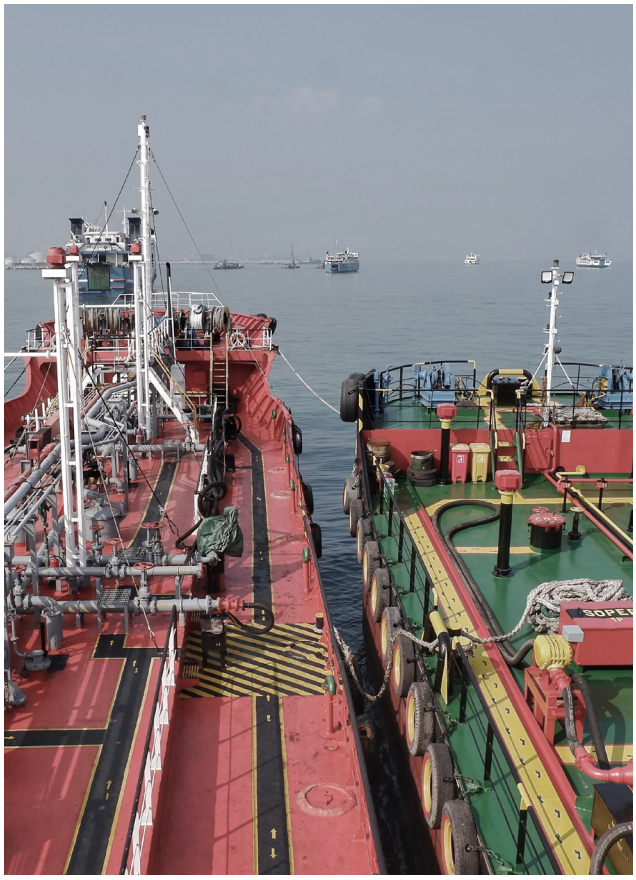
Operational success depends largely on system integration. Few of the difficulties reported in service were traced to methanol as a fuel or to the engine itself. Complexity was experienced at the interfaces between fuel supply, automation, and safety systems.



The design elements described earlier determined the physical configuration of the vessel, and the training elements determined how well crews and shore teams were able to understand and manage that configuration. Those two elements are tested together in the operations phase once the vessel enters service.

Respondents agreed that methanol operation was technically workable and increasingly stable, albeit more demanding than operation on conventional marine fuels in terms of system understanding, monitoring, alarm interpretation, and procedural adherence. The main engine itself was easier to operate than other parts of the methanol operation like the fuel supply system, pressure and temperature control, leak detection, purging, interlocks, and the burden placed on crews to understand what the automation was doing and why.

This section focuses on in-service engine and fuel operation, the surrounding systems, and maintenance and its consequences for the planned maintenance and safety management systems.



4.1 In-service engine and fuel operation

This section covers methanol operation at the level of the engine and its fuel supply:

- How combustion and load behavior compared with conventional marine fuels
- How changeover was handled and how idle methanol equipment was preserved
- What the fuel's properties meant for consumption and handling
- What the arrangement required of the crew in competence, access, and routine attention

4.1.1 Operational differences: methanol versus conventional marine fuels

In dual-fuel engines, methanol is integrated into an already mature engine layout as the alternative fuel that provides the main energy input, while a smaller quantity of primary fuel (in this case, also functioning as pilot fuel) ensures reliable ignition. Hence much of the core engine performance remains familiar regardless of whether the engine runs on conventional marine fuels or methanol.

Maximum cylinder pressure was generally reported as stable and broadly comparable to conventional marine fuels, with some operators observing no increase and others noting slightly lower peaks at low loads. At the same time, methanol operation was consistently associated with lower

combustion and exhaust-gas temperatures. The practical consequence emerged downstream: reduced effectiveness of waste-heat recovery. One reported case described an Organic Rankine Cycle system whose output fell from around 180 kW on conventional marine fuels to about 120 kW on methanol — roughly two-thirds of previous performance. This could reduce the energy available to waste-heat recovery systems and other consumers dependent on exhaust-gas energy, requiring case-specific assessment during vessel design. Methanol's thermodynamic impact was therefore expressed less in cylinder-pressure behavior and more in diminished recoverable exhaust heat.

Piping leading to the engine room. Image provided by NYK.



Hence, the real technical differences were experienced in fuel supply and control, not in combustion limits. Respondents consistently located this shift within the fuel system. Methanol had to be maintained strictly in the liquid phase throughout supply and injection, requiring tightly coordinated pressure–temperature control: pressure is regulated against engine demand setpoints, while temperature is managed to keep the fuel below its boiling point at operating pressure. This integration was essential to prevent flashing, cavitation, and vapor-pocket formation. In contrast, conventional marine fuel systems do not require the same degree of active management to preserve a pressurized liquid state.

Within this framework, day-to-day combustion characteristics remained stable and predictable. Knocking was not a characteristic issue in steady methanol running. Methanol combustion followed a diesel combustion principle with direct injection, with combustion pressure development and pressure-rise rates monitored and kept within defined limits in a way comparable to other low-flashpoint liquid and gas engine concepts. Fuel quality remained important for smooth engine operations. Respondents referred not only to methanol quality itself but also, in cases where methanol–water emulsions were used, to the quality of the water introduced into the system. In those arrangements, water alters thermodynamic conditions in the cylinder and therefore influences combustion process and emissions.

A specific issue reported by some operators concerned changeover at high engine loads. Some respondents described a knocking-like noise or roughness during transition into methanol at high engine loads. These findings primarily reflect early operational experience and first-generation vessel implementations, and respondents noted that subsequent design improvements have reduced the frequency of these issues. The practical response involved reducing load, for example from around 85% down to about 70%, before initiating changeover. This behavior was confined to the transition phase and was not observed during steady operation. Current operational experience was inadequate to offer a robust comparison between two-stroke and four-stroke methanol engine performance. Respondents said that their attention to date had been on achieving stable methanol operation and extracting early-stage learnings, not on systematic benchmarking of specific fuel oil consumption or efficiency across engine types. In practice, interviewed organizations had experience with only one engine category, making the basis for comparison too narrow.

4.1.2 Fuel flexibility and changeover procedure

Dual-fuel methanol vessels retained full flexibility to operate on conventional marine fuels at will. From an operational point of view, methanol and conventional marine fuel systems remained independent. Best practice during conventional-marine-fuel-only operation focused on two things simultaneously: preserving methanol-specific equipment during inactivity and keeping conventional marine fuel systems fully ready for immediate use.

Conventional marine fuel system transfer arrangements, purifiers, and standby equipment remained under their own maintenance and testing routines. Respondents stressed that regular testing of standby equipment remained important to preserve operational flexibility, especially when methanol was consumed in limited quantities only and frequent switching may be required.

Measures taken to preserve methanol equipment depended mainly on how long the vessel was expected to remain on conventional marine fuels only. See Table 4.

Table 4: Methanol equipment preservation by duration off methanol

Time off methanol	Measures reported	Why
Up to about one month (the OEM-recommended window)	Keep methanol-specific equipment from sticking, overheating, or degrading while the system stays ready to return to service. Where methanol is onboard, run short methanol periods — from 1-2 hours per week to about 1 hour every few days.	Thermally cycles methanol valves, seals, and injectors, and keeps crews familiar with the system.
Any duration, while methanol operation is suspended	Nitrogen purge the methanol fuel system weekly or biweekly.	Keeps the system dry, reduces corrosion risk, and exercises methanol-train valves so they do not stick after long idle periods.
More than 1-2 months	Remove methanol injection valves and fit dummy nozzles or plugs. Vessels carried dummy nozzles as standard.	Prolonged operation without methanol injection removes the cooling effect at the injector tip, accelerating wear in the atomizer and spindle-guide areas. Replacement parts have long lead times.
Several months	Consider consuming the methanol remaining onboard rather than leaving it stagnant in tanks.	Long storage can cause evaporation losses and discrepancies in recorded volumes.

Changeover from methanol to conventional marine fuels was described as highly automated and seamless. Transitions occur without engine stoppage and, in some descriptions, within a single engine revolution. If the methanol system shuts down, the engine continues running on conventional marine fuels without interruption. Change-over from conventional marine fuels to methanol followed a fully automated sequence controlled by the vessel's engine automation system. A command from the bridge or engine control room triggers a predefined state-machine logic that verifies methanol supply readiness, valve feedback and tightness, double-wall pipe integrity, safe LELs, and stable pressure and temperature before methanol is admitted. Methanol substitution then proceeds gradually, with the methanol share increasing and the pilot-fuel fraction reducing to its nominal level, followed by a short stabilization period.

Automatic shutdown and fuel isolation were commonly linked to safety-critical alarm conditions, including gas-detection thresholds around 40% of the LEL. At that point the system isolated, depressurized, and was brought to a safe inerted condition through the automated shutdown sequence. Respondents were explicit that these safety sequences cannot be overridden by operators. Changeover was described as most sensitive at low load, where transitions were harder to stabilize and engines could revert automatically to conventional marine fuels, particularly during maneuvering. While the automation handled the sequence, crews still needed operational awareness to manage the transition smoothly.

Fuel transitions were managed through vessel-specific engine-control platforms such as Integrated Control Systems or Main Operating Panels depending on supplier and vessel configuration. Crews were generally familiar with the sequence logic, with their role centered on supervision, mode selection, and monitoring rather than manual execution.

Blackout behavior followed an especially conservative and safety-driven sequence. After a blackout, the engine restarts on conventional marine fuels because methanol operation requires a minimum engine load, often around 10%, that cannot be achieved during initial recovery. If the blackout occurred during methanol operation, the methanol fuel system automatically shut down and was brought to a safe condition by stopping methanol supply, isolating, depressurising, purging, and venting the high-pressure methanol side until a safe purged condition was achieved. Methanol mode did not restart automatically. The crew is required to re-initiate the automated dual-fuel start-up and changeover sequence, and all readiness checks must pass again. Some respondents also noted that blackout-specific work instructions remained an area where practice was still maturing, and the importance of nitrogen purging practices was highlighted repeatedly.

4.1.3 Fuel consumption and fuel properties

Actual methanol fuel consumption in service was generally consistent with OEM-indicated theoretical values, when assessed on an energy-equivalent basis. Operators and OEM both reported that real engine performance broadly matched design calculations and test results. Methanol requires higher fuel delivery by both mass and volume to achieve the same engine power output due to its lower energy density, while engine-level conversion efficiency remains broadly comparable.

> Actual methanol fuel consumption in service was generally consistent with OEM-indicated theoretical values, when assessed on an energy-equivalent basis.

Dual-fuel pilot ignition performance was more variable than methanol consumption itself, and strongly dependent on engine load, operating strategy, and engine tuning. All percentages below are reported on an energy basis. Because methanol's low calorific value does not support reliable auto-ignition at reduced compression temperatures, a larger fraction of conventional marine fuel used for pilot ignition is required to sustain stable ignition and combustion at low engine loads. Operators described the highest pilot-fuel shares at low loads: around 10% of total fuel energy was commonly cited, with some cases reaching around 20% and, in more extreme reports, around 30% during prolonged low-load operation in the range of roughly 35–40% of the main engine load. As load increased, pilot-fuel demand generally declined and stabilized, with multiple respondents indicating more consistent values in the range of 5-10% above roughly 60–70% of the main engine load. Some designs were described as aiming for a constant energy-based pilot fraction of around 5% across the main engine load range, while others reported lower values around 2% under certain conditions. Tanker experience was described as spanning a relatively wide range across both low and higher loads.

Handling of dual-fuel injection systems required more precise maintenance and assembly practices than conventional marine fuel engines because of the more advanced injection equipment and associated safety design. Respondents reported cases where incorrect assembly of fuel-injection components led to methanol leakage onto hot engine surfaces and resulted in fire. Engine safety systems were described as important in detecting abnormal conditions and preventing escalation. To support both safe fuel handling and the intended fuel-system and engine design, methanol is handled onboard as a pressurized liquid rather than as a vapor-based fuel. Fuel systems are designed around segregation, double-wall piping, automated monitoring, and safety logic that cannot be bypassed. Continuous monitoring of the annular space within double-wall piping allows immediate leak detection, while automatic shutdown and fuel isolation occur at predefined thresholds. Nitrogen purging, pressure testing before maintenance, and hardcoded start-up and shutdown sequences are all integral to preventing methanol vapors from accumulating in machinery spaces.

These system-level safeguards extend consistently across both fuel handling and storage arrangements. Methanol volatility is also managed during storage. Tank atmospheres were maintained under controlled inert conditions and positive pressure, displacing oxygen in the tank headspace and limiting the formation of flammable atmospheres. Tank temperature was monitored or managed where required by the specific vessel design. Respondents described inerting, pressure control, and temperature management together as the primary safeguards for safe methanol storage onboard.

Leak management followed a containment-at-source philosophy. Methanol systems are segregated from other onboard systems, including freshwater cooling, and leak detection is performed through double-wall monitoring and dedicated gas-detection arrangements rather than through indirect methods such as cooling-water sampling. Auxiliary cooling circuits around methanol equipment typically use water–glycol mixtures and are handled with standard maintenance logic.

Methanol fumes were therefore not described as a dominant operational issue in ordinary running. Under normal operating conditions, significant vapor formation was not expected because pressure and temperature were controlled. Dedicated vent masts exist as defined safety discharge points rather than as continuous fume-extraction devices, and those zones are treated as high-risk areas with restricted access and PPE requirements.

Methanol transfer pump starting panel. Image provided by V-Ships.



4.1.4 Crew competence and manning

Methanol operation changed daily engine-room work and crew management primarily through higher demands on competence, monitoring, and responsibility. Core diesel-engine tasks remained, but methanol introduced additional systems — including injection valves, fuel supply and circulation arrangements, seal-oil systems, pressure control, nitrogen production, double-wall leak detection, and logic-driven safety interlocks — that required continuous supervision. Operators consistently reported that routine work shifted toward control screens, methanol-specific alarms, valve verification, and confirmation of dual-fuel system integrity. Although highly automated, these systems still required crew intervention for troubleshooting and validation, making routine operations more alarm-driven and cognitively demanding than on conventional marine fuel-only vessels.

Methanol also altered maintenance planning and execution. Full technical documentation was often delivered only at or near vessel delivery, meaning PMS structures and operating routines were still being developed during early operations. Several operators described a period of learning by doing, with reliance on manuals, engineering judgment, and feedback loops while systems matured. Daily work increasingly combined conventional maintenance activities with additional safety checks, verification activities, and procedural compliance requirements associated with methanol systems. While respondents did not necessarily describe a disproportionate increase in heavy maintenance work, maintaining both conventional and methanol fuel systems, together with increased monitoring, inspection, and safety responsibilities, increased overall maintenance complexity and cognitive workload.

Manning levels generally remained unchanged, with most vessels retaining standard crew complements, including Electrical Technical Officers where applicable. The key requirement was ensuring adequate competence and continuity within the existing crew. Respondents highlighted a structural concern that high-value, high-complexity methanol systems may still fall under the responsibility of relatively junior engineers whose formal preparation and practical experience could vary considerably.

Closed-circuit television (CCTV) in the engine room was identified as a practical support measure in this more demanding environment. It enabled incident reconstruction, alarm-response assessment, and rapid visual checks during night watches, allowing quicker and more informed decisions without increasing physical workload. Handover procedures and manning practices remained broadly unchanged, with methanol-specific considerations integrated into standard handovers and overlap periods.

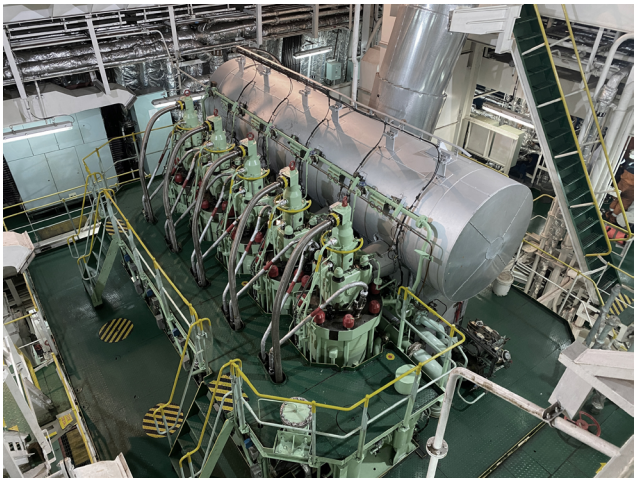
4.1.5 Access to methanol spaces

Access to machinery and fuel-supply systems was more tightly controlled than on conventional vessels due to hazardous-zone requirements. Methanol-related spaces, particularly fuel preparation and supply rooms, were treated as hazardous or enclosed spaces with restricted access. Entry required confirmation of ventilation, hydrocarbon and oxygen levels, and compliance with checklists and SMS procedures. Portable gas detectors were mandatory, and only equipment certified for explosive atmospheres (ATEX) could be used; standard mobile devices were prohibited. When equipment was dismantled, enhanced PPE, including face shields, was required despite limited residual methanol following purging.

By contrast, the main engine room remained classified as a non-hazardous area, and access was generally not restricted because methanol piping in this area was double-walled and did not release directly into the space under normal conditions. Some arrangements, however, relied on procedural compliance rather than hard physical lock-out to prevent unsafe entry into methanol spaces under unsuitable conditions.

4.1.6 Ancillary systems in service

Operational experience indicated no methanol-specific negative impacts on most ancillary systems, including turbochargers, pumps, and oil-mist detectors. Methanol was consistently described as producing less soot than conventional marine fuels, with turbochargers and exhaust systems remaining clean and no abnormal wear observed. There is no evidence so far that methanol causes more contamination than conventional marine fuels, despite its lower lubricity and higher corrosivity introducing a theoretical risk of accelerated lubricant degradation. Pumps in the methanol module were not reported to experience unusual wear. Oil-mist detectors behaved as in conventional engines, since the crankcase is not directly affected by methanol combustion.



4.2 Systems: auxiliary, automation, and leak detection

This section covers the systems around the engine and its fuel supply:

- What exhaust after-treatment required once sulfur oxides were no longer the issue
- What changed, and what did not, in lube oil, filtration, and bilge and sludge handling
- How nitrogen generation and ventilation worked as safety-critical services
- How automation and leak detection behaved, and where the crew's judgment was still required

The main challenges reported in service were related to system complexity, automation, and safety requirements. Methanol introduced additional subsystems, including injection equipment, nitrogen inerting, leak detection, and logic-driven safety interlocks, which increased demands on monitoring, procedural and system understanding.

4.2.1 Exhaust cleaning systems

Methanol-fueled vessels did not require sulfur-oxide scrubbers, as methanol contains no sulfur. The focus of exhaust after-treatment therefore shifted to nitrogen-oxide reduction to meet IMO Tier III requirements. Respondents identified three main solution options: selective catalytic reduction (SCR), exhaust gas recirculation (EGR), and water-based nitrogen oxides (NO_x) reduction methods such as water injection or methanol–water mixtures.

Feedback on formaldehyde emissions was limited. One operator reported that no dedicated mitigation system had been installed and that the SCR configuration in use was not designed for formaldehyde removal.

4.2.2 Lube oil

Methanol operation did not introduce fundamental changes to lube-oil or filtration systems compared with conventional marine fuel operation. System design, purifier arrangements, and maintenance routines remained broadly unchanged.

For two-stroke main engines, methanol remained confined to a segregated fuel circuit with double-wall piping and sealing-oil barriers, preventing cross-contamination with lubrication systems. OEM feedback confirmed that no methanol-specific lube-oil monitoring regime was required, with oil condition driven primarily by engine operation and primary fuel rather than methanol itself. Auxiliary engines generally continued operating on conventional marine fuels and therefore followed standard lubrication practices.

Table 5: NO_x reduction options and reported issues

Option	Application and performance	Main issues reported
Selective catalytic reduction (SCR)	Widely applied, particularly on auxiliary engines and in some cases on main engines, depending on vessel design and operator preference. Stable and manageable, provided valve routines were followed and adequate spares were held. Uses urea as the reducing agent, typically around 7% of fuel consumption, requiring significant onboard storage.	Urea crystallization at nozzles during shutdown — the most common maintenance issue reported.
Exhaust gas recirculation (EGR)	Commonly used, functioning in line with conventional dual-fuel applications. Reduces NO_x by lowering combustion temperature through exhaust recirculation. Compact, but generally more labor-intensive than SCR.	Water treatment and sludge handling; limited OEM support in some cases; higher operating cost and workload in certain installations.
Water-based reduction (water injection, methanol–water mixtures)	Used by some operators for Tier III compliance, and regarded as the most challenging of the three. Adding water reduces the calorific value of the fuel mixture and increases injector throughput.	Thermal stress, nozzle-tip failures, incomplete-combustion risk, and higher maintenance demand. The reported problems concerned reliability and maintenance rather than the ability to achieve NO_x compliance.

Lubricant selection and monitoring remained aligned with established dual-fuel practice for two-stroke engines. Standard system and cylinder oils from major suppliers were used, typically in the base number (BN) 40 to BN 100 range. Early experience with lower-BN oils led to deposit formation, shifting practice toward higher-BN Category II oils. Monitoring continued through routine onboard checks, laboratory analysis, and scavenge inspections, without methanol-specific sampling requirements.

One configuration-specific issue was reported with sufficient frequency to retain. Methanol's affinity with lubricating oil, combined with certain hydraulic arrangements, could contribute to gradual oil accumulation in service tanks or filter clogging over time. In one reported case, accumulation reached approximately 500 liters. Respondents characterized this as an oil-management issue requiring monitoring and operational adjustment rather than a fundamental compatibility concern.

4.2.3 Filtration, purification, OWS, bilge/ sludge handling

Methanol was widely regarded as a clean fuel from a combustion perspective, but onboard filtration and handling remained important. Operators consistently reported cleaner engine internals and scavenge spaces compared with conventional marine fuels , in some cases reducing or eliminating routine scavenge-space cleaning. The OEM interviewed confirmed that no methanol-specific onboard purification system was required at engine level, with fuel cleanliness maintained through upstream quality control, enclosed system design, and standard final filtration.

Centrifugal purification was generally not applied, and operators instead relied on fuel-quality control and filtration to protect methanol systems. Filtration systems therefore functioned primarily as protective barriers rather than active purification units. Some operators reported rapid filter clogging during early operations, linked to tank-cleaning residues or particles from coatings such as zinc silicate, although these were treated as localized and manageable issues.

Methanol-contaminated water introduced more significant procedural implications. Because methanol is fully soluble in water and not detected by standard oil-in-water monitors, such mixtures could not be processed through conventional oily water separators. Operators therefore prohibited routing methanol-contaminated liquids through oily water separator (OWS) systems and reinforced this through procedures and notices. Instead, contaminated water was collected in dedicated tanks or segregated systems and discharged ashore or otherwise handled only under controlled conditions with appropriate port or local authority approval.

Bilge and sludge handling remained broadly similar in equipment terms but required stricter segregation and greater crew awareness. Methanol did not increase sludge generation; several respondents reported lower sludge volumes due to cleaner combustion. Vessels were typically equipped with dedicated methanol drain systems, separate from conventional bilge and sludge streams. Drainage operations involving methanol required additional attention to ventilation, flammability, and alcohol content. Where contaminated liquids could not be reused or treated onboard, they were retained for discharge ashore.

4.2.4 Nitrogen generator and ventilation

Methanol-fueled vessels were equipped with dedicated nitrogen-generation systems, described by respondents as safety-critical. Nitrogen was used for purging methanol lines and, in designs using inerted annular spaces, for maintaining inert conditions. Before maintenance, isolated methanol circuits were purged and verified safe. In addition, full gas-freeing required replacing the inert atmosphere with air where entry or work demanded it. Two main technologies were employed: membrane-based systems and Pressure Swing Adsorption units, supported by compressors, separation elements, receivers, pressure-regulating valves, air dryers, oxygen meters, and distribution networks.

The nitrogen system operated as a tightly integrated and largely automated part of the fuel-control architecture. Purging sequences, pressure regulation, gas supply, and monitoring followed predefined logic and interlocks, with manual control reserved for testing or abnormal conditions. System capacity was sized to meet maximum inerting demand, often driven by full tank inerting during survey conditions. Reported capacities ranged from approximately 4,500–5,000 m³/h for engine-focused systems to around 14,000 m³/h on tankers requiring full tank inerting. Buffer tanks, typically around 1 m³, ensured immediate availability and pressure stability. Redundancy philosophy evolved over time: earlier vessels sometimes relied on single-generator arrangements with critical spares, while newer designs increasingly incorporated redundancy and high-pressure nitrogen cylinders for short-term backup.

Ventilation philosophy built on conventional engine-room arrangements, with additional safety-driven requirements. Main engine-room ventilation generally remained similar in size and configuration, as fan capacity continued to be governed by engine air demand, heat removal, and temperature control. Methanol operation, however, required defined ventilation conditions to be met before activation. Methanol-related spaces typically required around 30 air changes per hour and were served by dedicated ventilation systems independent of the main engine-room airflow. Depending on vessel design, annular spaces in double-wall piping were protected either through dedicated mechanical ventilation or through inerting arrangements with associated leak detection and monitoring. Fuel-preparation and pump rooms were usually fitted with redundant ventilation arrangements, such as two 50% capacity fans.

4.2.5 Automation, monitoring and control systems

Automation is where the integration dependence described in the introduction to Section 4 was most visible in daily operation.

Respondents said that methanol adoption had not produced a uniform increase in automation in the sense of adding a new overall philosophy. Dual-fuel methanol engines still relied on safety and control concepts broadly familiar from other alternative-fuel systems such as LNG or LPG. At the same time, methanol operation relied very heavily on tightly integrated automation at a functional level, especially for safety-critical processes including fuel changeover, system start-up and shutdown sequences, leak management, and emergency response.

From the operator's perspective, this automation simplified day-to-day handling. Entering methanol mode could often be reduced to a single command, while the control system executed complex safety sequences automatically. Operational workflow therefore shifted away from manual execution and toward supervision, confirmation of successful sequences, and alarm interpretation.

Continuous monitoring was central to this framework. Safety-critical parameters included leakage detection in double-wall piping and around engines and preparation rooms, ventilation status in enclosed spaces, inert-gas pressure in tanks, methanol fuel pressure and temperature, valve position and feedback, seal-oil pressure, combustion behavior, and pilot-fuel consumption. Respondents said that while automation reduced human error and manual workload, it increased both maintenance complexity and competence requirements. Many failures were not mechanical but related to automation logic, sensor signals, or automated sequences stopping because required interlock and permissive conditions had not been satisfied. Crews therefore needed to understand why automated sequences stopped and which safety condition was blocking progression. Several operators said that they had become more dependent on OEM specialists when failures occurred in automation or networked systems rather than in hardware.

Automation was described as both an advantage and a challenge. When functioning as intended, automated systems operated smoothly and reduced manual workload. When faults occurred — particularly in software or control logic — troubleshooting became demanding and often depended on remote OEM support. Crews reported difficulties in interpreting methanol-specific alarms, understanding automated safety logic, and working with interlock-driven start-up and shutdown sequences that could not be manually overridden. Limited hands-on experience, uneven familiarity with system behavior, and gaps in documentation contributed to hesitation and, in some cases, preference for continued conventional marine fuel operation. Respondents noted that many of these challenges reflected early operational experience while operators, OEMs, and suppliers were still building familiarity with methanol systems, refining documentation, and incorporating lessons learned into subsequent designs and procedures.

4.2.6 Leak detection, material compatibility, and structural vigilance

Leak detection shows the same dependence from the other direction, because the safeguards engineered into the system and the practical work of localization depend on the crew.

Operational experience indicated that methanol did not materially increase vigilance requirements for leaks and cracks compared with other dual-fuel systems, as detection was largely embedded in system design rather than dependent on manual inspection. Any inner-pipe leak in the double-wall system was captured in the interstitial space and triggered automatic shutdown, isolation, and changeover to conventional marine fuel operation. The alarm thresholds and the shutdown sequence are set out in 5.3. Leakage quantities were typically very small and fully contained.

> Existing guidance was insufficient or impractical, leading crews to develop onboard methods, such as applying chalk to suspect areas and observing wash-off patterns after system restart.

The primary challenge identified was leak localization. In several cases, existing guidance was insufficient or impractical, leading crews to develop onboard methods. These included the use of inspection plugs to detect minor leakage, as well as simple techniques such as applying chalk to suspect areas and observing wash-off patterns after system restart. Leak localization was often performed using nitrogen rather than methanol. Thermal imaging was available on some vessels but not part of a standard detection regime. Such locally developed practices remained important as evidence of first-mover problem solving.

In spaces without double-wall piping, such as fuel-preparation rooms, leak management relied on continuous surveillance and engineered safeguards including CCTV, drip trays with level sensors, and controlled ventilation arrangements. Respondents highlighted a trade-off in ventilation design: while higher airflow reduces vapor accumulation, excessive ventilation can dilute small leaks before gas detectors respond, reducing early detectability. Controlled ventilation levels were therefore recommended over maximizing airflow. The design response to this is covered in section 2.4.4.

4.3 Maintenance, PMS/SMS, and spares

This section covers the activities methanol added to maintenance and the management systems around it:

- How work was divided between automated checks and crew routines, and what isolation procedures were required
- What incidents were reported in service
- What new planned-maintenance tasks arose and how they interacted with conventional-fuel intervals
- What the safety management system gained, and how spares were provisioned across two fuel systems

4.3.1 Automated checks and crew routines

Routine checks and procedures for methanol fuel systems were described as governed primarily by automated safety and control systems, supported by targeted crew routines. The most critical verifications were embedded directly in start-up and changeover logic and executed automatically whenever methanol mode was initiated. Each start-up sequence included nitrogen purging, pressure and tightness verification, and flushing with methanol before full operation was permitted. These checks formed part of the normal operational cycles.

During operation, continuous supervision was handled by engine control and safety systems. Parameters including injection characteristics, combustion pressure, fuel supply pressure, seal-oil differentials, valve feedback, and leak-detection integrity were monitored automatically. Methanol leak detection relied on double-wall piping combined with continuous LEL monitoring, enabling early identification of even minor leakage without manual inspection. If predefined thresholds were exceeded, alarms were triggered and the system automatically reverted to primary fuel operation.

Crew routines therefore focused on operational vigilance, condition monitoring, and preservation of system readiness, with particular emphasis on nitrogen purging and ventilation due to methanol's low flash point and toxicity. Across all intervals, observed deviations triggered immediate corrective action.

Planned maintenance included inspection and overhaul of methanol-specific components such as methanol fuel-injection components (including hydraulic booster injectors), with intervals defined by OEM guidance and updated based on operational feedback. Leak localization formed part of routine diagnostic practice. Respondents described the systematic use of portable equipment and nitrogen purging to isolate leaks by observing oxygen displacement or gas behavior across system sections. One OEM noted that leaks were frequently associated with recently serviced components, highlighting the sensitivity of assembly quality in methanol systems.

Permit-to-work approval depended on assessed risk level. Routine work could be authorized onboard, whereas higher-risk maintenance on methanol systems required shore-based review and approval. Where risk assessments or isolation plans were considered inadequate, authorization was not granted.

Table 6: Checks by interval

Interval	What was checked
Every start-up and changeover (automatic)	Nitrogen purging, pressure and tightness verification, and flushing with methanol before full operation is permitted.
Continuous (automatic)	Injection characteristics, combustion pressure, fuel supply pressure, seal-oil differentials, valve feedback, and leak-detection integrity. Double-wall piping with continuous LEL monitoring; alarms and automatic reversion to primary fuel if thresholds are exceeded.
Daily watchkeeping	Pumps, valves, pipelines, nitrogen systems, and ventilation, together with fuel pressure and temperature, inerting pressure, pilot-fuel availability, and alarm status.
Weekly or biweekly	Nitrogen purging to maintain dryness; exercising valves and actuators to prevent sticking; leak monitoring. Short methanol operation or flushing cycles on vessels running mainly on primary fuel.
Monthly	Visual inspection of methanol piping and valves, alarm testing, leak-trend review, vent inspection, and verification of nitrogen and ventilation performance.
Quarterly	Formal testing of safety-critical functions, including alarm simulations, emergency-shutdown verification, and selective pressure testing of pipe sections.
Per OEM interval	Function testing and calibration of methanol detectors, emergency-shutdown systems, and safety sensors in accordance with OEM and class requirements.



4.3.2 Isolation procedures

Isolation procedures before maintenance on methanol systems were described as significantly more stringent than for conventional marine fuel systems due to toxicity, flammability, and the enclosed nature of installations. The most critical step was nitrogen purging, initiated through the automated control system when methanol operation was stopped, to remove residual methanol from pipework and components. Maintenance was not permitted until purging was complete and the system was confirmed safe. Crews then verified gas-free conditions using portable methanol gas detectors, checking both the immediate work area and adjacent spaces, including annular spaces in double-wall piping. Methanol maintenance built on established isolation and permit-to-work practices, with additional requirements for methanol-system purging, gas-free verification, and leak management.

4.3.3 Incidents and maintenance experience

Operational experience across first-mover vessels indicated no critical technical incidents directly attributable to methanol as a fuel. Respondents partly attributed this to dual-fuel flexibility, which allowed immediate reversion to conventional marine fuels when required. Reported issues were generally minor to moderate and concentrated on methanol-specific components rather than the main engine.

Early operational experience highlighted reliability issues with methanol injection equipment (including hydraulic booster injectors) in some first-mover projects, particularly during changeover phases. Premature wear and occasional failures were reported in methanol fuel-injection equipment, particularly nozzle tips, atomizers, and associated injection-system components. Contributing factors included carbon build-up, thermal expansion, cracking, sticking, and mechanical damage, while some cases were linked to material limitations, methanol-water operation for Tier III compliance, or extended conventional fuel-only operation. These components typically required shorter maintenance intervals than conventional injectors. Operators responded by increasing inspection frequency, accelerating replacement cycles, and applying revised OEM guidance and design updates. Once injectors operated correctly, steady-state methanol running was generally stable, and respondents noted that these experiences have driven ongoing OEM design improvements, although injector reliability remained a key operational focus. No comparable methanol-specific damage was reported on ancillary systems or core engine components.

From an operational perspective, coating integrity in methanol fuel tanks was identified as critical to long-term performance. Respondents reported minor coating defects that were detected early and rectified through local repair under warranty. Larger failures would have required full tank preparation during dry docking, reinforcing the importance of inspection regimes aligned with chemical-tanker practice.

> First-mover vessels indicated no critical technical incidents directly attributable to methanol as a fuel.

Additional issues included internal leaks within double-wall piping systems. These were contained events but were often difficult to locate, particularly between piping and cylinder heads. They were treated as design-related challenges, with sealing reliability improved over time. Other reported issues included dry-air solenoid valve failures, electrical and software faults, sensor malfunctions, false indications leading to automatic shutdowns, increased filter fouling on certain tanker designs, sporadic flange leaks not directly attributed to methanol, and one pump seizure managed through standard shutdown and nitrogen purging. A brief semi-blackout during changeover was also noted, linked to power-management interaction rather than fuel-system failure.

Overall, respondents considered methanol operation to have introduced no major system-level incident risk, while increasing sensitivity around specific fuel-system components, coating integrity, and documentation quality.

4.3.4 New PMS tasks and interdependencies with conventional marine fuels

Methanol had a clear impact on the PMS, primarily by requiring more adaptive scheduling. While many safety-critical checks were executed automatically during start-up and changeover, methanol introduced an additional layer of systems that had to be reflected in PMS. Respondents associated this with methanol injection equipment, fuel pumps and fuel trains, sealing-oil and hydraulic systems, nitrogen purging and inerting arrangements, double-wall piping, annular-space ventilation, leak-detection sensors, shutdown systems, and numerous additional valves, actuators, and instruments.

> PMS development often lagged vessel delivery, as full manuals and technical documentation were frequently available only after operations had begun.

A consistent observation across respondents was that PMS became more complex primarily due to additional methanol-specific equipment, evolving maintenance requirements, and greater reliance on automation and safety-critical systems. A key challenge was that PMS development often lagged vessel delivery, as full manuals and technical documentation were frequently available only after operations had begun. Crews and superintendents therefore developed PMS structures during early service using a combination of manuals, service letters, and engineering judgment.

Methanol equipment also did not align well with traditional hour-based maintenance logic. Components such as injectors continued to accumulate engine hours during primary fuel-only operation, making running hours an incorrect representation of actual usage. OEM recommendations to flush or periodically exercise methanol systems during inactivity further complicated scheduling. PMS logic therefore evolved toward a combined approach incorporating running hours, elapsed time, and operational state.

Injection equipment was the primary driver of new PMS tasks. Methanol injectors were more complex and time-consuming to inspect and overhaul than conventional units. Early experience indicated higher replacement rates and sustained focus on methanol fuel-injection components (including hydraulic booster injectors), with overhaul intervals around 8,000 running hours and intermediate inspections. These injectors were also significantly larger and heavier — often exceeding 1 meter in length and around 120 kg for a medium sized container vessel — requiring specialized handling and careful post-installation sealing verification, including vacuum testing following cylinder-head work.

Methanol and conventional marine fuel PMS were operationally interdependent. Each fuel system retained its own injectors, pumps, and maintenance tasks, but methanol operation remained dependent on a functioning primary fuel system. As a result, both PMS structures had to be maintained in parallel to ensure neither constrained dual-fuel capability. Respondents therefore described methanol as introducing a full layer of fuel-specific, safety-critical maintenance tasks on top of an otherwise mature conventional-fuel PMS.

4.3.5 SMS additions: procedures, permits, and drills

Methanol-specific content within the safety management system is described in 5.1, covering the gap analysis against existing procedures and the checklists, permits-to-work and drills that followed.

4.3.6 Spare parts management and shore support

Because methanol functioned as a secondary fuel in dual-fuel systems, it did not fundamentally change the core spare-parts philosophy. Vessels could revert to primary fuel operation, meaning methanol-specific components were not class-critical for basic operability. Minimum stock therefore remained centered on class-mandated diesel-engine spares. Methanol did, however, expand recommended and extended inventories. Operators generally followed OEM spare-parts lists and supplemented them with methanol-related items required to sustain operation, including injection-system consumables, methanol-compatible seals and O-rings, gas-detection sensors, pressure and temperature sensors, and actuator components for shutdown and valve systems. Support systems such as nitrogen generation were also highlighted as operationally critical.

Methanol bunker couplings. Image provided by V-Ships.



Managing two fuel systems introduced additional complexity. Conventional marine fuels spare strategies were mature and standardized, whereas methanol systems were still evolving and their failure behavior was less well understood. Methanol components therefore tended to be held in recommended or extended inventories rather than minimum critical stock. Material compatibility influenced spares planning, particularly for elastomers, seals, and gaskets. Sensor shelf life and long lead times were also significant constraints, with some sensors limited to around 12 months' shelf life despite replacement lead times of up to 6 months.

Routine methanol-related maintenance was increasingly handled onboard as crews gained experience, certification, and procedural support. However, shore-based involvement remained important for major interventions, software updates, automation validation, troubleshooting, and assurance of safety-critical systems. Methanol did not require entirely new shore-side organizations or significant headcount increases, but it did increase the involvement of technical superintendents, vessel managers, and HSEQ personnel in safety oversight, OEM coordination, and regulatory compliance.

Additional challenges arose from unclear boundaries between tasks manageable onboard and those requiring OEM or shore support. Documentation quality, manual updates, and clarity of procedures for low-load and extended-idle operation were recurring concerns. Respondents consistently observed that methanol operation was technically robust and manageable but required greater effort than conventional marine fuels in terms of monitoring, system understanding, and safety discipline.

05 Safety and regulatory learnings

Safety is achieved through layered protection. Safety performance was the combined outcome of engineered safeguards, automation, detection systems, procedures, risk management controls, emergency preparedness, and competent crews. Most incidents stemming from methanol operations were minor, tracing back to procedures and human factors during maintenance or configuration changes.



Building on the operational, commissioning, and inspection experiences described in Section 4, respondents highlighted several safety and regulatory themes that shaped how methanol systems were managed in practice. Operating on methanol required operators to extend established safety practices into areas where fuel properties and system behavior influenced how crews recognized, interpreted, and responded to risk. Across interviews, four characteristics of methanol consistently shaped onboard safety practice:

- A low flash point increasing ignition likelihood,
- Toxic vapors particularly relevant in enclosed or poorly ventilated spaces,
- Limited flame visibility affecting detection and firefighting response, and
- Liquid storage at ambient conditions that maintained familiar handling frameworks while reducing visible warning cues.

These characteristics were managed through a combination of procedures, risk management measures, detection systems, PPE, equipment, and training. Early operations were approached conservatively, with crews relying heavily on checklists, supervision, and system feedback while building familiarity. One respondent described this transition directly: “Methanol was not a fuel that people usually knew, and they were not comfortable with it.” Several respondents reported that methanol’s liquid storage at ambient temperature and pressure simplified implementation compared with some other alternative fuels, allowing operators to build on familiar handling practices. With repeated operations and drills, familiarity increased and operational handling stabilized.

Taken together, these characteristics moved the primary means of detection away from the crew’s judgement solely and onto instruments: fixed and portable gas detection for vapor that gives little warning, and thermal or infrared equipment where flame is not reliably visible.

This section focuses on how safety systems and regulatory requirements were interpreted and applied in practice, highlighting how procedures, equipment, and crew behavior combined to manage methanol risk during operations.

5.1 Safety management system changes

Methanol called for methanol-specific content inside the safety management system that crews already used. Operators conducted structured gap analyses, identified where methanol-specific risks were not addressed, and integrated new procedures and checklists into the established SMS framework. In early phases, methanol risks were sometimes assessed using LNG-based assumptions, following the LNG-centric structure of the IGF Code, resulting in conservative initial controls. As operational experience accumulated, procedures were selectively simplified, reflecting the fact that methanol, while toxic, is operationally less complex than LNG, as it is neither cryogenic nor gaseous under normal conditions.

Operators built methanol into familiar procedural structures, adding methanol-specific topics that crews could apply using formats they already recognized from conventional operation. Operators with LNG experience reported that the overall SMS structure remained familiar, with methanol representing an incremental extension. These updates covered three main areas: procedural definition, execution tools such as checklists and permits, and continuous refinement through operational feedback.

These procedures were used to establish baseline safety expectations, such as the number of portable gas detectors to be carried and the locations where methanol-specific equipment should be stored for immediate use.

Operational activities involving methanol systems were formalized in detail using adapted checklists derived from existing guidance frameworks such as International Association of Ports and Harbors. These methanol-adapted checklists included controls such as confirmation of gas-detector readiness, PPE verification, communication alignment, and controlled isolation and purging steps associated with methanol system handling. These checklists were also linked directly into permit-to-work and risk-assessment processes and included mandatory gas testing before maintenance, explicit nitrogen purging before any system was opened, and methanol-specific risk prompts linked to entry, spills, inhalation, and system opening.

> “... retained the same permit-to-work checklist format used for conventional vessels to keep crews “on the same page”.

One operator explained that they deliberately retained the same permit-to-work checklist format used for conventional vessels to keep crews “on the same page”, while adding methanol-specific countermeasure flowcharts, material safety data sheet references, and prompts relating to methanol space entry, inhalation and spill scenarios. The same respondent also noted that the fuel preparation room and pump room were under continuous exhaust ventilation at around 30 air changes per hour and, because of this, were not treated as enclosed spaces in the same way as traditional confined spaces, even though methanol-specific entry controls still applied.

In relation to how methanol procedures were distributed and updated, some operators created dedicated channels for methanol-related procedural updates so that only vessels operating methanol systems received the relevant revisions and feedback. This was used not only to circulate updated checklists and procedural changes, but also to share first-mover learnings such as adjustments to PPE requirements or refinements in detector-handling practice. Respondents indicated that this became particularly important as fleets expanded and operational experience accumulated unevenly across vessels.

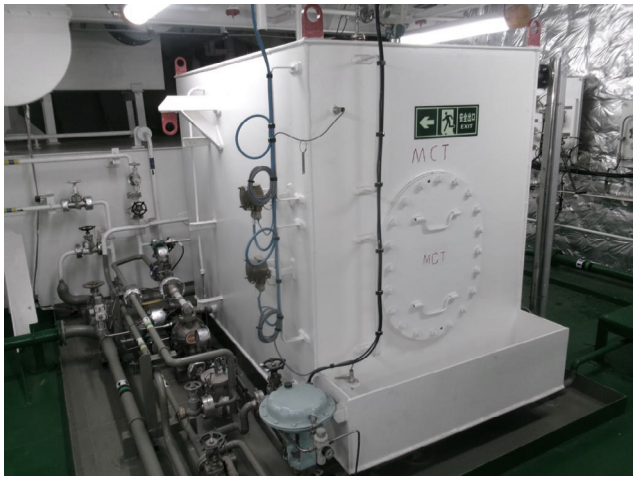
Emergency-response procedures were structured as flowcharts that matched the actual order of tasks onboard, allowing crews to follow them directly in operation rather than interpret long descriptive text, particularly under time pressure. These covered system-related incidents such as methanol spills in engine and fuel-preparation spaces, fires associated with methanol systems, escalation of gas-detection alarms, and nitrogen-exposure situations linked to purging operations. The gas-detection alarm flowchart, for example, followed the two-stage escalation logic set out under Fixed and portable gas detection below.

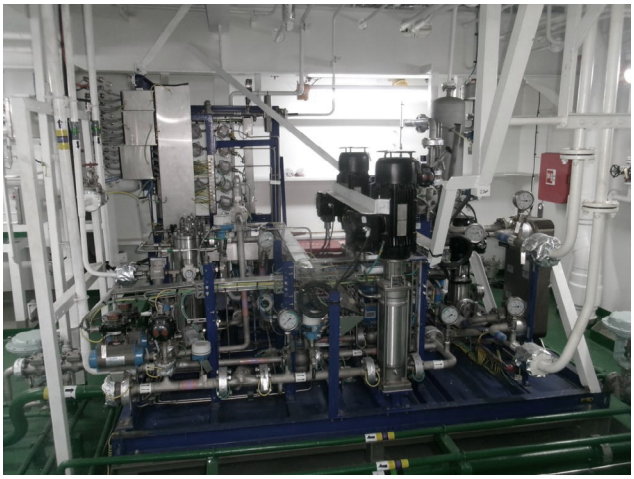
Respondents indicated that these flowcharts were developed iteratively. In one case, early spill-response flowcharts did not clearly include methanol-specific gas filters and the correct donning sequence, and that this gap was only identified when crews physically walked through the drill scenario, after which the flowcharts were revised.

The most visible SMS changes were the introduction of methanol-specific procedures, checklists, permits-to-work, and associated risk-assessment processes in engine-room operations. These included dedicated processes for fuel changeover, spill response, emergency-shutdown testing, methanol-system isolation, and targeted drills. Additions focused on systems incremental to conventional-fuel vessels, particularly gas detection, methanol-space ventilation, shutdown systems, and verification of purging and inerting arrangements.

Methanol introduction also increased shore-based involvement in SMS governance, especially during early operations. Greater support from safety and technical teams was required as procedures and practices matured. Respondents observed that tanker segments were generally more accustomed to gas detection and safety instrumentation, while container trades required additional training and support. Several operators responded by introducing dedicated methanol chapters within their management systems, supported by regularly updated procedures and checklists that evolved through operational feedback.

LFSS room. Image provided by V-Ships.





5.2 PPE requirements

Operators specified PPE by task rather than by a single onboard standard, and provisioned it above the minimum so that response was not delayed. PPE arrangements for methanol-fueled vessels were developed considering that crew could be exposed to both liquid methanol and methanol vapors during operations, particularly during leaks, maintenance, and bunkering. Crews were equipped with chemical-resistant suits suitable for splash-exposure and, where required, full chemical-response suits. These were supported by chemical gloves, face shields, goggles, and flame-resistant clothing. Respiratory protection was provided through full-face masks fitted with methanol-rated filters, while self-contained breathing apparatus equipment was available for work in spaces where methanol vapor concentrations were elevated or oxygen levels were reduced, particularly during nitrogen purging.

One vessel manager reported that vessels were fitted with eyewash stations and emergency showers in both deck and engine-room locations, and that safety data sheets together with medical-response materials were kept onboard for immediate use in contamination or inhalation scenarios.

PPE application was structured according to task-specific risk. Routine methanol-related work could be carried out using lighter protection such as gloves, while tasks involving opening of the system or potential exposure required the usage of full chemical suits and respiratory protection. Operators developed onboard PPE matrices linking specific methanol tasks to defined protective configurations conveniently displayed for crews to verify requirements before undertaking a task. Dedicated PPE storage arrangements were also implemented close to methanol stations to ensure immediate availability during system intervention or response scenarios. An example of such a matrix is presented in Figure 1.

Figure 1: An operator's PPE matrix, linking each methanol task to the equipment required at all times and the equipment required only where circumstances or risk assessment call for it.

	Bunkering	Sampling	Loading/ discharging	Gas freeing	Tank entry	Tank cleaning
Safety shoes	○	○	○	○	○	○
Boiler suit	○	○	○	○	○	○
Safety helmet	○	○	○	○	○	○
Glove	○	○	○	○	○	○
SCBA	○	○	▲	▲	▲	▲
Chemical suit	○	▲	—	▲	▲	▲
Chemical glove	○	○	▲	○	○	○
Chemical shoes	○	○	—	○	○	○
Chemical face shield	○	○	*	▲*	▲*	▲*
Chemical apron	—	—	▲	—	—	—

○ All times. Essential equipment

▲ As required. Depend upon circumstances or risk assessment

* Eye protection

PPE quantities varied across operators but followed a consistent operating principle: sufficient equipment must be available to support immediate response without delay. Respondents described configurations such as four full chemical-response suits supporting a two-in/two-out intervention model, together with additional anti-splash suits for supporting personnel. Others carried higher quantities depending on vessel type and company standard. Typical configurations referenced included six anti-splash suits and four chemical-response suits forming part of planned emergency-response capability. In general, PPE provision was deliberately higher than minimum requirement during early methanol operations.

PPE maintenance involved routine inspections and testing and was integrated into planned maintenance systems and carried out in accordance with manufacturer guidance. Maintenance practices varied by equipment type, with some vessels storing chemical suits vertically as required, and newer suit designs in certain cases incorporating onboard test capability, while older models relied more on periodic shore-based testing after extended service. Formaldehyde exposure in engine and aftertreatment spaces was also identified as a specific operational consideration. In these areas, respiratory protection was applied with the same intensity as for methanol vapor exposure due to its toxic characteristics.

5.3 Fixed and portable gas detection

Fixed installations cover the spaces where methanol could accumulate; portable units cover the person doing the work. Gas detection forms one of the core protection layers in methanol operation. Fixed gas detectors were installed across methanol-relevant spaces, including fuel-preparation rooms, engine rooms, tank-connection areas, ventilation outlets, and double-wall piping sections. These were locations where methanol could accumulate or be released, ensuring that both source-adjacent and surrounding spaces were covered.

The fixed detection systems operated on a two-stage alarm logic. A lower threshold, often reported at around 20% of the LEL, triggered audible and visual alarms and required crew investigation. A second threshold, reported in some configurations at around 40% of the LEL, triggered automatic shutdown and system isolation. These were operator-specific reported settings and should not be interpreted as universal industry alarm thresholds. Once the second threshold was reached, the plant transitioned automatically to a safe condition while propulsion was maintained through automatic changeover to conventional marine fuel operation. This automated response includes controlled nitrogen purging of the isolated methanol fuel circuit, which formed part of the integrated shutdown sequence. One operator gave a more explicit description of this purge sequence, explaining that purging continued for about 300 seconds until return-line level sensors indicated dry condition, followed by a further 30 seconds of purging after dry indication. Respondents also described a start-up integrity check: on some systems, methanol start-up involved an integrity test in which inner and outer pipes were pressurized and valve positions checked before methanol was admitted, and allowable leak limits were protected by two independent safety valves.

Gas detection, ventilation, and shutdown logic operated as one connected safety system. Ventilation in methanol spaces was continuously active during methanol operation, and in spaces such as cofferdams or fuel-preparation rooms the air-handling strategy supported vapor removal after alarm. Accommodation spaces were arranged as protected zones, with positive-pressure ventilation and air intakes positioned away from likely release points. One operator also described the presence of tank-pressure alarms and bursting disks set at about 10% above normal working pressure, creating an additional layer around tank-pressure control.

Portable gas detectors were routine operational tools used before starting work during bunkering, maintenance, and entry into methanol-related spaces to verify safe conditions, and then kept active during tasks, particularly when methanol systems were opened. There was strong reliance on portable equipment to capture minor leaks or seepage at flanges, filters, or confined corners that might not have immediately produced vapor concentrations high enough to trigger the fixed systems.

Some vessels carried five portable detectors so that every person entering a relevant space could carry an individual unit; others carried three to five depending on vessel and response concept. Some operators referred explicitly to methanol-capable detectors chosen for their ability to detect methanol vapors rather than relying solely on conventional multi-gas units. Calibration practices varied as some operators described monthly onboard calibration checks using calibration gas, others followed quarterly checks, and some relied on vendor-certified maintenance schemes. Where shore-side calibration support was weak, onboard bump-test kits were introduced to ensure detectors were kept in service. Detector settings were also adjusted based on operational use, for example very low parts per million (ppm) thresholds created constant nuisance alarms and were therefore revised upward to values aligned with realistic crew exposure limits. Table 7 sets out the settings, timings, and provision respondents reported.

Table 7: Reported gas-detection settings, purge timings, and detector provision

Parameter	Reported value
Fixed detection, first alarm	Around 20% LEL: audible and visual alarm requiring crew investigation with portable detectors; methanol operation could continue
Fixed detection, second alarm	Around 40% LEL: automatic shutdown and system isolation, automatic changeover to the primary fuel, and nitrogen purging of the isolated circuit
Nitrogen purge sequence	About 300 seconds until return-line level sensors indicated dry condition, followed by a further 30 seconds after dry indication
Portable detector alarm settings	One operator raised settings from 2 ppm to 50 ppm with a high-high alarm at 100 ppm; another used detectors set around 200 ppm
Portable detectors carried	Three to five units depending on vessel and response concept; five where every person entering a relevant space carried one
Portable detector calibration	Monthly onboard checks using calibration gas, quarterly checks, or vendor-certified maintenance schemes; onboard bump-test kits where shore-side support was weak
Tank pressure protection	Tank-pressure alarms and bursting disks set at about 10% above normal working pressure

5.4 Emergency preparedness and response

Preparedness and response were built as one chain: drills rehearsed the sequence that automatic protection, isolation, and the response team would follow in an actual release.

5.4.1 Emergency drills and preparedness

Emergency preparedness for methanol-fueled vessels was developed by adapting existing drill structures and embedding methanol-specific scenarios into the regular drill cycle. Operators revised existing drill matrices so that methanol response could be exercised through familiar organizational structures but with fuel-specific conditions. One operator praised their crew by mentioning that “the revision of the drill matrix had been initiated by vessel crews themselves, who recognized that methanol operations required different practical capability”.

The scenarios reflected the actual way methanol systems were arranged onboard. These included fire scenarios at the bunker station, in the fuel-preparation room, methanol spills in engine and system areas, and nitrogen-exposure scenarios associated with purging.
Bunker-station fire drills were especially significant because crews had to approach the scenario without relying on visible flame. Instead, they used detector indications, thermal tools, and predefined isolation logic.

Drills were designed to follow actual operational sequence. In fire scenarios, crews were required to prepare alcohol-resistant foam systems physically, verify detector readings before entering affected spaces, and establish safe boundaries around the incident. Where thermal-imaging equipment was carried onboard, crews also practiced using it to identify heat sources in place of visual flame recognition. One operator said that gas detection had become the mandatory first step in any methanol-related drill and that crews were expected to verify atmospheric conditions before taking any further action, even in simulated settings. Another respondent explicitly distinguished between tabletop discussion and physical drills and stated a preference for practical execution over reliance on tabletop exercises.

A repeated drill method described by operators was to run the same scenario twice—first under conventional-fuel assumptions and then under methanol conditions. That allowed the crew to execute the same broad emergency sequence while changing detection method, PPE level, extinguishing medium, and isolation logic. One operator gave this point very directly: “Once you think of a fire which has been caused by a conventional marine fuel, second time you think that the fire has been caused by methanol and manage accordingly.” Another operator added that dual-fuel fire drills were run at least twice per year and deliberately alternated between operational situations based on conventional-fuel or methanol-fuel.

Spill drills required crews to isolate the area, don chemical PPE, and use portable detectors to monitor vapor levels before approaching the source. Nitrogen-exposure scenarios were also included more explicitly than on conventional vessels. In these cases, crews were required to verify oxygen levels, use respiratory protection where needed, and secure the space before assisting affected personnel. Respondents noted that this kind of drill addressed a type of hazard that was much less familiar to crews from non-tanker sectors. In terms of drill frequency, if around one quarter of the crew changed, drills were repeated shortly after crew change to restore a common standard of understanding.

5.4.2 Emergency responses and incident handling

Accidental methanol release onboard was treated as a high-priority emergency managed through layered automatic protection, procedures, spatial control, and trained crew response. The first line of response was automatic isolation. Methanol leak detection and other safety-critical alarms triggered protective actions at predefined thresholds, including shutdown of methanol supply, valve closure, depressurization, and immediate changeover to conventional marine fuel operation. The methanol circuit was then depressurized and purged, minimizing the quantity of methanol available for release and reducing escalation potential.

Early response also required activation of emergency shutdown systems and verification of effective ventilation to establish safe zoning, prevent vapor accumulation, and eliminate ignition sources. Where engine-room sensors activated, the general alarm was raised, non-essential personnel evacuated, and re-entry prohibited until conditions were confirmed safe.

A designated emergency-response team then managed the situation using appropriate chemical PPE and breathing protection. Actions focused on compartment isolation, controlled ventilation, and, where required, nitrogen introduction into methanol fuel lines, tanks, or other isolated sections of the fuel system to prevent formation of flammable atmospheres. Leak localization and verification were carried out using portable gas detectors and, where applicable, nitrogen pressurization, with full system isolation and purging required before maintenance.

Respondents linked response effectiveness directly to training and drills, including simulation of methanol-release scenarios and firefighting involving invisible flames. At the same time, they noted that realistic fire training remained difficult and that the consistency of methanol-specific drills varied across fleets. Emergency response was therefore well supported technically but still evolving in procedural maturity.

5.5 Fire safety

Two properties drove the changes: methanol's limited flame visibility, and its incompatibility with conventional firefighting foam.

Fire safety arrangements for methanol operation involved modifications to both equipment and response practice, especially for limited visibility of flames and methanol's interaction with conventional firefighting equipment. A major adaptation was the use of alcohol-resistant foam in methanol-handling areas as conventional foam systems were insufficient since they were not designed to effectively suppress alcohol-based fires, where the fuel can dissolve or degrade standard foam blankets. For container-vessel operators, the installation of a fixed foam tank represented a departure from standard vessel arrangements and required new operating routines and regular foam-testing requirements.

Firefighting layouts were adjusted to extend foam coverage to methanol-handling locations including fuel-preparation rooms and bunkering zones. On vessels with deck-mounted methanol service tanks, additional water spray or cooling arrangements were introduced to manage exposed tank positions. These changes were reflected in fire plans, where methanol-related spaces and systems were explicitly identified.

Fire detection practice also incorporated thermal-imaging and infrared equipment to compensate for limited flame visibility. Respondents described the use of intrinsically safe cameras to confirm the presence of heat or flame where visual detection was unreliable. One operator positioned such equipment near critical system areas as part of readiness preparation, while another kept cameras under officer control for flexible deployment across the vessel.

Drill preparation. Image provided by V-Ships.



5.6 Incident learnings and insurance impact

The events respondents reported cluster in maintenance, entry, and configuration changes rather than in system failure. Across interviews, no respondent reported methanol-related incidents that escalated beyond the vessel or triggered insurance claims. However, some near-miss situations such as entry into methanol-related spaces without portable gas detection were experienced. In these cases, crew entered fuel-preparation rooms, cofferdams, or adjacent spaces assuming that conditions were safe and only later realized that portable detection had not been carried. No adverse consequence was reported, but the events were treated as procedural, permit-to-work, and risk-management gaps. Maintenance was another area where near misses appeared. Operators described cases where work on methanol filters, pumps, or piping had been initiated without full PPE, often because the task was perceived as routine or low risk. Those events reinforced permit-to-work requirements and mandatory gas testing before any system opening.

Another reported category of near-miss involved incorrect valve alignment. One respondent described a situation in which a drain valve had been left in the wrong position, causing unintended leakage into the fuel-preparation room. While similar mistakes could happen on conventional-fuel systems, methanol's low flash point and vapor toxicity made the consequence more severe.

Vapor leakage was repeatedly identified as the most likely operational event over time. Respondents expected small, yet manageable, leaks at connections or flanges to become more likely as maintenance interventions increased. Nitrogen-related incidents were another talked-about topic in the interviews. One respondent described a case in which a crew member was unintentionally exposed to nitrogen while handling a pressure-related valve connected to the purging system. The incident did not escalate, but it demonstrated how quickly oxygen-deficient conditions can develop during routine maintenance of such systems.

> The systems themselves—detection, isolation, purging, and fallback logic—were generally described as having worked as intended.

Respondents agreed that most observable risks arose due to crew inexperience with methanol during maintenance, entry, and configuration changes. The systems themselves — detection, isolation, purging, and fallback logic — were generally described as having worked as intended.

Insurance instruments were likewise unchanged. Respondents saw no methanol-specific civil liability convention (CLC) requirement: class issued the certificate in the same way as for any other vessel, and ports did not require a different certificate, regarding it as a protection and indemnity and insurance matter rather than a methanol-specific one.



5.7 Inspection experience in service

Inspection followed familiar patterns. A new development was the weight placed on crew understanding and on evidence that safety-critical systems were being used correctly. Port state control inspections of methanol-fueled vessels were broadly aligned with standard inspection practice but with a stronger emphasis on crew understanding and practical operation of methanol systems. Inspectors often asked officers and engineers to explain in operational terms how gas-detection thresholds functioned, what happened automatically during alarm escalation, and how the vessel behaved during changeover from methanol to conventional marine fuels.

Calibration and readiness of gas-detection equipment formed a consistent inspection point. Inspectors requested calibration records for fixed and portable detectors and in some cases asked crews to demonstrate that the equipment was charged, available, and being used correctly. They also reviewed methanol-specific procedures, bunkering checklists, permit-to-work documentation, and drill records, sometimes cross-checking those records against actual crew understanding by asking individual crew members to describe their role in methanol-related scenarios.

At times, inspectors also visited during methanol bunkering and focused on communication, exposure control and monitoring arrangements such as CCTV, and restricted access around the bunker station.

A key difference arose during five-year surveys, where methanol fuel tanks typically required inspection and gas freeing prior to entry, creating additional operational burden. Some operators were exploring alternatives, such as drone-based inspections, to reduce this requirement.

Inspector familiarity with methanol systems varied by region and individual. Some inspectors demonstrated detailed understanding of system design, hazards, and automation logic, while others focused primarily on procedural compliance and documentation. This variability did not change the inspection framework but influenced the depth and technical quality of onboard assessments. Some respondents also noted that inspectors and auditors used vessel visits as opportunities to build familiarity with methanol systems and procedures, with knowledge exchange between crews and inspectors contributing to their understanding of practical methanol operations.

Inspectors focused on understanding hazards, alarm systems, shutdown logic, and emergency procedures, as well as on methanol handling arrangements, leak detection, nitrogen purging, and automation interlocks. Because methanol systems were not always operating under representative load conditions during inspections, assessments often relied on visual inspection, documentation review, and crew demonstrations rather than direct observation of system behavior in service.

A particular focus was also placed on procedural compliance and documentation. Operational logs were examined with particular attention to safety-related entries, while emissions-control records, including EGR status and NO_x performance, were reviewed where relevant. Overall, the inspection regime reflected a shift in emphasis toward system readiness, crew understanding, documentation quality, and execution of safety management practices. The regulatory interpretation behind those requirements is covered next.



5.8 Regulatory experience and evolving guidance

The framework enabled the first projects to proceed; the difficulty was that the same arrangement could be read differently by different parties. The current IMO framework for methanol as marine fuel, centered on MSC.1/Circ.1621, was described as a workable interim basis that enabled early projects to proceed, but still requiring substantial interpretation during design and approval. Respondents experienced inconsistencies around how specific provisions were defined and the way different class societies, yards, and flag administrations interpreted them.

> You can take the same arrangement to two different class societies and get two different answers.

One respondent captured this variability saying that "you can take the same arrangement to two different class societies and get two different answers." Similar technical arrangements were treated differently depending on interpretation, which in turn led to further clarification work, redesign, or alternative design preparation. The treatment of tank connection space was one of the most frequently referenced examples. Respondents said that the term and its associated requirements originated in other fuel frameworks and did not always translate cleanly into methanol arrangements. This created uncertainty around space classification, ventilation rates, fire-protection expectations, and adjacent-space treatment. Methanol-contaminated water handling was another area where respondents saw limited detailed guidance, particularly around required storage capacity, handling method, and separation between small local leaks and larger spill cases.

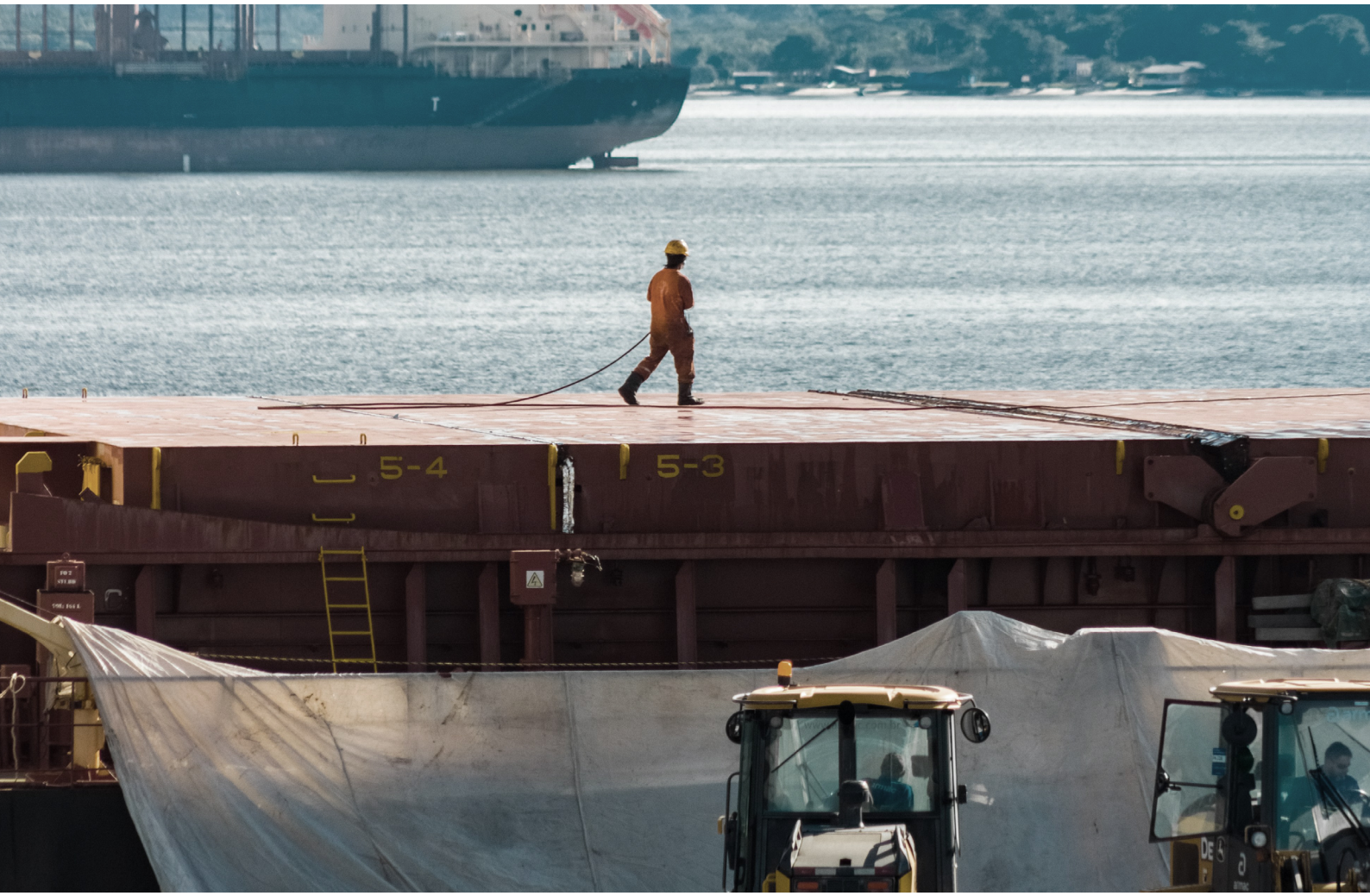
Hazardous-area zoning around vent masts and vent outlets was also identified as an area of interpretation. Prescribed zoning distances could in some arrangements extend into spaces that conflicted with normal vessel operation or layout constraints, especially in retrofits. Some stakeholders therefore relied on dispersion studies or alternative design iterations, while others applied more conservative zoning to avoid approval delay.

Operators emphasized active coordination among owners, operators, shipyards, class societies, and flag administrations throughout the approval process. Although respondents generally supported a goal-based regulatory approach and did not favor highly prescriptive rules, they consistently recommended clearer definitions, stronger alignment across IMO instruments, and more explicit guidance in those areas where interpretation currently drives variability. The same pattern in bunkering standards, connection arrangements, and sampling practice is described under Cargo, port and bunkering operations.



06 Cargo, port and bunkering operations

Bunkering has become increasingly routine, but readiness remains essential. First-of-a-kind bunkering operations required extensive coordination between operators, suppliers, ports, regulators, and emergency responders. As experience accumulated, methanol bunkering procedures became increasingly standardized, although success continues to depend on local readiness, stakeholder competence, and clear operational procedures.



Methanol-specific operational considerations were most visible where cargo operations, port routines, bunkering, terminal activity, and local governance were interacting. Methanol bunkering introduced additional planning, vapor management, zoning, and behavioral controls that affected both vessel and port practice.

This section focuses on the fuel–cargo boundary where methanol produced the strongest first-mover lessons.

6.1 Operational context and baseline port treatment

Across respondents, methanol-fueled vessels did not experience routine restrictions in port entry, berth allocation, anchorage use, or ordinary cargo calls purely because methanol was onboard. Both port authorities and vessel operators repeatedly described methanol-fueled vessels as being handled like conventional vessels once pilots, terminals, authorities, and service providers were familiar with the arrangement. Ports did not apply special pilotage, waiting, anchorage, or berthing rules simply because a vessel was methanol-fueled. As one port representative expressed: "From a port-handling perspective, a vessel remains a vessel, irrespective of fuel type, and no preferential pilotage or berthing treatment is granted just because a vessel was methanol-fueled."

At the same time, respondents also described methanol bunkering as a governance shift in how bunkering was licensed and controlled. Conventional bunker licensing was largely oriented around quantity assurance, fuel quality, and fraud prevention. Methanol and other clean marine fuels were licensed primarily around safety culture, SMS maturity, operator audits, terminal readiness, and operational implementation. Methanol still required chemical-handling rigor and a structured end-to-end risk management approach involving quantitative risk assessment (QRA), gas-dispersion work, zoning, bunker maps, operator licensing, terminal readiness, and active operational checks.

> Wherever we did the first one (bunkering), there was a lot of involvement – port, supplier, class, everybody. But once the plan was agreed, it became routine.

Operators experienced their early first-of-a-kind methanol bunkering operations as being carried out at anchorage rather than alongside because stakeholders wanted to observe and validate the complete bunkering chain in a lower-risk environment before executing the operation into a routine alongside process with simultaneous operations (SIMOPS). One operator described the first calls very openly: "Wherever we did the first one (bunkering), there was a lot of involvement — port, supplier, class, everybody. But once the plan was agreed, it became routine." Respondents said that once the joint plan of operation had been proven across all parties, these first-call constraints were withdrawn for sister vessels as well.

An emerging difference from conventional handling in the form of fuel-use reporting was that ports were increasingly interested in which fuels were onboard and actually used in port to support their own carbon-accounting requirements; this was seen as a developing data requirement rather than an operational restriction.

In addition to operational differences, several administrative distinctions from conventional bunkering also emerged. One major administrative distinction was that bio-methanol bunkering involved a proof of sustainability certificate over and above the conventional bunker delivery note. This had to be used months later in the end-of-year fuel and emissions reporting process, including weighted averaging where different batches with different carbon intensities had been mixed in the tanks. Respondents indicated that these calculations formed part of the emissions-reporting process and were supported by the associated proof of sustainability documentation.



Finally, respondents were concerned that port treatment could still be affected in exceptional situations not linked to routine calls. One example concerned dry-docking, where yards were not prepared to receive a vessel with methanol onboard, resulting in forced debunkering in advance or requiring alternative berth/yard arrangements.

6.2 Voyage planning, routing, and trade deployment

Methanol's lower energy density reportedly impacted deployment planning, route lock-in, and cargo trade-off. Both feeder and mainline operators explained that methanol-capable vessels were tied to fixed routes anchored around methanol-ready hubs, particularly Rotterdam in Europe, because of repeatable methanol supply, established bunkering procedures, and operational confidence.

Some operators bunkered initially at hubs such as China and Singapore before later settling into routine supply patterns centered on Rotterdam. Some liner operators moved away from spot methanol procurement and instead adopted regular bunkering from the same supplier aligned with weekly or biweekly service loops. One operator described using one supplier in Rotterdam on a highly regular two-week pattern because it matched the round-voyage cadence of the vessels. Respondents regarded this as both fuel-sourcing strategy and stabilizing operational planning.

Methanol's lower energy density had an impact on cargo deadweight. Operators noted that carrying full methanol volume could impact cargo deadweight in certain cases. This led to strategies such as bunkering more than once during a voyage, bunkering methanol on back-haul legs only, and avoiding full methanol loading where the cargo penalty was commercially unattractive.

6.3 Port, terminal, and stakeholder readiness

Ports consistently emphasized that methanol readiness grew out of LNG-era governance experience. They reused familiar structures — QRA, risk studies, port readiness levels and checklists — but adapted them to methanol's own liquid, toxic, low-flashpoint behavior. Methanol was described as a smaller conceptual step than LNG because it remained a liquid at ambient conditions. One port described the move from LNG to methanol very directly, saying that after the effort of LNG familiarization, the step to methanol "was not big at all" by comparison. Even so, ports still carried out new risk assessments, fire-brigade dialogues, pilot familiarization, transport-agency coordination, emergency-response coordination, and terminal-specific readiness work before allowing methanol bunkering.

A typical port-side methanol bunkering readiness package included safety assessment through QRA and gas-dispersion work, spatial planning through bunker maps and approved locations, a safety-driven licensing regime for bunker operators, terminal-readiness work, and standardized tools such as International Association of Ports and Harbors checklists. Within this framework, ports generally licensed bunker operators as the primary responsible entities. At the same time, terminals were assessed and designated as "ready" for methanol bunkering through the overall readiness process, even though they were not licensed directly. Bunker operators were therefore permitted to conduct operations only at terminals that had been verified as suitable within this framework.

For container terminals, readiness was described as being mainly about awareness, alarm and evacuation planning, PPE understanding, and incident-response familiarity. For liquid-bulk terminals, readiness also included more technical handling and response capability. Some ports also introduced or referenced digital familiarization and awareness training for shore-side personnel and described the need for dangerous-goods enforcement staff to understand methanol well enough to judge whether operations were being carried out at the intended standard.

> Initial hesitation often became active support when the people doing the work were involved in the actual assessment.

Several respondents noted that involving stevedore representatives directly in terminal risk assessments changed the tone of first-mover methanol readiness. Initial hesitation often became active support when the people doing the work were involved in the actual assessment. This was one of the clearer portside first-mover lessons.

6.4 Planning, permitting, and pre-arrival coordination

Planning and permitting required structured documentation and advance coordination. Respondents described methanol bunkering as requiring an operation-specific joint plan of bunkering operation (JPBO) document, especially for first-of-a-kind transfers. These plans were described as practical operating documents defining mooring arrangement, transfer sequence, gas-dispersion assumptions, zoning, communication, contingency handling, and emergency response.

Ports and operators both stressed that secure mooring between bunker barge and receiving vessel was central to keeping the operation stable and the control zones within the assumed footprint. Poor mooring could cause the transfer to become unstable or the control zone to expand under surge or weather. Operators also noted that these JPBOs were vital for SIMOPS, because any impact of methanol bunkering on cargo work had to be agreed in detail before the port would accept the operation.

Ports also described methanol bunkering maturity through port readiness levels. Some ports described current methanol operations as sitting at an interim stage between existing methanol cargo infrastructure with modular safeguards and a more mature future state with dedicated bunker vessels, integrated ESD links, and boom-mounted protection. This maturity framing was useful because it explained why methanol bunkering could feel operationally routine in one port and still structurally provisional in another.

6.5 Methanol bunkering operations

Operational execution of methanol bunkering depended on transfer mode, system arrangement, and supporting equipment.



Transfer mode



System arrangement



Supporting equipment

6.5.1 Modes and locations

Methanol bunkering was reported predominantly as ship-to-ship transfer by barge. Truck-to-ship operations occurred only in isolated early cases and were not the preferred bunkering mode as it required many connect–disconnect cycles, took longer, and increased hose-handling exposure. Pipe-to-ship arrangements appeared mainly in special terminal configurations. In practice, first-mover experience converged around barge-based ship-to-ship transfer as the standard operating mode.

6.5.2 Bunker transfer and hose connections

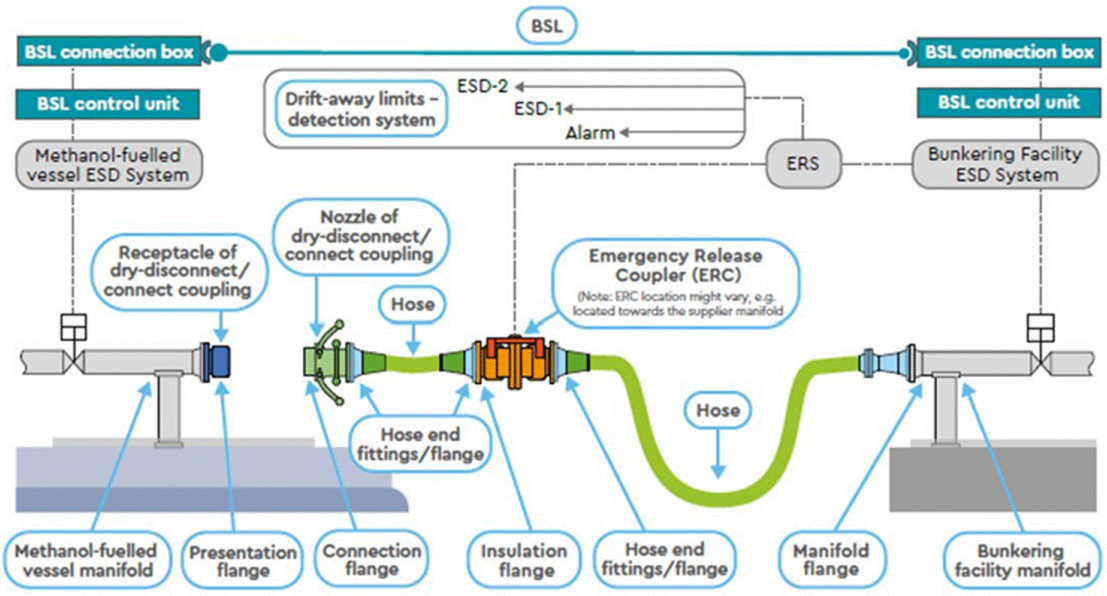
A significant practical detail was that many methanol bunker vessels still do not have hose booms. This meant that the receiving vessel often had to lift and support the methanol bunker hose itself, typically through a davit above the manifold. Respondents referred to davits in the approximate range of 0.5 t, 1 t, and 2 t safe working load depending on vessel size and transfer arrangement.

Methanol bunkering was repeatedly described as involving higher safety measures with vapor management as one of the biggest differences. The vapor return line was actively used during transfer, returning displaced tank vapor to the bunker barge and, where relevant, onward to the terminal. One operator said that vapor return line backpressure could materially reduce bunker-pump rate, in one case by about half. At the same time, respondents appreciated that methanol did not require LNG-style hose cooldown, which simplified the operation.

During connection and disconnection, personnel access to the manifold area was tightly controlled and chemical PPE was mandatory; the task-based inventory is set out in Table 9 under Crew roles, PPE, and monitoring during bunkering. Nitrogen padding and purge/blowback were described as standard operating procedure. Fuel tanks were maintained under positive nitrogen pressure. Transfer lines were purged before transfer to remove oxygen and establish inert conditions, and were purged again before disconnection to minimize residual liquid and vapor release. Operators also pointed out that barges were not yet universally required by regulation to be inerted, although vapor-return and inert-gas handling were already embedded into practical operations.

A preferred liquid supply hose arrangement described by operators is illustrated in Figure 2.

Figure 2: A typical bunker connection. Image provided by SGMF.



FP22-01_Methanol – Safety and Operational Guidelines – Bunkering, 2024, SGMF, Figure 4.7, p 77

A similar but simpler arrangement applied to the vapor-return line. A quick connect/disconnect coupling (QCDC) was strongly preferred because it reduced crew exposure and minimized drips during connection and disconnection, although some barges still preferred flange-to-flange arrangements on their own side. Respondents noted that this mismatch between vessel preference and barge practice was an example of where methanol transfer standardization remained immature. In some fleets, operators had effectively imposed QCDC as their preferred connection mechanism because they were so comfortable with it as a cleaner and safer transfer solution.

Figure 3: Typical Bunker Hose connection. Image provided by V-Ships.



Ports prescribed methanol-compatible hoses, QCDC where fitted, ESD arrangements, dry breakaway or powered emergency release couplings depending on berth maturity, and insulating flanges or electrical isolation where required. At lower readiness levels, existing methanol cargo infrastructure was supplemented with modular safeguards, including pendant-style emergency stop arrangements where full electronic ESD integration between bunker vessel and receiving vessel was not yet available.

6.5.3 Duration and practical complexity

> … once repeat operations with the same suppliers and ports became established, methanol bunkering converged toward something much closer to a normalized standard operating procedure.

Respondents experienced methanol bunkering as only slightly longer than conventional marine fuel bunkering once operators became familiar with the process, typically by around 1-2 hours for comparable transfer operations. This additional time was mainly associated with vapor-return arrangements and nitrogen purging before disconnection. Initial operations were slower because of heightened caution, coordination, and first-of-a-kind stakeholder involvement, but once operations with the same suppliers and ports became established, methanol bunkering converged toward something much closer to a normalized standard operating procedure.

6.6 Venting and vent-mast location

Operators did not vent methanol in port as both a design and operational philosophy. Fuel tanks were nitrogen padded, tank pressure was managed through pressure–vacuum (PV) valves and related devices, and vapor displaced during bunkering was returned to the supplying vessel through the vapor-return line instead of being released. In some arrangements there was no dedicated vent mast, only PV-based arrangements. In others, mast risers and PV valves were located forward and away from cargo areas. Additional PV valves for cofferdams were also mentioned, together with signage around those zones.

Respondents explained that methanol vapor would only be vented after multiple failures, because those spaces were ventilated and gas-detected. Ordinary port operation therefore did not treat venting as a routine feature. One operator was explicit that, in their configuration, there was effectively no normal possibility to vent methanol at all. Any atmospheric release was expected to occur only as a very small residual post-purge release during disconnection after line pressure had been relieved.

6.7 Cargo operations during methanol bunkering

Cargo constraints were encountered during methanol bunkering, not during ordinary port calls when methanol is carried onboard as fuel. These constraints involved imposing temporary safety and hazardous zones established around the bunkering station and its surroundings for the duration of the bunkering and subsequent hose purging. The hazardous zone represented the immediate area where a methanol release could create flammable conditions and was therefore subject to strict controls on ignition sources and personnel access, while the surrounding safety zone provided an additional buffer in which operational activities were restricted to reduce overall risk exposure and prevent interaction between cargo handling and fuel transfer.

In practice, the size and extent of these zones were defined based on risk assessment and gas-dispersion analysis. The dimensions respondents reported are set out in Table 8. Examples of these zones are illustrated in Figure 4.

Table 8: Reported safety and hazardous zone dimensions during methanol bunkering

Zone	Reported extent and controls
Hazard zone	Around 10 meters, with full ATEX measures observed
Safety zone	Approximately 20 meters, with cargo operations and non-certified electronics restricted
Awareness or control zone	Up to 100 meters in some cases, depending on vessel configuration and port requirements
Single restricted radius (alternative arrangement)	Approximately 25 meters, referred to by other operators in place of the tiered arrangement

Figure 4: Safety and hazardous zones on a medium-sized container vessel. The profile and upper-deck views show the zones implemented during Methanol Bunkering.



Safety Zone from the manifold (distances vary by shipowner)

Outer container rows to remain lashed while Bunker barge is alongside

Ports confirmed that such zoning was applied only during active methanol bunkering. Under normal conditions, these zones remained contained within the vessel footprint and typically did not extend onto the terminal. Wider port communication and traffic controls were therefore linked to the bunkering operation itself rather than to the presence of methanol as fuel.

During methanol bunkering, cargo work was suspended inside the defined safety zone around the manifold. Non-intrinsically safe devices such as mobile phones and personal radios were prohibited inside the hazardous zone. The operators interviewed did not permit simultaneous methanol and conventional-fuel bunkering. SIMOPS were possible in principle, but in practice they depended heavily on vessel layout, terminal arrangement, and port tolerance. Some operators still preferred lay-by berths rather than bunkering alongside active cargo berths because the spatial conflict and workload became too complex for their crew.

This was especially relevant for SIMOPS on smaller vessels where the bunkering manifold was always in close proximity to cargo-working areas. At the same time, respondents were clear that other vessel activities like crew changes, provisions, lube-oil handling, stores, and garbage disposal could still be managed during methanol bunkering provided they did not interfere with the transfer operation and that responsible personnel remained available.

> “... mobile phones were regarded as one of the most likely ignition sources to be overlooked ...

On container vessels, reefer containers were unplugged if they fell inside the ATEX area, or operators planned stowage so that reefer boxes never entered that zone during transfer. Dangerous-goods containers were not worked or placed inside the restricted zone during methanol bunkering, and specific operators also avoided cargo work above the bunker manifold. In some cases, sea-side rows were kept lashed during bunkering to eliminate the possibility of containers falling onto the bunker barge. Additionally, stevedores and terminal labor had to be educated on the practical implications of methanol bunkering. Visible signage, briefings, supervision, and active exclusion of mobile phones and other non-certified personal devices formed part of the operational control regime. One operator explicitly said that mobile phones were regarded as one of the most likely ignition sources to be overlooked, which was why their use was controlled aggressively during methanol bunkering. Several operators also described practical stowage responses, such as keeping only through-containers in the bays adjacent to the manifold so that no cargo work would be needed in the safety zone while methanol transfer was in progress.

6.8 Crew roles, PPE, and monitoring during bunkering

The Chief Engineer was consistently described as holding overall responsibility for the fuel-system side of bunkering, while deck personnel handled the manifold connection, hose handling, zone control, and deck-level communication. CCTV and remote observation were heavily used to reduce the need for continuous crew presence in the manifold area during transfer. One operator explicitly said that much of methanol bunkering was handled through CCTV, with no need for continuous physical involvement at the manifold once transfer had started.

One of the strongest recurring lessons was that methanol bunkering on dry vessels required crews to be brought much closer to tanker-style discipline. Respondents noted that crews from tanker backgrounds were more comfortable with chemical PPE, ATEX observance, and hazardous-liquid handling, whereas dry-vessel crews had to be trained and managed up to that standard.

> … methanol bunkering on dry vessels required crews to be brought much closer to tanker-style discipline.

One operator explained that this was easier in their case only because the shore-based management organization already had a tanker background and could import those norms directly.

PPE during methanol bunkering was task-based, with the heaviest requirements at hose connection and disconnection, when the risk of drips or residual vapor release was highest. The equipment respondents described is set out in Table 9. During the transfer phase itself, physical presence at the manifold was minimized because monitoring was carried out remotely via CCTV and continuous manifold presence was not regarded as necessary unless an abnormal condition arose.

Table 9: Task-based PPE and monitoring equipment reported during methanol bunkering

Task or phase	Equipment reported
Hose connection and disconnection	Chemical-resistant suits, rubber boots, and portable gas-detection equipment for personnel directly involved; chemical PPE mandatory and access to the manifold area tightly controlled
Work in and around the manifold area	Methanol-specific gas detectors, ATEX-rated radios, explosion-proof flashlights, anti-static clothing, and methanol-appropriate boots
Transfer phase	Presence at the manifold minimized; monitoring carried out remotely by CCTV, with attendance not regarded as necessary unless an abnormal condition arose
Spill-response standby	Chemical suits, gas detectors, and rubber boots

A particularly important practical learning was that portable gas detectors were useful but not sufficient on their own in open manifold areas because methanol flames were not readily visible. Respondents therefore valued portable flame-detection or thermal-imaging equipment for personnel working near the manifold, especially during connection and disconnection.

6.9 Sampling and quantity reconciliation

No operator experienced any off-spec methanol incident to date. Respondents' experience was that methanol compatibility was simpler than conventional marine fuels and that different methanol batches could be commingled without the kind of compatibility concerns associated with conventional marine fuels. Several said explicitly that they saw no need to segregate one methanol batch from another. It should be noted that respondents' operational experience was developed during a period when methanol fuel standards and industry practices were still evolving.

Sampling practice, however, was not uniform. Some operators relied mainly on supplier certificates and did not take representative onboard samples after bunkering. Others retained onboard samples for around 90 days requiring dedicated storage arrangements consistent with methanol's handling characteristics and low flash point. Sampling sometimes occurred later in the bunkering process, and in some cases drip samples were taken on the bunker-barge side and then passed to the receiving-vessel crew. Respondents also noted that methanol as marine fuel was not treated under the same sample retention regime as conventional marine fuels under International Convention for the Prevention of Pollution from Ships (MARPOL)[5] Annex VI, so current practice was driven more by commercial assurance than by a uniform legal requirement. Ports also noted that future local requirements, such as mass-flow meter expectations, might be imposed with one example pointing toward around 2027.

Quantity reconciliation produced one of the clearest practical "teething problems" in the entire operations dataset. Some vessels did not have manual or hermetic sounding capability for methanol tanks and instead relied on remote gauging based on pressure sensors. Operators described repeated discrepancies between vessel and bunker-barge figures, caused by issues such as condensation or liquid accumulation in sensing lines. These discrepancies were significant enough to generate claims and modifications with the yard until arrangements were corrected. Operators would have preferred a more direct sounding option, but in practice this was difficult.



6.10 Spill response, waste, and discharge management

Respondents stated that the core shipboard oil pollution emergency plan framework remained relevant, but that the conventional oil-spill response assumptions did not fully apply to methanol because of its water-miscible behavior and different response requirements. Standby PPE for spill response was drawn from the same task-based inventory used for bunkering (Table 9). Respondents described controlled water application as one possible response for dilution or washdown, subject to the vessel's spill-response procedures, containment arrangements, ignition control, and applicable discharge restrictions. Where practicable, released methanol or contaminated wash water was to be contained and recovered rather than discharged.

One operator explained that in the event of a larger spill the preferred action, where possible, would be to return the methanol into a primary or secondary tank rather than treat it as an oil spill. Ports reinforced this by noting that absorbents had to be fit for such purposes. Vermiculite was cited as suitable, whereas sawdust was explicitly rejected. Closed scuppers, onboard containment, and local pumping or collection arrangements were also highlighted.

Operators did not report significant waste or bilge issues related to methanol in service. No respondent identified methanol-contaminated bilge water as a recurring operational problem, and methanol use did not generate meaningful new waste streams.

6.11 Where standards were still maturing

Several of the constraints described in this section reflected a framework still taking shape rather than settled operational limits. Ports described current methanol bunkering as sitting at an interim Port Readiness Level between existing methanol cargo infrastructure with modular safeguards and a more mature future state. Connection standardization remained immature, with quick-connect couplings preferred on the vessel side while some barges retained flange-to-flange arrangements. Bunker barges were not yet universally required by regulation to be inerted. Methanol was not treated under the same delivered-sample retention regime as conventional marine fuels under MARPOL Annex VI, so sampling practice was driven by commercial assurance rather than a uniform legal requirement, and ports pointed to future local requirements such as mass-flow meter expectations. Read together with the interpretation differences described under Safety and regulatory learnings, these were the areas where respondents saw the clearest need for methanol-specific guidance.

07 Conclusion

Methanol has moved from concept to operational reality. First-mover experience shows that methanol can be operated safely and effectively in commercial service. Respondents reported no fundamental barriers to vessel operations when alignment between systems, procedures, and people competence was in place.

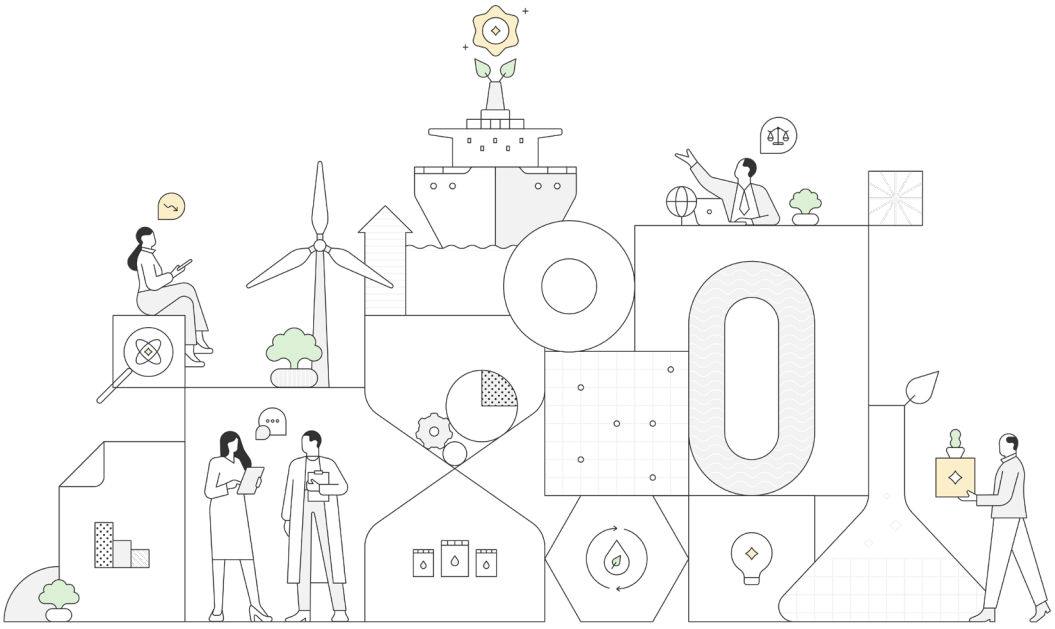


This report records the experience of first movers. The organizations that took methanol into service worked with equipment designs, documentation and operating practice that were still maturing. Early-life issues were reported in injection equipment, auxiliary-engine injectors, high-pressure supply arrangements and solenoid valves, some of which became apparent only after commissioning.

Many of these challenges reduced as equipment designs, commissioning practices and operational experience matured, and as operators, OEMs and suppliers built familiarity with methanol systems, refined documentation, and incorporated lessons learned into subsequent designs and procedures. Crews contributed directly. Where existing guidance was insufficient or impractical, they developed onboard methods, using inspection plugs to detect minor leakage, applying chalk to suspect areas and observing wash-off patterns after system restart, and localizing leaks with nitrogen. Such locally developed practices remained important as evidence of first-mover problem solving.

Commissioning was a demanding stage. Newbuild takeover was more time-consuming and more integration-intensive than for conventional vessels, and the weaknesses that emerged sat between system interfaces, particularly in signal alignment, sequencing logic and responsibility boundaries. Trials revealed design weaknesses such as pressure build-up in return lines during repeated purging. Where delivery schedules were compressed, incomplete testing led to deficiencies becoming visible only during initial service. Several operators deployed crews and shore-based personnel well before delivery and involved them in commissioning and initial bunkering, which built familiarity and allowed onboard procedures to be refined before the vessel entered service.

Organizations adopting methanol now begin from a more developed position. Equipment designs have advanced, procedures exist as a starting point for adaptation, and first-mover operating experience is available to draw on. The clearest lesson from that experience concerns timing. The most valuable work was done early: system integration understood before delivery, procedures developed with the people who would use them, and shore-based teams brought to the same level of understanding as the crews.



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Project manager: Capt Sameer Bhatnagar (MMMCZCS)

Lead author: Capt Sameer Bhatnagar (MMMCZCS)

Contributing authors and project participants: Anaïs Boulay* (Cargill), Pilar Hermosilla (MMMCZCS), Masatoshi Fujita* (NYK), Christopher Fairless* (CF Industries), Jan Otto de Kat (MMMCZCS – up to June 2026), Avisek Nath* (APMM – up to December 2025), Jun Ito* (NYK – up to December 2025), Hiroyuki Uchibori* (Tsuneishi – up to April 2026), Sophie Nadine J. De Decker* (Stolt Tankers – up to December 2025)

Report Reviewers: Sarnbir S. Sawhney* (Seaspan), Seb Brindley* (Seaspan), Kjeld Abo (The Global Methanol Alliance), Alexander Doll (Methanol Institute), Eirik Nyhus (DNV), Marius Leisner (DNV)

Steering committee: Martin Eriksen (MMMCZCS), Evangelos Fragkoulis (MMMCZCS), Utkarsh Dubey (MMMCZCS)

Editors: David Hoskin (cylindr)

Design: Julia Garbowska (MMMCZCS)

Abbreviations

Acronym	Full form	Short explanation
ATEX	Atmosphères explosibles/Explosive atmospheres	European equipment certification framework for use in potentially explosive atmospheres.
BN	Base number	Measure of alkaline reserve in lubricating oil, relevant to cylinder/system oil selection.
CFD	Computational fluid dynamics	Simulation method used to model gas or vapor dispersion and ventilation behavior.
CLC	Civil liability convention	Convention linked to liability and insurance certification for pollution-related claims.
DBC	Dry breakaway coupling	Coupling designed to minimize liquid release during hose connection and disconnection.
EGR	Exhaust gas recirculation	NO_x-reduction system that recirculates exhaust gas to lower combustion temperature.
ESD	Emergency shutdown	Safety system or sequence that shuts down fuel transfer or fuel operation during abnormal conditions.
GHG	Greenhouse gas	Emissions category relevant to decarbonization and lifecycle fuel assessment.
HSEQ	Health, safety, environment and quality	Shore-side function involved in safety governance, procedures, and operational support.
IAPH	International Association of Ports and Harbors	Industry body whose checklists/guidance were referenced for bunkering procedures.
ICS	Integrated control system	Vessel/engine control platform used to monitor and manage operational sequences.
IGF Code	International code of safety for ships using gases or other low-flashpoint fuels	IMO safety framework for low-flashpoint marine fuels.
IMO	International Maritime Organization	UN agency responsible for international maritime regulations and guidance.
IP rating	Ingress protection rating	Electrical equipment rating indicating protection against dust and water ingress.
JPBO	Joint plan of bunkering operation	Operation-specific plan defining bunkering sequence, communications, zoning, contingency measures, and emergency response.
LEL	Lower explosive limit	Lowest concentration of fuel in air that can ignite; used for gas-detection alarm thresholds.
LNG	Liquefied natural gas	Cryogenic alternative marine fuel used as a comparison point for methanol systems and rules.
LPG	Liquefied petroleum gas	Alternative fuel referenced in comparison with tanker-derived bunkering practices.
MARPOL	International convention for the prevention of pollution from ships	IMO convention governing pollution prevention, including fuel and discharge-related requirements.
MGO	Marine Gas Oil	Distillate marine fuel used as backup or conventional marine fuels in dual-fuel operation.
MSDS	Material safety data sheet	Safety document providing hazard, handling, PPE, and emergency-response information for chemicals.
NO_x	Nitrogen oxides	Regulated exhaust emissions addressed through SCR, EGR, or water-based reduction methods.
OEM	Original equipment manufacturer	Manufacturer of engines, fuel systems, or equipment providing technical guidance, training, and support.
OWS	Oily water separator	Equipment used for oily water treatment; not suitable for methanol-contaminated water.
PAUT	Phased array ultrasonic testing	Advanced non-destructive testing method used to detect weld or material flaws.
P&I	Protection and indemnity	Marine liability insurance covering third-party risks and operational liabilities.

Acronym	Full form	Short explanation
PMS	Planned maintenance system	System used to schedule, record, and manage maintenance tasks onboard.
PPE	Personal protective equipment	Protective suits, gloves, masks, detectors, and other equipment used to manage exposure risk.
ppm	Parts per million	Concentration unit used for gas/fuel exposure monitoring.
PRV	Pressure relief valve	Pressure-protection valve that relieves excess pressure from a tank or system.
PSC	Port state control	Inspection regime under which port authorities verify vessel compliance and operational readiness.
PV valve	Pressure–vacuum valve	Tank breathing valve that protects against both over-pressure and vacuum conditions.
QCDC	Quick connect/disconnect coupler	Coupling used to reduce crew exposure and minimize drips during hose connection/disconnection.
QRA	Quantitative risk assessment	Risk assessment method used for bunkering, zoning, and port-readiness evaluations.
RASCI	Responsible, accountable, supporting, consulted, informed	Responsibility-allocation matrix used to clarify ownership across complex projects.
RCA	Root cause analysis	Structured method for identifying underlying causes of failures or operational issues.
SCR	Selective catalytic reduction	NO_x-reduction system using ammonia-based reductant to reduce nitrogen oxides in exhaust gas.
SIMOPS	Simultaneous operations	Concurrent activities, such as cargo work and bunkering, requiring coordinated risk controls.
SMS	Safety management system	Company/vessel safety framework containing procedures, permits, checklists, and emergency controls.
SOPEP	Shipboard oil pollution emergency plan	Pollution-response plan adapted where methanol spill behavior differs from oil.
SOLAS	International convention for the safety of life at sea	Core IMO convention governing ship safety requirements.
STCW	International convention on standards of training, certification and watchkeeping for seafarers	IMO convention setting competence and certification requirements for seafarers.
TEU	Twenty-foot equivalent unit	Standard unit for measuring container capacity.
UV	Ultraviolet	Detection method referenced in relation to fire/flame detection limitations.
VLSFO	Very low sulfur fuel oil	Conventional compliant marine fuel used as a comparison point for methanol operation.
VRL	Vapor return line	Line used during bunkering to return displaced vapor to the supplying vessel or facility.
VR/AR	Virtual reality/Augmented reality	Simulation-based training tools for bunkering and operational practice.

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Appendix A: Methanol design parameters reported by first movers

The design parameters reported across the projects are shown in Table 10.

Table 10: Methanol design parameters reported by first movers

Parameter	Reported value	Where
Retrofit business-case threshold	10–12 years of remaining trading life	2.1
Delivery window	Retrofit ~3–6 months; newbuild ~24–36 months	2.1
Cargo impact (feeder retrofit)	8 TEU lost, ~950 TEU retained	2.2
Methanol share of operation	~50% methanol / 50% conventional marine fuels in one reported case	2.2
Cofferdam width	~640 mm, rising to 1,000–1,500 mm where access, rescue or routing required it	2.4.2
Nitrogen supply (ME-LGIM)	Two separate supplies, minimum 8 bar, 95% purity	2.4.3
Nitrogen generator sizing	40–50% above maximum expected purging demand	2.4.3
Tank inerting oxygen target	Below 8%; ~3% cited as automatic nitrogen shut-off threshold	2.4.3
Bunker transfer rate	~1,600 m^3/h to load 16,000 m^3 in ~12 hours: two 8-inch liquid hoses and one vapor return	2.5
Fuel preparation room ventilation	Interim Guidelines specify 30 air changes per hour; a reduced rate was approved on a risk basis	2.6.2
Added electrical load	~100 kW, driven mainly by the nitrogen generator and compressor demand	2.6.4
Yard crane capacity	~150 tonnes cited, determining module subdivision and lifting	2.6.5
Plate thickness at structural transitions	Up to 100 mm; one operator required Phased Array Ultrasonic Testing	2.6.5

Appendix B: Gap-to-training matrix

Table 11: Gap-to-training matrix (methanol competencies)

Gap Category	Specific Gaps Identified	Required Competence	Training Need / Solution
Fuel-specific safety knowledge	IGF courses are largely LNG-oriented; methanol hazards such as invisible flame are not adequately covered; variability in course quality across providers	Competence in methanol-specific hazard awareness; correct detection and response to invisible flames; confidence to operate safely under methanol conditions	Add methanol-specific modules beyond IGF; hands-on methanol firefighting with thermal/heat detection; standardize quality through manufacturer-aligned content and vetted providers
Emergency response & firefighting	Crews are trained on LNG fire behavior; limited exposure to methanol fire scenarios; lack of practical response experience	Competence in detecting and assessing methanol fires; correct PPE usage; structured emergency response actions	One-day live or realistic firefighting focused on methanol; drills using detection tools and extinguishing techniques; frequent refreshers
Crew background & safety culture	Non-tanker crews lack liquid-cargo safety culture compared with tanker operations; greater initial uncertainty in handling methanol	Tanker-level capability in hazard recognition, permit-to-work systems, leak and atmosphere monitoring, and procedural rigor	Tiered training pathway combining IGF, company-specific methanol training, and onboard mentoring by experienced tanker or methanol personnel
Simulation & practice environment	Limited availability of methanol-specific simulators and realistic pre-bunkering training environments	Procedural fluency in bunkering operations, ESD logic, coupling/uncoupling, monitoring, and communication	Develop augmented reality/virtual reality-based bunkering simulators; expand availability of methanol-specific simulation platforms
Vessel, engine, and system specificity	Generic training does not reflect vessel-specific layouts, yard variations, or installed fuel-system configurations	Competence in engine platform fundamentals, methanol system architecture, supply-skid behavior, interlocks, and vessel-specific procedures	Two-week OEM training pathway combined with company-specific curricula aligned to vessel configuration
Automation and control-system understanding	Limited understanding of system logic, automation behavior, alarm hierarchies, interlocks, and automatic fallback modes	Competence in interpreting system state, alarm cause–effect relationships, and automation-driven responses	Dedicated training on control logic; simulator-based alarm interpretation; system walkthroughs linked to operational scenarios
Electrical, hydraulic, and software literacy	Limited foundational electrical, hydraulic, and automation knowledge; difficulty interpreting control logic and interlocks	Competence in reading schematics, understanding hydraulic systems, interpreting alarm logic, and safe parameter handling	Front-load foundational modules; intensive digital-twin training; case-based diagnostics
Troubleshooting	Reliance on component replacement rather than structured diagnosis; wiring or configuration issues leading to extended downtime	Competence in systematic fault isolation, signal tracing, alarm interpretation, and evidence-based decision-making	Scenario-based troubleshooting with fault injection; structured root-cause analysis; instructor-led assessment
Prior knowledge transfer / misapplied concepts	Misapplication of LNG or IGF-based learnings to methanol systems; informal or outdated mental models	Competence in correct mental models of dual-fuel operation, fuel pathways, protection systems, and manufacturer procedures	Structured reset of incorrect assumptions; alignment of third-party training with OEM guidance
Learning attitude & preparation	Variable trainee preparation; limited awareness of vessel assignment or training objectives	Preparedness, engagement, and clarity of role and learning objectives	Pre-course briefings; readiness checks; prioritization of candidates assigned to imminent dual-fuel operations
Long-term competence / complacency risk	Initial caution may reduce over time as methanol operations become routine	Sustained vigilance; retention of perishable emergency and operational skills	Biennial refresher training; periodic drills and simulation updates; onboard coaching and operational feedback
Shore-side capability & alignment	Variability in shoreside understanding of methanol risks and operational requirements	Shared technical understanding between ship and shore; ability to assess operational risk and support decision-making	Train shore personnel alongside crews; establish specialist internal competence tracks; reinforce cross-functional alignment

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