Roadmap for automated waterborne transport

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Aegis

Advanced, Efficient and Green Intermodal Systems

http://aegis.autonomous-ship.org/

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Executive Summary

This report presents the AEGIS roadmap for automated waterborne transport and is the result of the work related to Task 2.5 *Roadmap for waterborne logistics redesign* as defined in the AEGIS Grant Agreement. The task was to collect the results of the AEGIS work package 2 and 6, and the AEGIS use cases, to provide a publicly available roadmap for redesign of more sustainable waterborne transport. Furthermore, the main AEGIS solutions that can be used to realise the redesign was to be identified, and benefits and possible costs were to be described, exemplified by future transport systems, including intercontinental transport. Furthermore, the focus was to be on unitized cargo (i.e., containers and ro-ro trailers).

The report is based on the AEGIS use cases and outlines one logistics redesign for short sea shipping where the cargo is containers, and one for inland waterways shipping where the cargo is roro trailers. Intercontinental transport was not studied in detail within the AEGIS project, as it was not in scope. This means that no study investigating the applicability of AEGIS solutions for intercontinental transport has been done, and thus the background for creating a roadmap for intercontinental transport is missing. Instead, intercontinental transport is briefly discussed in a separate section of the report. Furthermore, even though the AEGIS solutions do not target the deep sea leg of intercontinental transport, they are highly applicable to the distribution and consolidation of cargo in the hinterland. For this part of intercontinental transport, the short sea and inland transport roadmaps are directly applicable.

For each of the two segments short sea and inland waterways, the bassline “as-is” scenarios are discussed to provide insight into current challenges and areas with potential for improvements. Then a redesign is introduced, where the AEGIS innovations and concepts are used to gain efficiency benefits and zero emission transport systems. As part of the redesign discussion, the gaps towards realisation are also discussed and identified. These are related to immature technology, certain issues that currently are not addressed and needs both research and development, and issues related to uptake and investment risk. Next, one roadmap for short sea shipping and one for inland waterways is presented, and discussed in terms of short term, medium term and long term phases and what advancements needs to be made (i.e., what gaps needs to be closed) within each of these periods. Finally, policy support and actions are discussed in terms of what will be required to realise the roadmaps.

The two roadmaps presented in this report includes discussions for the short-, medium- and long-term periods. The roadmaps are structured this way to facilitate a discussion around which aspects are mature, and which require more research and has a longer expected horizon to market. The roadmaps are written with the purpose of allowing the implementation of the new transport systems in the short, medium, and long term, and a discussion is made around the sustainability of the transport system at each maturity level.

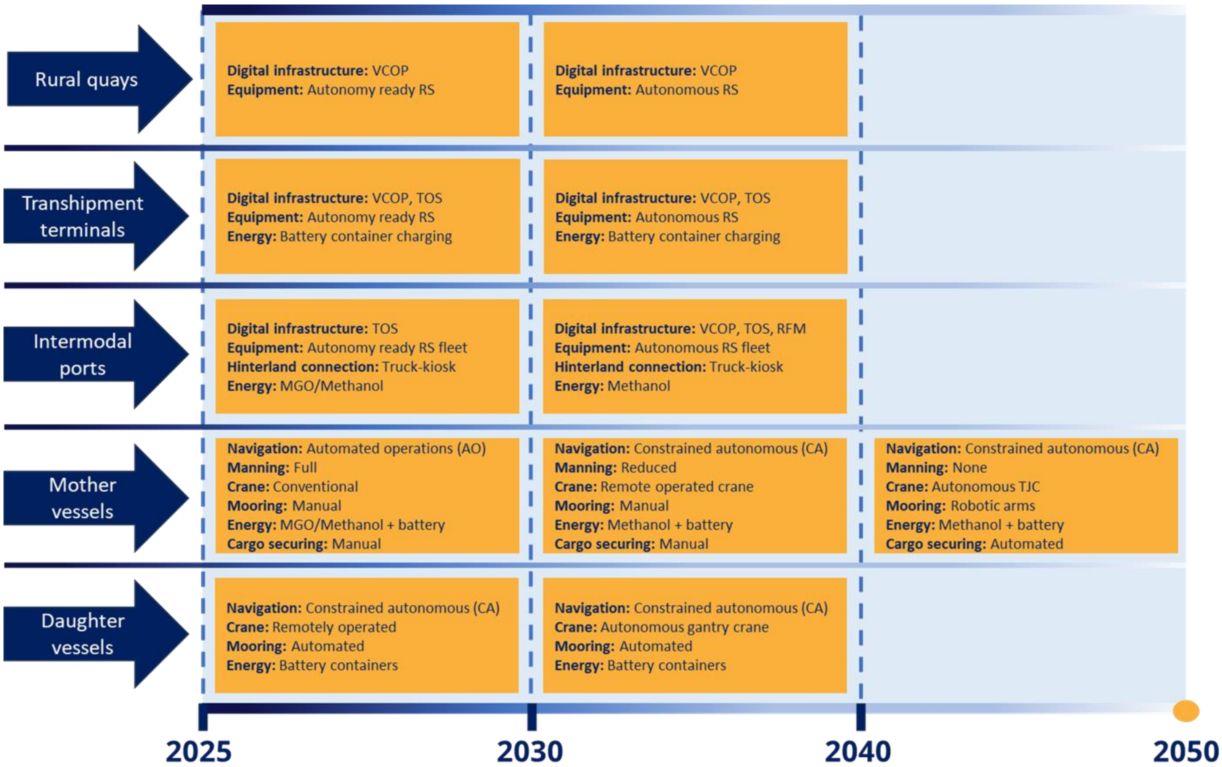


Figure 1: Roadmap towards autonomous short sea feeder loop service

The first roadmap in this report represents a path towards realizing the short sea shipping feeder-loop service that has been studied in the AEGIS use case A, along with the realization of the fully autonomous *intermodal ports* from the AEGIS use case C. It is split into 5 categories, *rural quays, transhipment terminal, intermodal ports, mother vessels* and *daughter vessels.* Within each category there are both common and unique barriers that need to be overcome to realize the transport system, with a varying degree of maturity.

The short term roadmap describes a short sea shipping transport system that could be implemented within 2030. It describes a transport system using crewed, battery container powered *daughter ships* visiting manned terminals and quays. The *mother vessel* still has a full crew and is ready for net zero emission future shipping by using dual-fuel engines running both on MGO and methanol. The *intermodal ports* still use crewed terminal equipment that is autonomy ready. This allows the terminal to go through a transition phase from manned, to unmanned terminal operation.

In the medium term, *daughter ships* get more advanced using autonomous cargo handling equipment. The *rural quays* are also equipped with autonomous reach stackers, allowing for fully automated port calls. At this stage, *transhipment terminals* are also automated. The motherships are still crewed, but the remote operation of the cranes allow for a reduced crew. *Intermodal ports* are also fully automated.

To achieve full autonomy in the AEGIS short sea transport system there is a need to fully automate the mothership. This is the biggest technological challenge that is presented and is assumed not to be realizable in the near future due to the complexities surrounding cargo securing, specifically the lashing process.

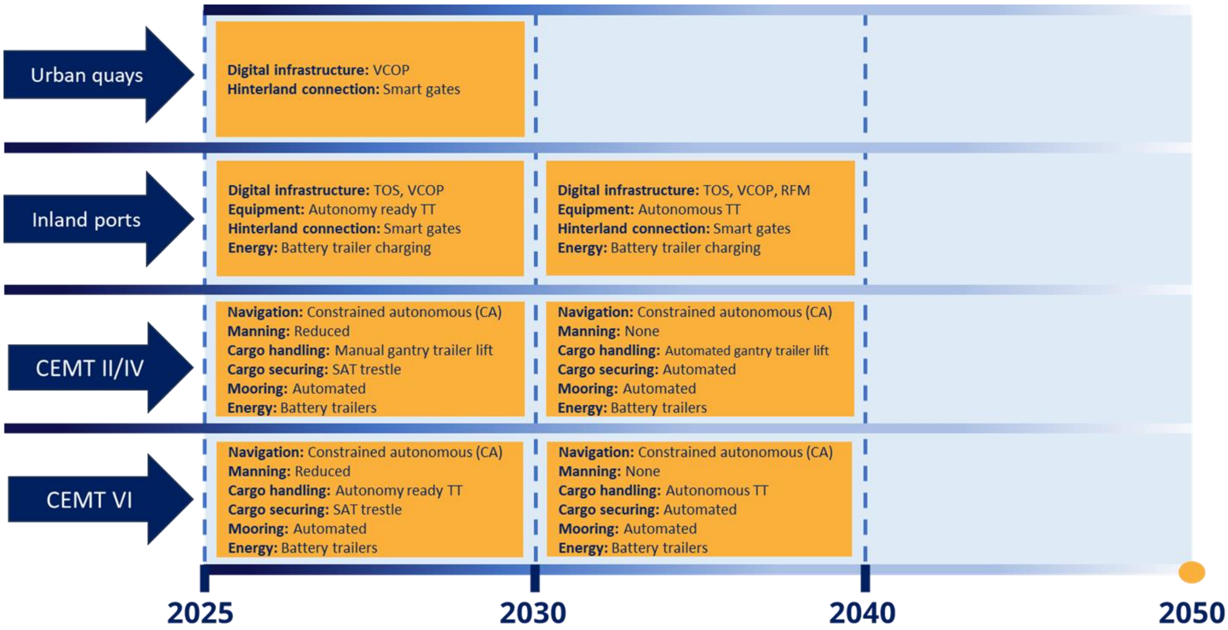


Figure 2: Roadmap towards autonomous inland shipping

The second roadmap describes the road towards revitalizing the inland waterway transport by a redesign based on the autonomous barges that were developed and investigated in AEGIS use case B. The four categories, *urban quays, inland ports, CEMT VI and CEMT II/IV* represent the four categories where there is a need for commitment and investments to realize the modal shift for inland waterways.

The short term sees *urban quays* that enable transhipment between urban distribution on trucks and reduced crew *CEMT II* and *CEMT IV* barges powered by battery containers. The urban distribution quay can be simple since the barges are equipped with their own autonomy ready terminal tractors. This phase sees smart gates both at *urban quays* and *inland ports* facilitating the shift towards autonomy. At *inland ports*, sideloaded *CEMT VI* barges with a reduced crew allow for the manual operations on-board such as cargo-securing and operating the cargo handling equipment.

The medium term already allows for the full implementation of the AEGIS transport system. The small *CEMT II/IV* barges travel autonomously in the waterways, visiting gated *urban quays*, and doing their cargo handling autonomously with the onboard autonomous terminal tractor. At this stage *inland ports* also use autonomous terminal tractors within the smart gates. The large *CEMT VI* barge can run autonomously with no crew on board, given that the cargo securing can be performed automatically.

In the long term we expect inland transport to have a large market share due to transport systems such as the one proposed in the AEGIS project being a cost competitive, green alternative to truck transport.

The realisation of the roadmaps will depend on policy support for stimulating the required research and development, but also, when technology is sufficiently mature, a dedicated strategy for stimulating market uptake. As an example, battery containers are market ready and there are several interested ship owners. However, ship owners will either need a dual power source or that infrastructure for charging and swapping battery containers is in place. Ports are potential providers of battery container charging; however, they depend on a certain number of vessels to ensure return on investment. This “chicken-and-egg” problem is discussed, and a proposed solution is presented.

Definitions and abbreviations

ARS: Autonomous reach stacker

ATT: Autonomous terminal tractor

AO: Automatic Operation [1]

CA: Constrained Autonomy

CA Standard RCC: Same as CA but with standardised RCC [1]

EMSWe: European Maritime Single Window environment

FA: Full Autonomy [1]

ICMASS: International Conference on Maritime Autonomous Surface Ships

IMO: International Maritime Organization

ISPS: International Ship and Port facility Security

ISSC: International Ship Security Certificate

IWT: Inland waterways transport

IWW: Inland waterways

KPI: Key Performance Indicator

LoLo: Lift-on/Lift-off

PMS: Port Management System

PU: Periodically Unattended [1]

RC: Remote Control [1]

RCC/ROC: Remote Control Centre, often also called ROC (Remote Operation Centre) where the latter also implies that responsibilities related to planning operations, maintenance activities and logistics, could be included.

ROC: Remote Operation Centre

RS: Reach stacker

RoRo: Roll-on/Roll-off

SDG: Sustainable Development Goals

SotA: State of the Art

SSS: Short sea ship(ping)

TEU: Twenty-foot Equivalent Unit

TJC: Tripple Joint Crane

TRL: Technology Readiness Level

TOS: Terminal Operating System

RFM: Robot Fleet Management

VCOP: Voyage and Container Optimisation Platform

1 Introduction

1.1 The AEGIS project and why we need a logistics redesign

When the AEGIS project was first presented in 2020 at the international conference on maritime autonomous surface ships (ICMASS) [2], the graph in Figure 3 was the first visualization. It shows how road transport work is growing in the European union. With this increase in road transport there is an inherent increase in societal cost.

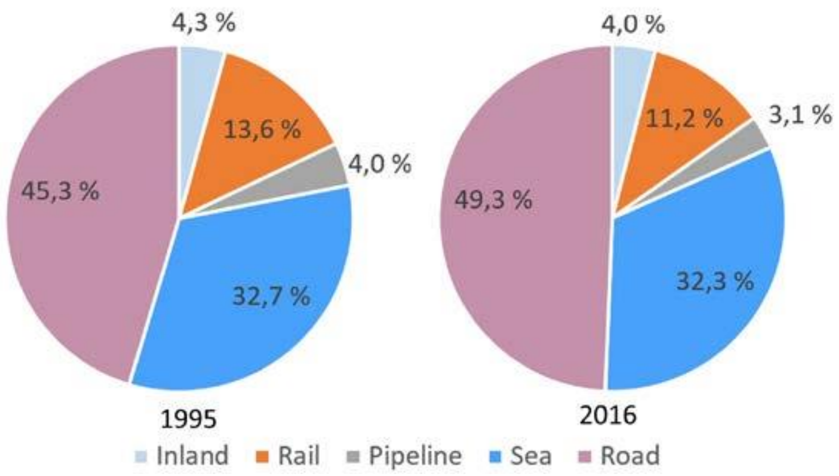


Figure 3: Share of transport in ton-km for the EU [2]

As discussed in [3], truck transport is the least sustainable form of transport in terms of societal cost impact, even when zero-emission trucks are compared to waterborne transport. While some transport legs are impossible to perform by ships, this difference in societal costs is why it is necessary to increase the modal share of sea transport.

However, trucks have a clear advantage over maritime transport; they can reach the end consumer wherever it is. The large truck-pool also inherently makes trucking a more flexible service. Figure 4 shows the key features of shipping vs road transport. Shipping can transport containers cheaper, but the terminals are generally located far from the consumer. Large volumes and set schedules make it less flexible for consumers. But what would the effects be if shipping could get further? If shipping could at least get closer to the end consumer?

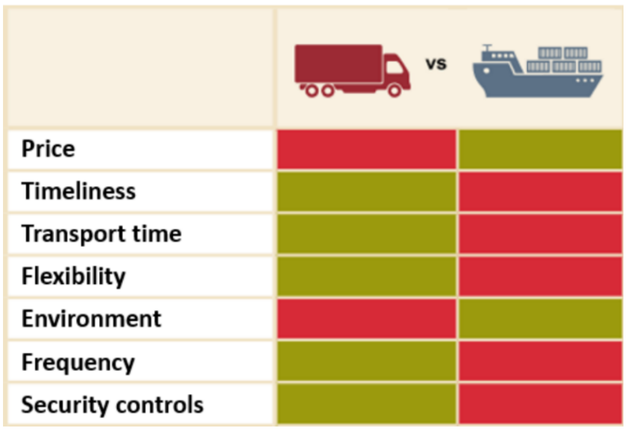


Figure 4: Comparison of key features road vs waterborne transport [2]

The AEGIS project shall consolidate the collective knowledge that has been gained into a set of proposals for redesigns of waterborne transport systems. These will be disseminated through the D2.6 roadmap deliverable. The scope of the redesign are logistics with corresponding business models, and the relevance of the proposed redesigns will be evaluated qualitatively[1] towards the sustainable development goals (SDGs), meaning that the societal impact of the redesign is prioritised[2].

The AEGIS project has mainly looked at fully uncrewed transport of unitized cargo in three different use cases. This includes Lift-on/Lift-off (LoLo) container transport as well as Roll-on/Roll-off (RoRo) transport of trailers. This provides the background for the roadmap. Passenger transport has very different constraints related to safety of the passengers during the voyage, in emergencies, and is therefore less relevant in the proposed roadmap. Breakbulk, dry, and wet bulk, as well as other types of RoRo transport may to varying degrees be relevant in conjunction with the roadmap, but one must carefully consider the differences in cargo handling in port to determine how well the roadmap fits.

The AEGIS roadmap gives short-, medium- and long-term propositions on how to facilitate for the logistic redesign and, qualitatively, what effects could be expected.

1.2 Overall structure

The AEGIS project has worked with both short sea shipping redesign as well as inland waterway transport. Both transport modes have a lot in common; both rely on ships and terminals to transport goods between locations. They also face unique challenges in the future.

Therefore, this report is divided into two main categories:

1. Short-sea-shipping container transport
2. Inland waterways RoRo transport

Within these categories different aspects, unique to the transport system are presented. Therefore, all these transport system innovations are motivated through a baseline section, that sets the stage for the redesign and why the innovations are needed. The chapters then introduce the roadmap for each transport system. More specifically:

Chapter 2 presents the short sea shipping container transport baseline, redesign, and roadmap. Section 2.1 presents the short sea shipping and *rural quays* researched through AEGIS use case A. Section 2.2 presents the automation of *intermodal ports* researched through use case C in AEGIS. Section 2.3 presents the roadmap for short sea shipping and discusses its implementation for the short, medium, and long term. Section 2.4 discusses the necessity for policy support to facilitate the modal shift through the realization of the AEGIS short sea shipping redesign.

Chapter 3 presents the inland waterway transport baseline, redesign, and roadmap. Section 3.1 presents the inland waterway transport system researched through AEGIS use case B. Section 3.2 presents the roadmap for inland waterway transport and discusses its implementation for the short, medium, and long term. Section 3.3 discusses the necessity for policy support to facilitate the modal shift through the realization of the AEGIS inland waterway transport system redesign.

[1] The qualitative evaluations will be supported by examples of quantitative calculations from other AEGIS work (WP7-10).
[2] Even though the societal impact is prioritized, we need to identify what gaps we have on business models that is needed to enable the redesign of the waterborne logistics. Some technology aspects will also be considered.

Finally, Chapter 4 discusses the potential synergies between the roadmaps in this report and intercontinental shipping.

1.3 Relation to the AUTOSHIP roadmap

A roadmap for autonomous ship adoption and development, provided by the AUTOSHIP[3] project, is given in [1]. The roadmap outlines the likely technological development steps through autonomy levels and uses these, along with findings on factors constraining development and market uptake, to propose a realisation roadmap. The realisation roadmap, given in Figure 5, is based on 4 concepts for ships and their operations. To put these in the context of AEGIS, the *sheltered water shuttles* correspond to the AEGIS short sea *daughter vessel* concepts, *Short sea shipping* corresponds to the AEGIS *mother vessel* concepts, and *Inland waterways* corresponds to the three AEGIS IWW vessel designs.

As the AUTOSHIP roadmap was developed for the technological development steps for ship autonomy, and how it can be used to realise autonomous ship concepts corresponding to the AEGIS vessel concepts, the AEGIS roadmap for automated waterborne transport will not focus on autonomous technologies for navigation and the uptake of these. Instead, we will use the findings of [1], and supplement with AEGIS findings related to terminals, automated cargo handling and mooring, digitalisation and automation of logistics, logistics redesign, and reduction of emission.

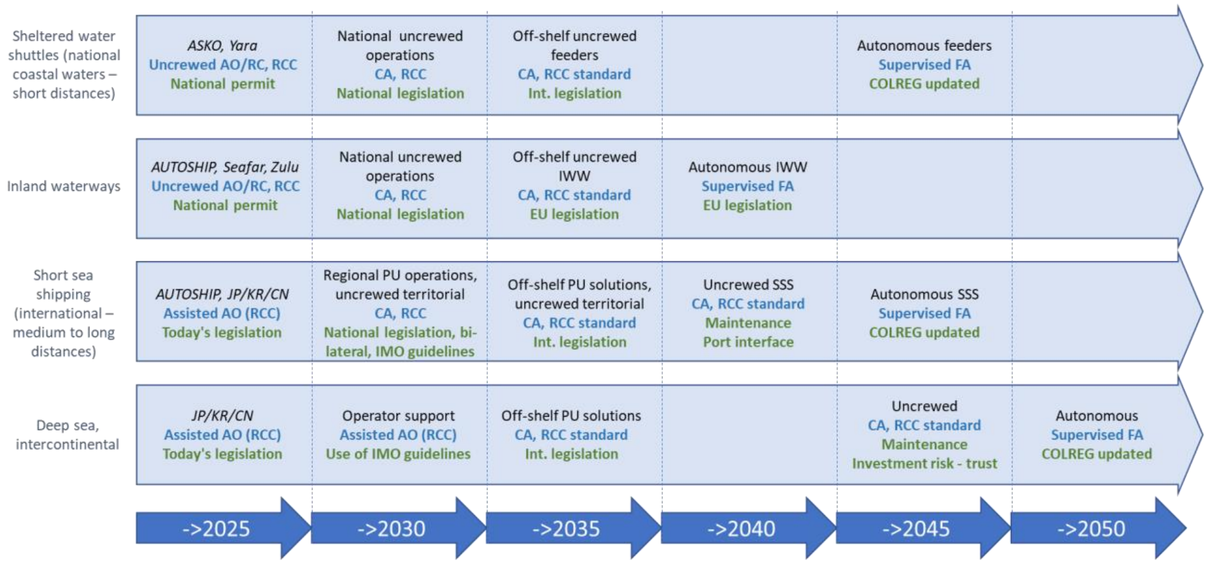


Figure 5: High-level realisation roadmap, figure from [1].

1.4 Assumptions and limitations

The roadmap is intended to address the implementation of the logistic redesign proposed in the AEGIS project. The focus of the report is hence on the realisation of the AEGIS concepts, and on closing the gaps related to these. Other related advancements, such as autonomous ship navigation technology and the different crewing concepts these enable, are not addressed in detail. This is because these aspects are covered by the recent AUTOSHIP roadmap [1].

[3] https://www.autoship-project.eu/

The AEGIS project deals with unitized cargo, specifically containers and Ro-Ro trailers, hence, all other forms of cargo are not considered in detail. However, the AEGIS concepts and logistics redesigns can be applicable to other forms of cargo.

When discussing energy systems, the roadmaps do not consider the production of the energy carriers, but rather assumes that the production of green alternative fuels will be possible within the considered timeframes of the roadmaps. It also does not discuss the source of electricity for battery-powered ships.

The presented roadmaps propose advancements in three distinct time periods, as discussed in section 1.2. These advancements are considered feasible, assuming required research, development, and investment actions, are supported by appropriate policies.

2 Short sea shipping container transport

To reach the European climate goals for 2030 and 2050[4], as well as the ambition to move 30% of road-going cargo to train and shipping [5], there is a need for a logistic redesign of the maritime sector. Ships are getting bigger, transporting larger and larger quantities of containers to and on the European continent. From large or medium terminals these containers travel mainly by truck or rail. This is the motivation for the mother-daughter transport system proposed in the AEGIS project. To enable this logistic redesign, container-shipping needs to reach further than ever before. This is enabled by the small autonomous *daughter ships* proposed in the project. The project has shown that such a logistic redesign can be a green, cost competitive alternative for the future, but to enable this there are gaps that must be closed at different levels. This chapter substantiates the logistic redesign based on the work performed in the AEGIS project, identifies some selected key gaps and ways to close them.

2.1 Short sea and rural quays

Container transport between Norway and the European continent is mainly split between long haul road transport and short sea liner transport. In the Green Shipping Program[4] report on new logistics and terminal structures between Europe and Norway, it is found that there is a potential to shift 2-3 million tons of imported cargo from road to sea in the short term, and 5-7 million tons in the long term [6]. This potential consists of cargo being transported by truck from Europe to Norway, and cargo being transported by truck over long distances in Norway after having been moved from Europe to the main terminals in eastern Norway by ship. The key challenge is shipment frequency and lead time, as well as the current logistics structure. Proposed solutions are increased frequency of liner services, cargo flow consolidation and cross docking at dedicated terminals in Europe (e.g., Rotterdam), coastal regional terminals that the liner ships call to and that serves as distribution hubs for the given region.

It is in this context that the AEGIS Use Case A logistics redesign aims at solving the challenges preventing a modal shift.

2.1.1 Baseline

Currently, NCL[5] operates a liner network of short sea ships (SSS) that offers container transport between the Norwegian west coast and the European continent. Four ships call regularly to more than 20 Norwegian ports, where most ports are on fixed routes wile a few are on-demand port calls. Large European ports like Rotterdam, Bremerhaven, and Hamburg are the main ports that the NCL SSS operate to and from.

Several of the Norwegian coastal ports are located a distance from the main fairway along the cost, into fjords. Examples are Orkanger, Bergen, Gjemnes, Glomfjord, Finnfjord, and so on. Furthermore, some of the coastal ports are located within the same limited geographical area, like Averøy, Gjemnes and Kristiansund, see Figure 6. This current structure of ports leaves room for improving the efficiency as most of the containers onboard the short sea liner ships takes several detours on the way to their destination. The AEGIS mother-daughter concept could be the means to solve this efficiency problem by reducing the liner ship sailing distance, and potentially, number of port calls.

[4] The Green Shipping Program comprises more than 94 private companies and organisations, as well as 12 public observers: https://greenshippingprogramme.com/about-green-shipping-programme/
[5] https://www.ncl.no/

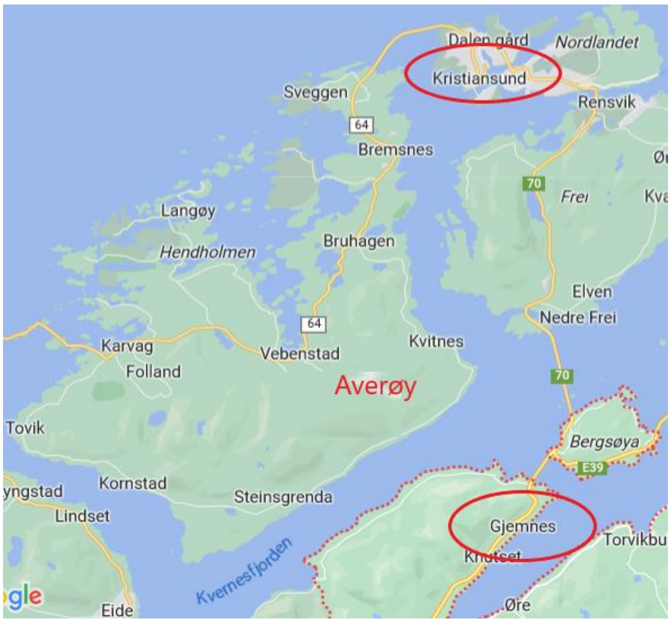


Figure 6: Small container terminals located in short distance from each other, Averøy, Kristiansund and Gjemnes.

The AEGIS use case A specifically investigates the cargo travelling from Rotterdam to Trondheimsfjorden. However, the concept could be applied to any of the areas with terminals inside fjords, or with several terminals close to each other. Currently, ships from NCL serve Trondheimsfjorden at the port of Orkanger. From there, the discharged containers travel by truck transport. The NCL SSS call to Orkanger twice each week.

Orkanger is 48 nm into Trondheimsfjorden and the total volume of containers unloaded and loaded in Orkanger is relatively low compared to the total volume onboard the NCL ships. This means that most containers onboard the NCL ships takes a detour of 96 nm due to the Orkanger port call. Establishing a terminal at the entrance of Trondheimsfjorden would thus save both time and energy as most containers onboard would get a reduced travelling distance of 96 nm.

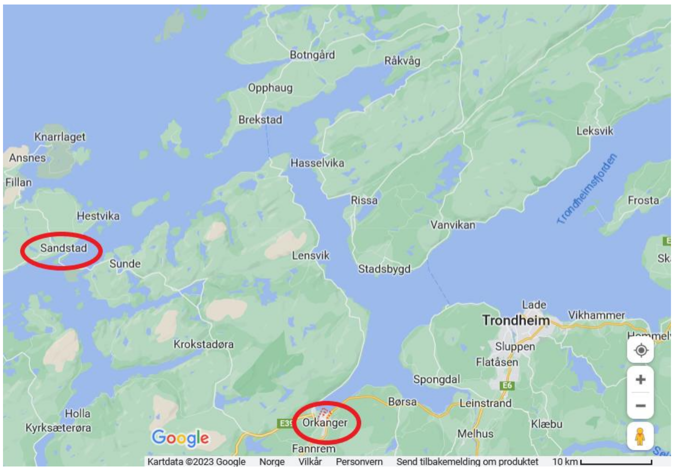


Figure 7: Use case A – establish terminal at Sandstad (Hitra Kysthavn)

The port of Trondheim is establishing a terminal at Sandstad (Hitra Kysthavn), which is at the entrance of Trondheimsfjorden. This new terminal is the perfect candidate for transhipment between a "mother" short sea liner vessel and smaller short sea shuttle *daughter vessels*. However, the new terminal at Sandstad (Hitra Kysthavn) will be relatively small and it is not expected that there will be continuous cargo operations at the terminal, at least not in the initial phase. This means that the business case for investments in infrastructure at Sandstad is challenging and that smart and sustainable solutions are needed.

2.1.2 Redesign

To enable maritime container shipping to reach further than ever, AEGIS use case A proposes the deployment of a mother-daughter concept. The *daughter ships* operate in fjords between rural factories or small ports, and *transhipment terminals*, and handles the consolidation and distribution of containers for the mother ships. Mother ships operate between *transhipment terminals* along the Norwegian coast and larger ports in Europe, such as Rotterdam, see Figure 8.

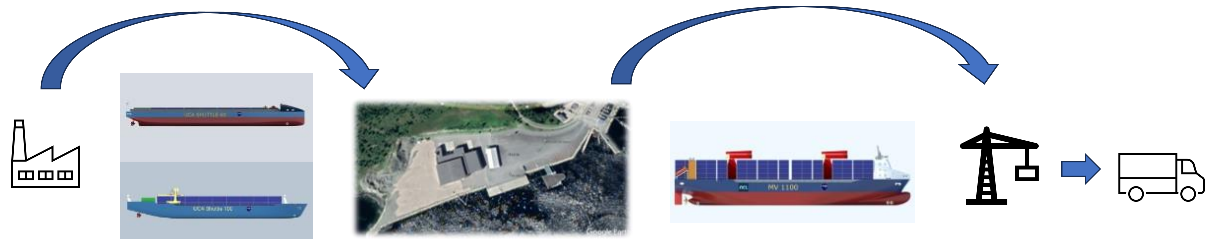


Figure 8: Rural factory – daughter ship – transhipment terminal – mother ship – end terminal – last mile

This logistic redesign is studied in detail for the Trondheimsfjorden area to investigate what daughter concept yields the best performance, and to what extent the concept can compete with trucks [7]. The mother-daughter network is given in Figure 9, and the developed ship concepts are given in Figure 10.

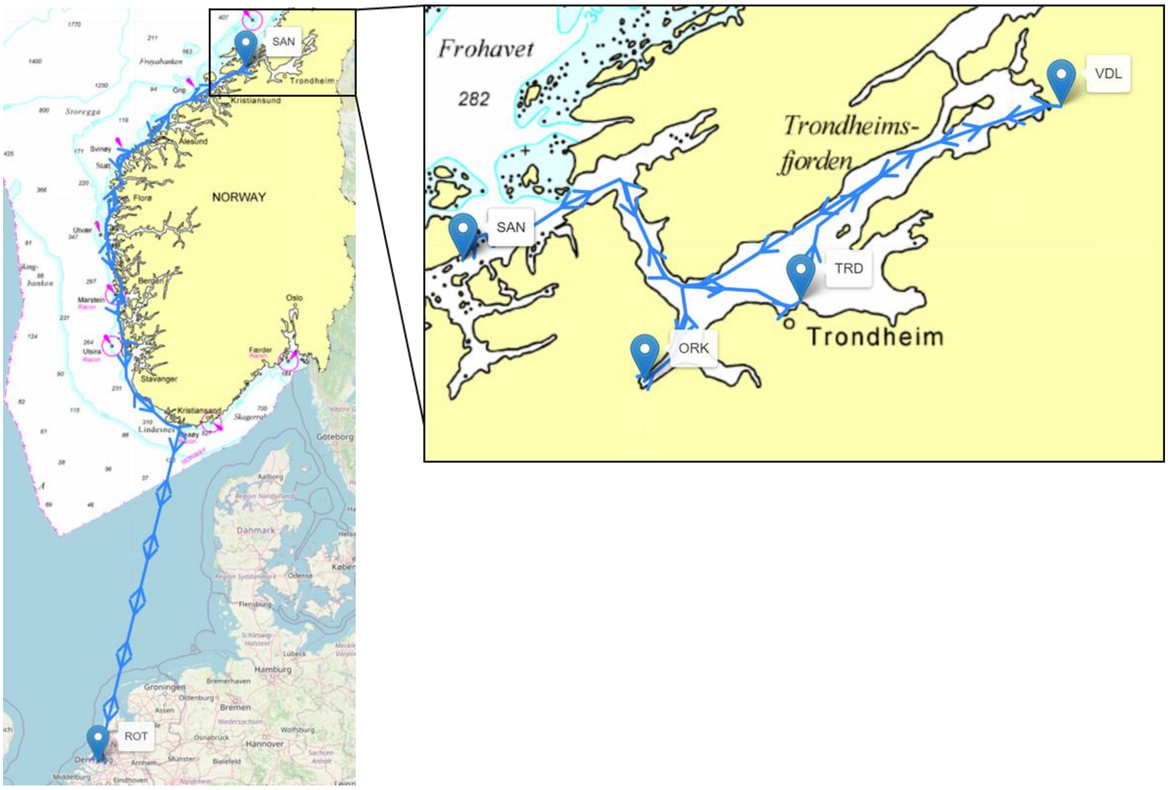


Figure 9: Use case A mother-daughter network, mother route to the left and daughter route to the right.

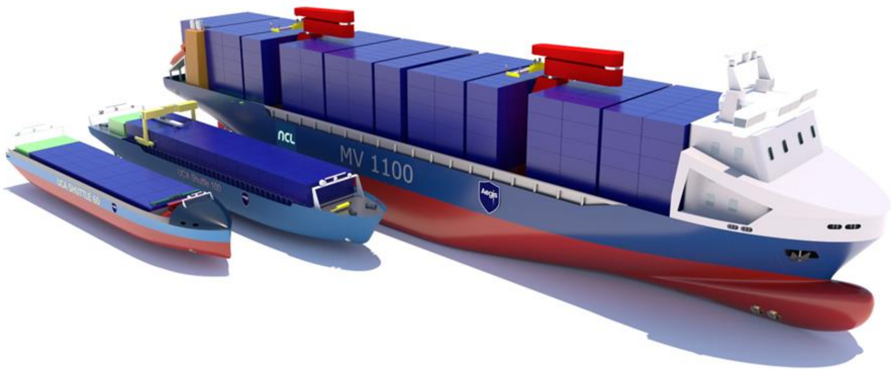


Figure 10: To the left 60 TEU daughter, middle 100- TEU daughter, to the right Mother vessel.

Rural quays: The *rural quays* concept are quays where cargo can be transferred from ships to trucks, and where the required intermediate storage is very limited or not needed at all. These ports could be factory quays, such as in Figure 11, or simply a quay close to a road but with next to no space for intermediate storage. Charging and cargo handling infrastructure is typically not required at *rural quays*. However, reach stackers will typically be needed for loading and unloading trucks, and in cases where the daughter route is too long in terms of the battery capacity it might be necessary to have infrastructure for charging battery containers in some centrally located *rural quays*. It should be noted that *rural quays* as a concept describes the minimal requirements. Which means that *rural quays* with more infrastructure than the minimal requirements can also be used. For use case A *rural quays* correspond to the locations “ORK”, “TRD” and “VDL” in Figure 9. Where the ports ORK and TRD are *rural quays* with both container storage and handling equipment.

Since *rural quays* have next to no intermediate storage, an advanced Port Management System is not needed. Instead, systems like the Voyage and Container Optimisation Platform (VCOP) can handle the loading and unloading sequence planning, vessel stowage planning, and coordination of transfer to trucks.

Figure 11: 100 TEU daughter at a rural quay on a factory site [8]

SSS GAP 1: Digital container logistics platform
A prerequisite for automating container handling is that loading, unloading, and stowage plans are digital. Both the planning and execution of plans, including replanning and status updating, need to be handled by a digital platform to coordinate trucks and terminal equipment like reach stackers, and the autonomous cargo crane onboard the ships. Another prerequisite for autonomous container logistics in terminals is digitalisation of administrative procedures related to reporting, and status and event updates. The MacGregor VCOP is such a system and is currently under development. It has been partially demonstrated in AEGIS by generating the loading sequence and transferring it to the autonomous crane [9]. It will be further developed and demonstrated in the Horizon Europe project SEAMLESS[6] as part of a full-scale demonstration of an autonomous shuttle (daughter) service, and a full-scale demonstration of a 90 TEU autonomous inland vessel calling to small and large terminals.

SSS GAP 2: Autonomous reach stackers
Conventional reach stackers could be used to enable the AEGIS use case A redesign; however, autonomous reach stackers (ARS) are important for realising the terminal efficiency gains. One important challenge is the availability of skilled operators, while another is the inefficiency of manual procedures, e.g., transferring plans into actions and status updates into digital systems. A step on the way is the deployment of a remotely controlled reach stacker, which was demonstrated in a Hardware-In-the-Loop setup by Kalmar in the AEGIS project[7]. Remotely controlled reach stackers will give some improvements in terms of terminal efficiency as this enables a higher utilisation of reach stacker operators and removes the need for the operators to be physically located at the terminal. The full efficiency gain is achieved when the reach stacker becomes autonomous. This is because the dependency on human operators during normal operations is removed, robotic fleet management will be deployable, and because it implies a full realisation of digitalised administrative procedures.

Transhipment terminals: An important part of the concept is the *transhipment terminal* placed at the coast near the entrance to the fjords, and centrally located for the region that is served by the *daughter vessels*. For Trondheimsfjorden, such a *transhipment terminal* is placed at Sandstad. The *transhipment terminal* is given in Figure 12 and Figure 13, and as can be seen, the *transhipment terminal* has intermediate storage for containers. The terminal infrastructure is minimal, which is made possible by equipping both the *mother* and *daughter vessels* with autonomous cranes. Reach stackers are however needed for moving cargo between the intermediate storage and the ships. Charging infrastructure is also needed for battery container charging, however handling of battery containers is done by reach stackers and the ship cranes. The *transhipment terminal* does typically not depend on a shore side container crane, but a Terminal Operating System and/or a Port Community System will likely be needed in addition to a system for planning stowage and cargo handling sequences, e.g., the VCOP.

SSS GAP 3: Battery container charging infrastructure
An important part of the *transhipment terminal*, and in some cases the *rural quays* efficiency improvement is that charging does not prolong the port call. Battery, or energy, containers are the key to solve this predicament. Swapping battery containers is significantly less time consuming than charging battery packs installed on ships. While

[6] https://www.seamless-project.eu/
[7] https://aegis.autonomous-ship.org/resources/media/

battery containers and battery container charging infrastructure are appearing as products, investments in these remains risky. The core problem is that ship owners will need to be certain that the necessary infrastructure is available before they can invest in ships based on battery or energy containers, while potential infrastructure owners like terminals needs to know that there will be a sufficient market for offering charging of battery containers. Companies like ZES offers battery containers and charging equipment for purchase, but also as pay-per use[8]. However, the pay-per use business model faces the same challenge; investments will be a bet on the market appearing. This situation can be solved by long term national and EU policies for realising uptake in the market. Initially, subsidies for infrastructure investments are needed, and in the short term it is probably needed to have some subsidising or other strong incentives for investing in battery container powered ships. A good example policy and resulting strategy can be found in Norway where ENOVAs strategy for subsidies and incentives for realising uptake of battery powered cars have yielded great results [1]. Such a policy and strategy with concrete incentives is missing for stimulating the establishment of infrastructure for, and investment in, battery container powered ships.

SSS GAP 4: ISPS and ISSC

All the terminals in the Trondheimsfjorden case (except Orkanger) are ISPS on/off, meaning that they can switch the ISPS status based on needs. Prior to arrival of international ship security certificate (ISSC) certified vessels, security procedures must be followed to switch the ISPS status of the facility to "on". In case of mother-daughter synchronisation this narrows down the time window when the *daughter vessels* can pick-up/deliver the containers. Another issue is that an ISSC vessel cannot visit a non-ISPS terminal and vice versa. This limits the flexibility of the *daughter vessel*.
It is not yet defined how ISPS requirements should be handled for autonomous vessels, in the IMO scoping exercise for autonomous vessels it was highlighted that ISPS is one of the topics that must be investigated further for autonomous vessels. The developments will go hand-in-hand with the development and implementation of the IMO Mass Code.

Figure 12: Transhipment terminal with the daughter vessel at berth [8]

[8] https://zeroemissionservices.nl/en/homepage/

Figure 13: Transhipment terminal with mother vessel approaching, and daughter vessel departing [8]

Daughter vessels: The *daughter vessels* are powered by battery containers, which are swapped at the *transhipment terminal* (and in some cases at *rural quays*), see Figure 12. The *daughter vessels* distribute and consolidate cargo within the fjord or a defined region, e.g., Trondheimsfjorden. To be able to call to *rural quays* and *Transhipment terminals* without shore side container cranes, the *daughter vessel* is outfitted with an autonomous gantry container crane, see Figure 11 and Figure 14. The crane is used both for container handling and for battery container swapping. The *daughter vessels* are also constrained autonomous, unmanned, and supported by a ROC [10].

SSS GAP 5: Autonomous gantry crane
The autonomous gantry crane is a key enabler for making the *daughter ships* able to call to small ports and the *transhipment terminals*. The concept has been studied in Watertruck[9] and AEGIS in terms of feasibility, however, it remains at a low TRL level, approximately TRL 3, and significant research and development is needed to realise it. The mechanical and structural design has not been validated, and the automation system for making it autonomous is not sufficiently studied. Highly automated and remotely controlled gantry cranes on shore are, however, already commercial products. This means that there are technological advancements made that forms a good basis, but that significant research and development still needs to be carried out.

SSS GAP 6: Constrained autonomous shuttles
There are still no commercially operating constrained autonomous shuttles. Research and development, as well as investments and commercial projects for full scale realisation is still needed. The road towards realising such ships is elaborated in [1].

[9] https://institut-se.de/projekte/watertruck/

Figure 14: Battery swapping by autonomous gantry crane onboard the daughter vessel [8]

***Mother vessels*:** The *mother vessels* call on *transhipment terminals* for all cargo transfer. This minimizes the need for navigating into fjords with large container ships to transfer small amounts of the total cargo volume. *Mother vessels* are conventionally crewed; however, they are outfitted with autonomous triple joint cranes. This allows for cargo transfer at terminals that do not have container cranes and relaxes the dependency to skilled crane operators. The ship is equipped with dual fuel engines and a small battery-pack. With the full proposition of the AEGIS transport system the *mother vessel* will be powered by green, net-zero methanol. In the short term, the dual fuel engines allow the mother to also run without access to methanol bunkering. The batteries are used to power the bow and stern thrusters, allowing for zero emission berthing, lowering noise and local pollution.

SSS GAP 7: Mixed energy systems
Being a first mover in using new fuel systems has inherent risks associated with it. A lot of shipping companies are on the fence when it comes to investing in new, potentially green energy-systems for their new-builds and retrofits. The reason is largely due to the market not settling on a single energy carrier. Ship owners fear that their ships will not have sufficient bunkering facilities, and that another fuel will give a competition advantage within their business-region. Currently, ammonia, methanol, and hydrogen are all being proposed and tested through demonstrators in different piloting projects. NCL is a first mover who has already ordered mother ships with methanol and ammonia[10].

The AEGIS project has, together with H2020 Moses project[11], demonstrated an autonomous container crane, electric (GLE), which is a ship crane. It was demonstrated onshore and remotely supervised. The demonstration showed that it is feasible to do container movements autonomously. However, there is still a lot to do before this crane can be commercially available as such:

[10] https://www.ncl.no/campaigns/sea-change
[11] https://moses-h2020.eu

- It has not been tested on board a ship with movement from the ship to the quayside or the other way around
- It has not been tested how to stack containers autonomously, nor has it been shown how to fit the container in cell guides autonomously
- There is currently no way of "seeing" beneath the container when lifting it

The project has developed a new autonomous crane design, called triple joint crane (TJC), see Figure 16. This crane is not yet realised neither as simulation nor in practical terms. The crane design will be further developed and tested in a simulation environment in the HEU SEAMLESS project.

SSS GAP 8: Cargo handling system
The autonomous triple joint crane is still at the concept level. It will be studied within the SEAMLESS project, however, only through modelling and simulation. This means that the realisation of this type of crane is still depending on significant research and development, and that it is likely that it lies quite some time into the future. Autonomous shore side container cranes, on the other hand, have been demonstrated in full scale as part of AEGIS [9]. Remaining gaps are thus to further develop autonomous container cranes for use onboard ships. This adds challenges such as automatic motion compensation (i.e., heave and roll motions).

On large, short sea ships the containers are secured in two ways. Twistlocks that interconnect the containers in each corner ensure they are secured against vertical forces. In addition to this, lashings secure the containers to deck, preventing them from shifting, or tipping over during high seas.

Figure 15: Containers lashed on ship (Courtesy: MacGregor)

Figure 15 shows an example of lashing bars securing containers to deck. The lashing process is highly manual, requiring deckhands to attach at port, and tighten during voyage.

SSS GAP 9: Container-lashing
Containers are secured in stacks by twistlocks. These twistlocks require manual locking and unlocking. There are semi- and fully-automatic solutions on the market today, however they are expensive, and not mature for autonomy [11]. New locking mechanisms, or improvements to the twistlock items would be required to make autonomy a reality where no humans intervene in any of the operations inside. The nature of the lashing process

requiring deckhands to be available is also an obstacle that needs to be overcome to introduce full autonomy to large, short sea vessels. The AEGIS project is not aware of any initiatives to automate the lashing process, or alternative solutions that would automate the securing of cargo.

Figure 16: Illustration showing mothership with MacGregor TJC [8]

2.2 Automated intermodal ports

Autonomous systems of any kind rely on sensors to observe and navigate the world. The personal car industry invests millions of dollars each year into improving their driving systems and have done so for many years. Autonomy has been promised, along the way, but what we see lately is a shift in rhetoric. Full autonomy is not in the vocabulary as much anymore, and, for road going vehicles, it seems more and more unlikely the better we understand the problem. However, a terminal offers a controlled environment for autonomous systems which may be the first arena where autonomous cars, or rather, autonomous reach stackers may be deployed.

This chapter presents the challenges addressed in use case C of AEGIS. Port of Aalborg has a vision of becoming a green intermodal terminal that will make short sea shipping, both domestic and international, more attractive to consumers. The use case investigates how port efficiency can be achieved by automating processes and smart port solutions.

2.2.1 Baseline

Currently a large volume of containers travels through Denmark by truck transport. The report *Potential transfer from road transport to short-sea-shipping in Denmark* [12] examines the gross volume that could be shifted from land to short sea shipping which is in line with both EUs ambitions [5], as well as the use case leader Port of Aalborg ambitions for their terminal in the future. It shows that 28% of international goods and 91% of domestic goods travel by truck. Some of these goods are more time-sensitive than others.

There is a potential for moving less time-sensitive cargo away from the roads and onto short sea ships. The report in [12] estimates that 18% of the current international road going cargo can be moved to short sea shipping, with the current short sea shipping cost-competitiveness. Furthermore, the report identifies that nationally within Denmark, there is a conversion potential of over 100.000 tonnes of bulk, 35.000 tonnes of food products, and over 30.000 tonnes of palletized mixed goods. This potential is currently prevented from being realised due to differences in cost, flexibility, and lead time between truck and short sea transportation. One way of addressing this challenge is to improve port efficiency.

To increase the short sea shipping market share, it is necessary to increase its competitiveness, specifically for the lower time-sensitive goods; waterborne transport must become cheaper and more flexible, with significantly reduced administrative complexity. Increasing the efficiency of terminals would decrease the difference between single mode and multi modal transport. The AEGIS project proposes an autonomous terminal consisting of a fenced area for autonomy and a kiosk for truck and rail transport to interact with the autonomous terminal system.

2.2.2 Redesign

To increase port efficiency, it is necessary to reduce the time of each port call, have fewer household moves at the port, seamlessly transfer cargo to trucks and rail, and to digitise and reduce the burden related to administrative processes.

As part of their vision to expand the terminal area, Port of Aalborg sees the potential of creating an autonomous fenced-in terminal area as part of their redesign to become more attractive. AEGIS has proposed a terminal redesign for the port of Aalborg, including a new container terminal layout and a future Ro-Ro terminal. The container terminal area is in direct contact with the already existing railway at the port. A proposition for terminal layout is shown in Figure 17.

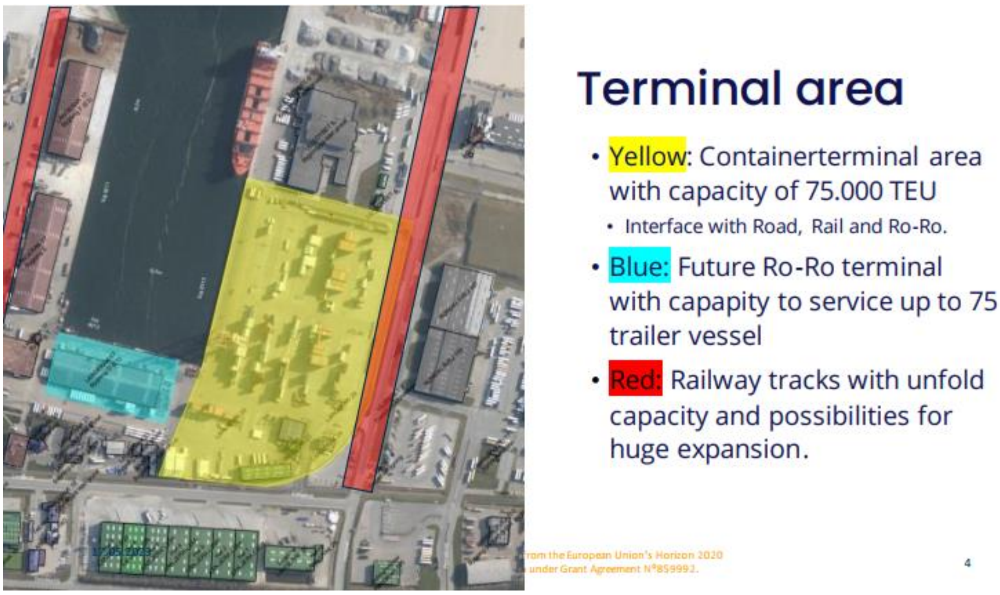


Figure 17: Suggested terminal layout for port of Aalborg *[13]*

AEGIS proposes a container-terminal design to address the issues presented in the previous section. The redesign uses green, advanced cargo handling equipment to increase efficiency and streamline port calls through digitising communication. It consists of a fenced in terminal for autonomous operations, keeping manual terminal equipment and trucks on the outside. Autonomous reach stackers will transfer goods between the kiosk where the trucks and rail stand to quay or temporary storage within the fenced area. AEGIS deliverable 10.4 *Technology gaps and regulatory challenges in Danish case studies* [14] has already laid the groundwork for this roadmap by identifying key gaps that present a challenge for realizing this type of terminal. The following sections summarize these findings in the context of the roadmap.

Automated terminal

Kalmar proposes creating a new automated container terminal in Aalborg. It is a fenced area where autonomous reach stackers can operate uninhibited by the manual operations at the rest of the terminal. An example of a kiosk terminal layout is shown in Figure 18.

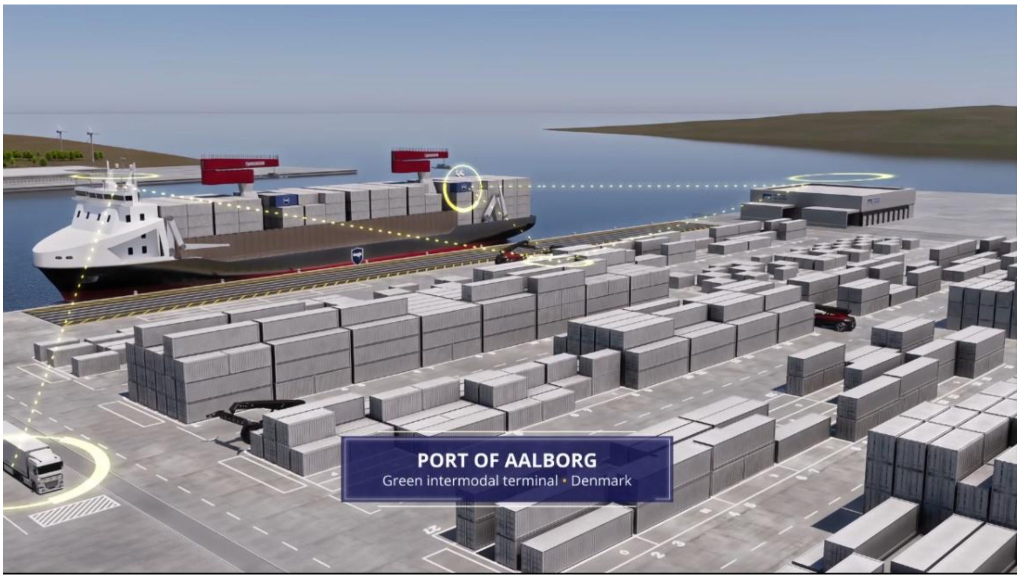


Figure 18: Image of AEGIS mother ship at Port of Aalborg autonomous terminal [8]

Trucks arriving at the kiosk to load or offload containers will park at assigned locations by the fence. Drivers will have to leave the truck before the autonomous operations are started. Sensors such as camera and lidar at the terminal pick up the position of the container on the truck. Once ready, the autonomous reach stackers would use this position, drive to the fence, and either load or offload the container. Once the reach stacker has moved back inside the fence, the driver may enter the truck and drive away. An illustration of this is given in Figure 19.

Figure 19: Illustration showing truck kiosk and gated autonomous terminal [8]

SSS GAP 10: Terminal Equipment

To realize the proposed autonomous terminal there needs to be investments into terminal equipment. The technology is currently not mature enough to have a completely autonomous, fenced in area. Kalmar proposes in their redesign to invest in electrically powered State-of-the-Art (SotA) reach stackers that are autonomy ready. This facilitates piloting gradually more autonomy in the future as the technology matures. In the short term, reach stackers could operate in the fenced area, manned or remotely operated. This period would not give the full effect of the autonomous terminal. It would be used to gather data about the behaviour of the reach stackers inside the fence. Simultaneously, a Remote Operations Centre (ROC) for control and monitoring of the terminal equipment inside the fenced terminal should be built. Gradually, more autonomous routines would be introduced, based on learning both by machines and by humans.

Communication

If autonomous reach stackers (ARS) are to be deploy, another gap appears as soon as several ARS cooperates. Namely, robotic fleet management will be needed. Such systems are at an early stage for smaller and medium ports and was demonstrated in simulations within AEGIS. Since the kiosk is autonomous this would both involve machine to machine, as well as machine to human communication.

SSS GAP 11: Digital infrastructure

Introducing robotic fleet management needs input from VCOP and TOS for the terminal to assign tasks for the autonomous reach stackers. Intercompany policies can make it difficult to provide the necessary information exchange between sea, terminal, and hinterland actors. For larger ports, there are some commercial systems, like the Kalmar One, available [15].

2.3 Roadmap

This section presents the roadmap towards the realization of the transport system proposed through use case A in AEGIS. The roadmap does not go into details on the realisation of unmanned ships as this was discussed in detail in [1]. In the realisation roadmap of [1], mother ships correspond to the short sea shipping segment and the *daughter ships* to the sheltered water shuttle concepts.

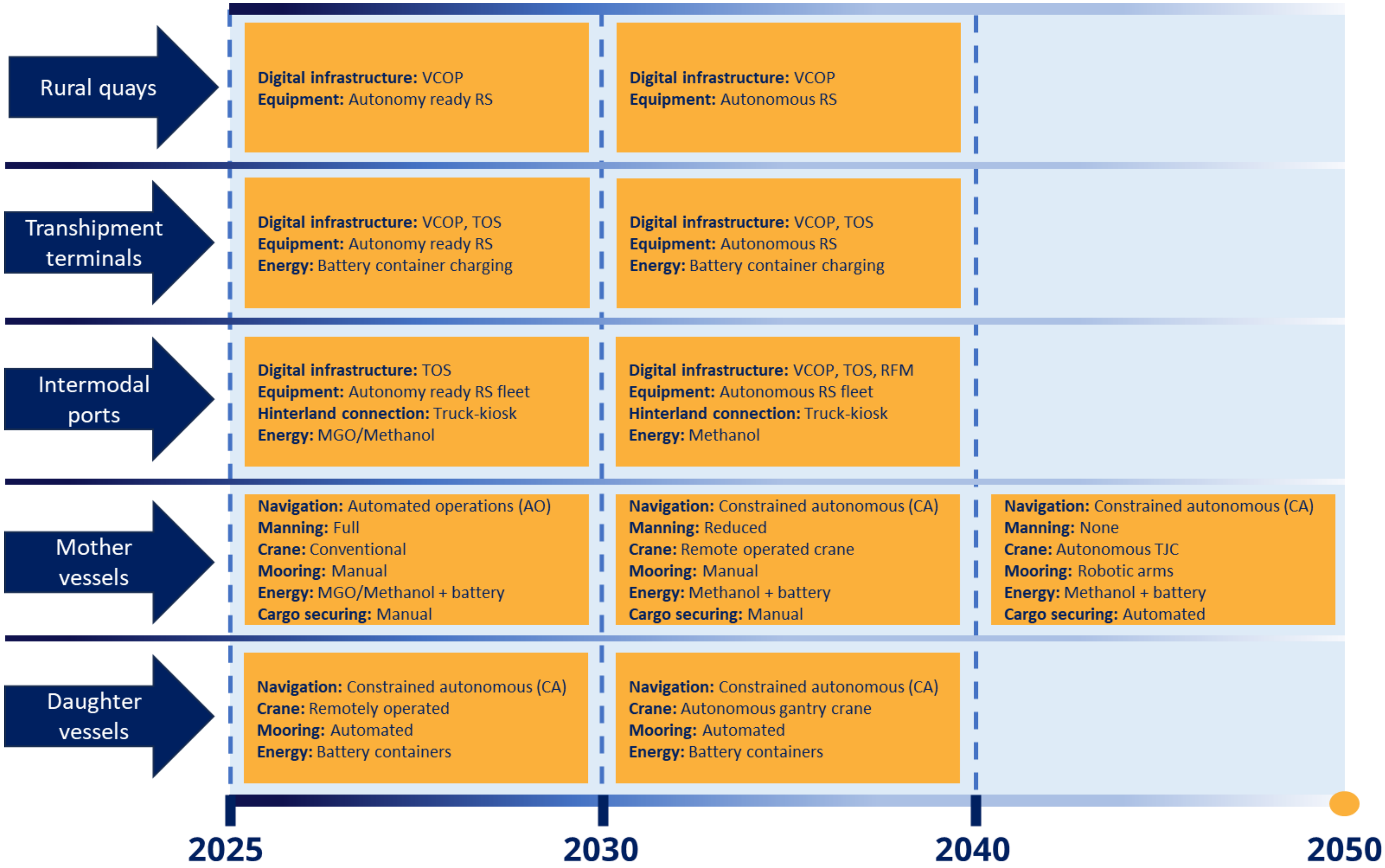


Figure 20: Roadmap towards autonomous short sea feeder loop service

Figure 20 shows the roadmap for logistic redesign. It is categorised through short, medium and long term solutions. The short term proposal enables early adopters to make investment decisions and pilot new technologies but does not enable the full proposition of the AEGIS short sea shipping feeder loop service.

2.3.1 Short term

The short term road map describes a short sea shipping transport system that could be implemented within 2030. *Rural quays* enable transhipment between hinterland transport and constrained autonomous *daughter ships*. For container moves on the shore side the *rural quays* and *transhipment terminals* concepts depends on reach stackers. These do not necessarily need to be autonomous to make the AEGIS redesign possible to deploy, however, since this equipment will not always be in operation, it is likely important in terms of the terminal costs that autonomous reach stackers are used. Through the implementation of VCOP, the quays can communicate with the constrained autonomous *daughter ships*. Remotely operated cranes onboard the *daughter ships*, triggered from a ROC, pick up containers at the quay. The daughters are equipped with automated mooring solution allowing for autonomous berth and de-berthing. The *transhipment terminal* facilitate transhipment between the *daughter ships* and mother ships. It also relies on the VCOP system to get cargo information from the different ships in the transport system, as well as TOS for arranging the terminal storage and household moves. Electric autonomy ready reach stackers transport the cargo between ships and temporary storage. Sensor systems allow for recording the reach stacker movement and can be used for algorithm learning purposes in this phase.

Battery container charging is already reaching market. Within the short term, the *transhipment terminal* will be able to facilitate this, which also enables the fast turnaround expected to be needed for *daughter ships* to be cost-competitive with trucks. The dual fuel mother ships can bunker MGO at some *transhipment terminals*, which means that some *transhipment terminals* may need to have facilities to bunker methanol in place.

The mother ship will still be equipped with a bridge, but automated operations allow for some freedom for the crew to not be always observing all processes. The crane can either be controlled from the bridge or in a wheelhouse. At this stage, a full crew is necessary on the mother ship since the bridge is manned, the cargo lashing is manual, mooring is manual, maintenance during transit is still needed, and the crane operations are manual.

At *intermodal ports* operators drive autonomy ready reach stackers within a fenced area. In the short term, this enables observations of the behaviour within the autonomous area, gathering data for learning algorithms. The use of TOS allows for container tracking within the terminal. Trucks load and unload their containers at the kiosk.

Short sea ships visiting the *intermodal port* will have the possibility of bunkering both MGO and methanol. For loading and offloading of the motherships, the onboard cargo handling equipment is used.

2.3.2 Medium term

The medium term road map defines an efficient short sea transport system, corresponding to a full realisation of the AEGIS short sea logistics redesign, but with crewed mother ships.

Rural quays move from manually operated reach stackers to autonomous reach stackers in this period. This means that it now becomes possible to do port calls without any people on the quay side.

Daughter ships were already unmanned and constrained autonomous in the previous period, however, in the medium term it is also expected that the onboard gantry crane becomes autonomous such that all vessel systems and functions are now at least constrained autonomous. This implies that the *daughter ships* still depend on the ROC for certain complex situations.

Transhipment terminals are also fully automated, enabled by autonomous reach stackers and automated battery container charging, as well as digital infrastructure in the form of the integration of VCOP and TOS. Some *transhipment terminals* will most likely need automated methanol bunkering facilities.

Mother ships are still crewed, however with a somewhat reduced crew enabled by constrained autonomy. They are powered by methanol and battery hybrid systems as described in [8]. Mooring and cargo securing are still manual processes handled by the crew. Cargo handling is now remotely operated, either from the ship bridge, or from a Remote Operation Centre.

Intermodal terminals are fully automated, ensuring efficient and cost-effective transfer of cargo between road, rail, and ships. Technological enablers, like autonomous vehicles, integration of the digital systems: robotic fleet management, the VCOP, and TOS, and automation of mooring and energy bunkering systems, are all needed for this phase.

2.3.3 Long term

The long term road map defines the target short sea transport system, which is a full implementation of the AEGIS short sea logistics redesign. Both mother and *daughter ships* are unmanned, enabled by constrained autonomy.

One important aspect to realize large autonomous container ships is the need for an automatic alternative to lashing. Currently, there are no viable concepts that solve this problem. Therefore, further research on this area is necessary.

To achieve moving 50% of all goods from road to sustainable maritime shipping through full implementation of the AEGIS solution, some key prerequisites need to be in place. Moving from the medium term we introduce at a minimum, constrained autonomy into all technological elements of the transport system. This enables the full cost competitiveness described in [7]. The roadmap assumes at this stage full internalization of external costs. At this time truck transport would most likely also benefit from greener energy, but studies show that even with both transport modes at zero emission, shipping has significantly lower external cost than trucks and thus gains a competitive advantage from internalisation of external costs [3].

2.4 Policy support

Note that policy actions specifically related to autonomous navigation is not discussed herein, as it is addressed in [1].

2.4.1 EC Policies for stimulating activities to close the major gaps

As discussed in section 2.3, the AEGIS redesign can be realisable within the period up to 2050. However, this requires that several gaps are closed. Some of these do imply policy support.

In general, there is still a need to launch research and development projects for automated and autonomous technologies for vessels, vehicles, and cargo handling equipment. Such efforts are ongoing, but at varying maturity level, and it is important to continue the funding of research and development until a sufficient maturity level is reached within each area.

In addition, there is one major challenge that needs dedicated attention as it is still uncertain what technological solutions are viable. Namely, securing cargo without any manual intervention. This challenge will probably require a solution that is both technical and logistical, and which might imply changes to existing business models. On the technical side, a solution for securing cargo without manual intervention is needed, on the logistical side it is possible that the technical solutions imply a flow of equipment within the supply chain that would need to be solved, e.g., in the case that automatic twistlocks is a part of the solution. For business models there could be a problem related to who makes the investment compared to who receives the benefit. This might require new, or updated business models.

2.4.2 EU Transport and Mobility policy

The objectives of EU transport and mobility policy can be summarised by eight points according to AEGIS deliverable *Policy implementation measures for a new European waterborne transport system* [16], where the highlighted ones are considered as highly relevant for this roadmap report:

1. Breaking the link between economic growth and traffic increase
2. **Promoting the revival of rail, sea, and inland waterway transport**
3. Eliminating cross-border bottlenecks and improving infrastructure
4. **Advancing technological innovation and automation**

   An important milestone for uncrewed autonomous ships is linked to the IMO Mass Code implementation, which is planned to be adopted as a non-mandatory goad-based Mass Code in 2025, which will form the basis for a mandatory code, expected to enter into force in 2028[12].

5. **Internalising external costs and promoting sustainable mobility**

   According to the EU Commission's "The Sustainable and Smart Mobility Strategy" [17] there should be a 90 % reduction in transport emissions in 2050, and related to internalisation of external costs of transport, there are two defined milestones, including via the EU ETS. The first one says that by 2030, waterborne intermodal transport will be able to compete on equal footing with road-based transport in the EU. The second states that by at latest 2050, all external costs of transport within EU to be covered by the transport users.

[12] https://www.imo.org/en/MediaCentre/HotTopics/Pages/Autonomous-shipping.aspx

The main conclusion regarding internalisation of external costs is that polluter pays, which means that the transport users bear the full costs rather than the society, which in the end will trigger a push towards more sustainable transport modes with lower external costs, where the maritime is by far the most promising option.

6. Establishing a Single European Transport Area and facilitating integration

7. **Decarbonising European transport and contributing to climate goals**

   On July 14th, 2021, the European Commission proposed to encompass GHG emission from the maritime sector through an extension of the EU ETS, a revision which is part of the "Fit for 55" package. As per the directive, the obligation to surrender (use) emissions allowances will be phased, with 20 % of emissions reported for 2024, 70 % for 2025 and 100 % in 2026. These requirements will be for ships 5000+ GT. By 2026 the European Commission will review whether general cargo ships between 400 and 5000 GT will be included. For the SSS case in this report this means that the mother ship will be subject to ETS from 2024, but the *daughter ships* will not until further notice.

   For further details regarding the ETS the reader is recommended to read the “Fit for 55 - Delivering the EU’s 2030 Climate Target on the Way to Climate Neutrality.”, launched by the EC in 2021.

8. **Achieving sustainable, smart, and resilient mobility**

   The Sustainable and Smart Mobility Strategy [17] points at the need of "a fully integrated and seamless multimodal system." Multimodality is key in achieving sustainable, smart, and resilient mobility based on the following strengths: Convenience, speed, cost, reliability and predictability. Resilient mobility is linked to the milestone: "A multimodal Trans-European Transport Network equipped for sustainable and smart transport with high-speed connectivity will be operational bey 2030 for the core network and by 2050 for the comprehensive network." [17]

2.4.3 Policies for stimulating charging infrastructure rollout

Medium and large terminals typically offer shore power facilities to ships moored at quay for longer periods. It is an important service that lets ships conserve fuel for their engines, leading to lower local pollution and less noise in and surrounding the harbour. The AEGIS project considers infrastructure for the Trondheim port authorities' terminals. The terminal at Hitra Kysthavn, used as a basis for transshipment in the short sea shipping redesign, is currently under development. This terminal is a good example of a location that is suitable for establishing charging infrastructure for the *daughter ships*.

To realize the container charging infrastructure there are some challenges that needs to be addressed. It is currently unclear who should do the investments, but if we assume that the ports should be the party that makes the investment, there will need to be an established market to defend the investment. On the other hand, establishing a market means investing into ships that have battery-containers, and for ship owners to invest in such ships, they need the infrastructure on the terminal to support the charging of the containers.

This scenario leads to a chicken-and-egg problem where no stakeholder moves on new innovations due to the reliance on the other stakeholders. The same challenge has already been faced in the EV market. In that case, ENOVA subsidised the building of charging infrastructure, stimulating the first movers.

ENOVA currently has a similar funding scheme for ports to establish shore power to ships. This was initially motivated to reducing noise and local pollution by reducing the need for ships to run their engines while at port. However, this funding is now being discontinued[13]. The reason for this is the fact that the uptake targets have been reached.

Both the EV and shore power subsidy programs are examples of powerful policy instruments that have led to the successful uptake of green technology in Norway. This indicates that a similar policy for subsidising battery-container charging infrastructure could stimulate the uptake of the technology and resolve the chicken-and-egg problem.

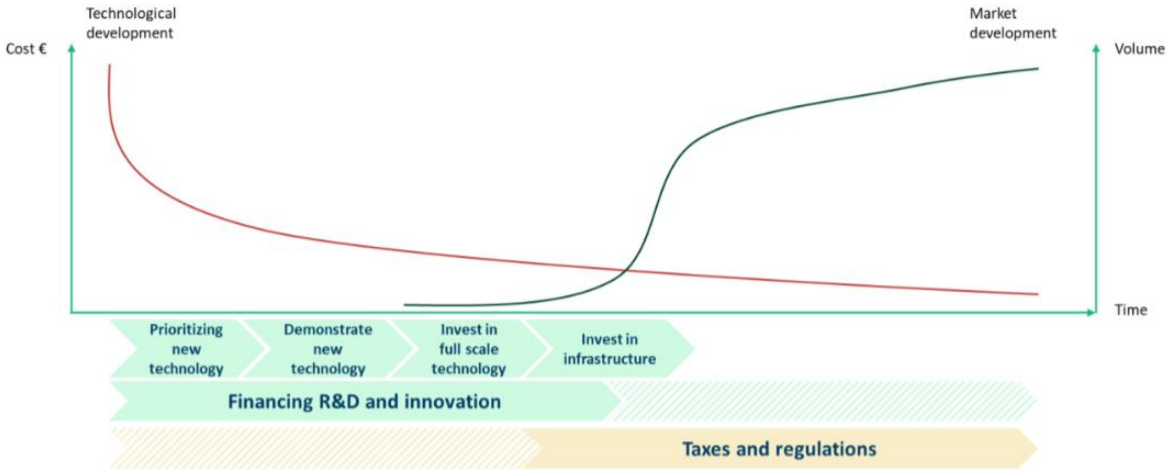


Figure 21: Illustration of the policy strategy for stimulating development and uptake of new technology, given in [1] as presented by [18]

2.4.4 Important digital connectivity initiatives

European Maritime Single Window environment

The EU regulation "2019/1239 establishing a European maritime single window environment"[14] introduces an interoperable EMSWe with harmonised interfaces to simplify reporting obligations for ships arriving at/departing from and staying in EU ports. The aim is to improve maritime transport's competitiveness and efficiency by reducing administrative burden, introducing digital components and services and reduce paperwork, in addition to improve the harmonisation of existing national systems compared to what was achieved through the previous EU Directive 2010/65 on reporting formalities for ships arriving in and/or departing from ports in member states.

The regulation applies from 15 August 2025.

IMO Reference Model

The IMO Reference Model[15] (also named the IMO Compendium) harmonizes the semantics and format for all information in the maritime domain relevant to the IMO, with focus on the reporting requirements approved by the IMO Facilitation committee, but also extended with operational information needed for efficient port calls, and ship-shore information exchange. The first version of

[13] https://www.enova.no/bedrift/sjotransport/landstromanlegg/
[14] https://eur-lex.europa.eu/EN/legal-content/summary/european-maritime-single-window-environment.html
[15] https://www.imo.org/en/OurWork/Facilitation/Pages/IMOCompendium.aspx

the IMO Reference Model was approved by IMO FAL in 2019, with new versions being approved at every FAL meeting (about once a year). Each new version covers more data sets, for instance related to just in time arrival, advanced passenger information, port state control, and inspections. Starting in 2024, work will be done to include a data set for noon reporting from ships to ship operators, which opens up for the definition of exchange of more technical onboard data.

The IMO Reference Model is not intended for direct implementation; however, it is an important starting point for the implementation of the IMO FAL Resolution FAL.14(46)[16] which requires ports around the world to implement a single window to support the data exchange within 1st of January 2024. In addition to this, the further work on the IMO Reference Model will focus on identifying the overlap between the various processes and data sets needed during a port call, when it comes to nautical information, administrative information, and operational information.

A challenge regarding reporting to the authorities, is that even if IMO defines the *maximum* reporting requirements that can be put on the ship, extra requirements are added by other authorities, and not always reported to IMO. When it comes to the introduction of electronic maritime single window systems, this is affected by the fact that several states still do this based on paper.

ISO 28005 – Electronic Port Clearance

ISO 28005 (protocol and data descriptions for electronic port clearance and ship-shore data exchange for operational data) is a series of technical standards that is suitable for the implementation of the IMO Reference Model. New parts will be added to this standard to cover new data sets in the IMO Reference Model. The newest part is Part 3 which is out for voting now (November 2023) and which covers port operational data related to just in time arrival. Digitalisation of port processes will require increased use of standardized electronic formats for exchanging information between different entities involved in container shipping to ensure more efficient and reliable communication between all actors involved in a port call. This is especially related to the geographical information needed when a ship is entering the port, being moored, and doing cargo operation (nautical information), and the relation to the operational information (information about ship and cargo services).

A challenge regarding the standardisation of ship-shore information exchange is that no single standard covers every aspect including authority information, operational information, and nautical information, and that no single standard is expected to be the dominant one. Describing the overlaps between the different standards will be more important as more advanced ship and port automation will require more digital information exchange. Agreeing on standards for these solutions is important to improve the systems integration.

[16] https://www.imo.org/en/KnowledgeCentre/IndexofIMOResolutions/Pages/FAL.aspx

3 Inland waterways RoRo transport

3.1 Revitalizing the inland waterways

The main rationale behind the project's focus on RoRo transport was to realize a shift of cargo volumes from today's road services to inland waterways. This becomes highly relevant when looking at the modal split of intra-European freight transport, where road-only solutions constitute the lion share of transport work performed. It is also the only mode of transport that can shows an increase in market share of significance. In contrast, the freight volumes of inland waterways have stagnated over the past 25 years, representing approximately 4.1 percentage of the total freight volumes in 2021 (including sea, rail, road and IWW, excluding oil pipeline and air transport). In comparison road only solutions accounted for 55.7 percent of the registered billion tonne-kilometers [19].

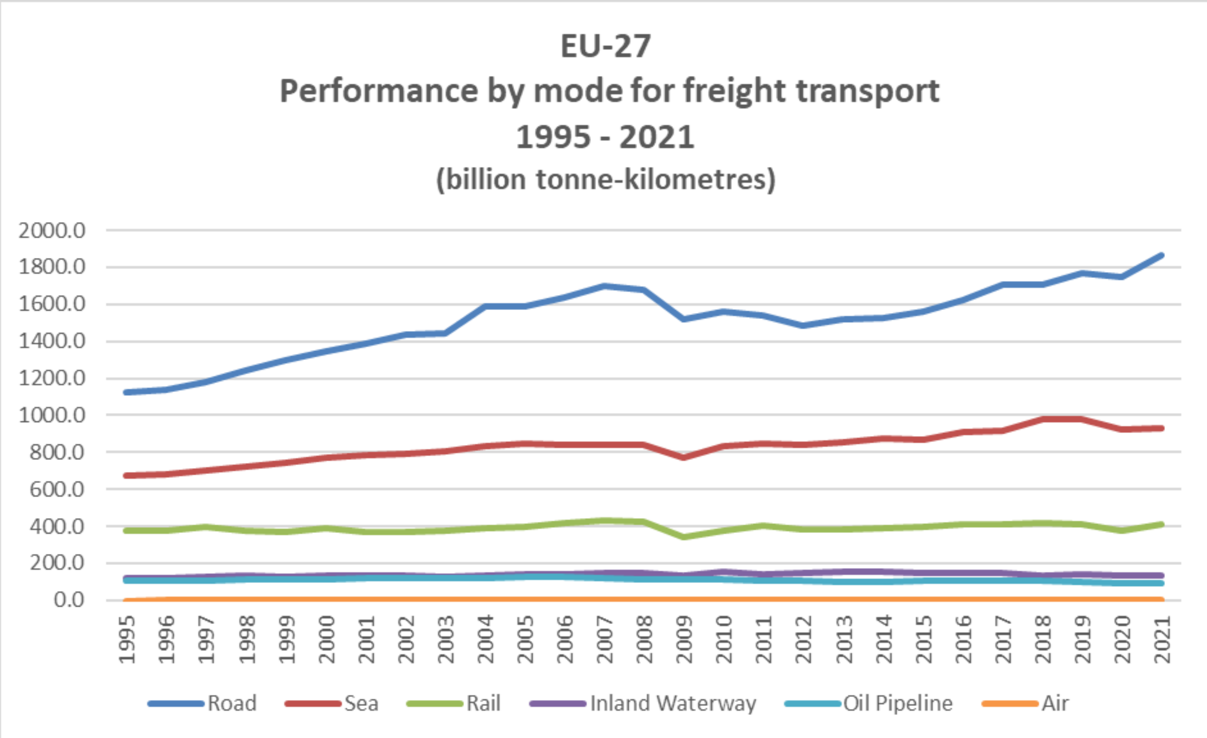


Figure 22: Intra EU-27 Modal split of freight transport, 1995-2021 [19]

However, road only solutions are seeing considerable challenges that may mirror themselves in increased volumes transported by alternative modes. In particular, [20] points towards the steady increase in congestion, putting a heavy strain on the efficiency of road only solutions – and hence, also the hinterland transport operations. The ripple effects of this leads to more costly operations, but also in terms of negative externalities such as increased local emissions to air, and reduced mobility for the public in general [20].

As such, increased utilisation of inland waterways (IWW) plays an important role towards reducing road congestion and local air pollution. And since IWW continues to lose market share to road only solutions, and significant efforts are necessary to stop this development, a redesign of the current transport system is therefore required. Hence, this section summarizes the main aspects of the current transport system (i.e., baseline), while also presenting the AEGIS redesign as a more economically, environmentally, and socially viable alternative [13]. A non-exhaustive list of important gaps that needs to be closed is also presented.

3.1.1 Baseline

As of today, RoRo short sea ships arrive at designated European ports (e.g., Rotterdam, Ghent, Antwerp) with cargo-trailers that have their end destination further into the hinterland. After the short sea ships are docked quayside at the terminal, the cargo is then offloaded by means of dedicated and manually operated tug masters, parking the trailers at dedicated slots awaiting further transportation by road. Then, external trucks collect the trailers, and after completing lots of paperwork, they are allowed to pass through the gates and leave the port for further hinterland transportation. In addition to tedious and time-consuming gate operations with unnecessary waiting-time for the truck drivers, the same drivers end up spending time in slow-moving traffic and congested roads (Figure 23). Especially in the vicinity of the port and inner-city areas, the traffic density is high – which primarily is caused by this way of organizing the transport system [13].

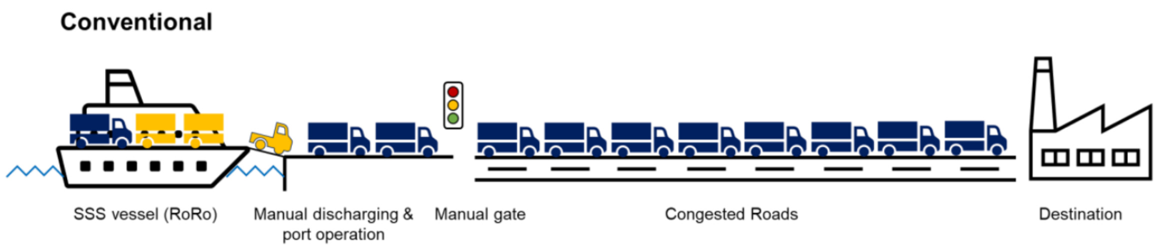


Figure 23: The inland waterways transport system – baseline [13]

3.1.2 Redesign

The AEGIS redesign of the inland waterways transport system is characterised by shifting parts of the cargo volume from road-only solutions over to inland waterway transport, realising a removal of significant cargo volumes from the congested road network. Then, the last mile distribution can be covered by smaller trucks, thereby bypassing the issue of traffic jams and congested roads around the major ports (Figure 24).

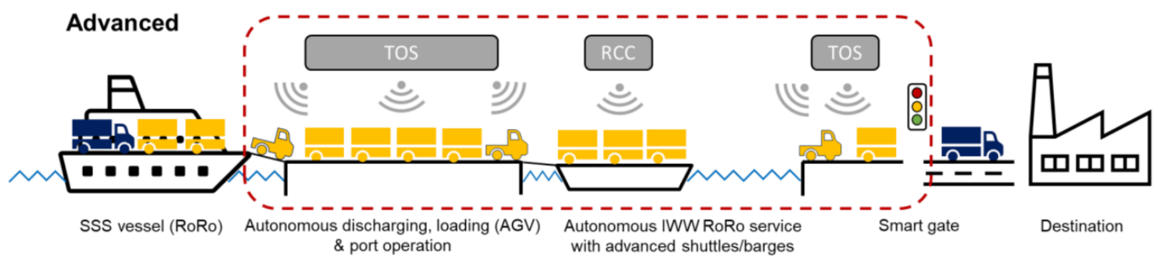


Figure 24: The inland waterways transport system – redesign [13]

However, to make this transformation economically, environmentally, and socially viable, some central aspects need to be covered. One of these aspects is that a redesigned and future oriented transport system would be characterized by a high degree of automation. AEGIS, through use case B has worked with several aspects addressing this redesign. The following section covers the findings and gaps that are necessary to close in order to realize the new transport system.

At a terminal, loading and discharging of the trailers are completed by autonomous terminal tractors (ATT), and all terminal operations – including transport of trailers from short sea vessel to the storage area, and then again to the designated IWW vessel – are controlled by a highly integrated system.

IWW GAP 1: Autonomous terminal tractors (ATTs)
Conventional terminal tractors are fully compatible with the AEGIS IWW logistics redesign and can be used to realise its impact. However, to harness the full potential of the redesign, ATTs are required as they give a high degree of freedom in terms of what ports to call – and when. Meaning that the vessel's operations is not hampered by port infrastructure or its opening hours. Similar as for the identified GAP for reach stackers (SSS GAP 2), one important step on the development ladder is enabling remotely controlled ATTs. This will provide some improvement in terminal efficiency as it enables a higher utilisation of the operators and removes the need for them to be physically located at the terminal. The full efficiency gain, however, can only be realised with the ATTs as this removes the dependency to human operators for normal operations and makes robotic fleet management deployable. It also implies a full realisation of digitalised administrative procedures.

This also includes areas for separating autonomous and manned terminal operations – both for securing operation efficiency and the safety of terminal personnel. In addition, the lashing of the trailers is also automated.

IWW GAP 2: Automatic (de)lashing of RoRo trailers
Currently, the (de)lashing operation of RoRo trailers requires manual operation, and the use of chain lashings require deck-hands. In total – eight lashings must be applied to prevent the trailer from moving under transport some of which are shown in Figure 25. As such, the semi-automatic version is a clear step in the right direction with two twistlocks on each side. To complete the loading and unloading without deck-hands, autonomous terminal tractors are needed, and the trestle must be fitted by semi-automatic twistlocks. As for the SSS and containers, semi-automatic twistlocks exists on the market today, but their applicability into autonomous transport systems remain highly questionable.

Figure 25: Conventional lashing of trailer trestles (to the left), and semi-automatic trailer securing to the right [Courtesy of DFDS]

The IWW transport is carried out by small vessels (shuttles or barges), which can be either fully autonomous or controlled by a remote operation center (ROC). This enables one ROC operator to be in control of several vessels, thereby tapping into the aspect of economies of scale, but also as a viable remedy to the looming shortage of qualified seafarers.

IWW GAP 3: Constrained autonomous IWW vessels
There are still no commercially operating constrained autonomous shuttles or IWW barges. Research and development, as well as investments and commercial projects for full scale realisation is still needed. The road towards realising such ships is elaborated in the AUTOSHIP roadmap [1].

The interaction between vessel and port is also supported by smart gate or similar solutions, being applied at interfaces between autonomous and manned operations. Increased operational flexibility, and thereby the opportunity to visit smaller ports more easily, is also increased by the vessels opportunity to complete the (un)loading operation by having an ATT onboard as well as automatic mooring solutions.

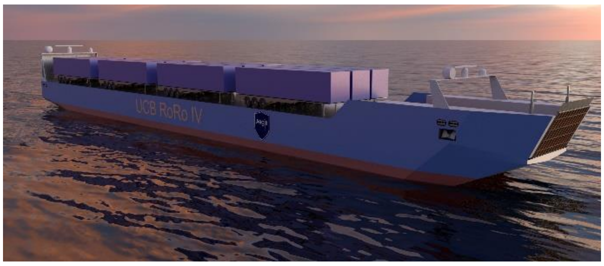
IWW GAP 4: Autonomous berthing and mooring
The vessels must be able to berth and moor autonomously, and existing systems are either vacuum based, magnetic based, or robotic arms[17]. Several of such automated mooring systems are commercially available, and well suited for the *CEMT II* and *IV*, but there are reported issues regarding daily operational stability. For the AEGIS *CEMT II* and *IV* barges a magnetic rail solution is proposed. Such a solution would require investments on both barges and terminals to facilitate the mooring system. In addition, the mooring solution required for transverse loading of the class VI needs to be developed, representing a gap in itself.

The last mile distribution from the *urban quays* to the destination is done by conventional road transportation. Still, in an optimal case the destination would be located at the IWW and thereby being possible to serve directly by the IWW vessel.

Another key contributor is new, and more energy efficient vessel designs in combination with zero or low-emission propulsion technologies. For the latter, a fully electric or hybrid solution combining batteries and hydrogen, or ammonia is proposed.

IWW GAP 5: Mixed energy systems
This is the same gap as SSS Gap 7.

In AEGIS, three (3) new conceptual IWW vessel designs were developed, each with two cargo decks (Table 1). In general, the designs are long and slim for reduce resistance, and with a low draft to cater for waterway limitations.



[17] https://www.macgregor.com/intelligent-solutions/automated-mooring-system/

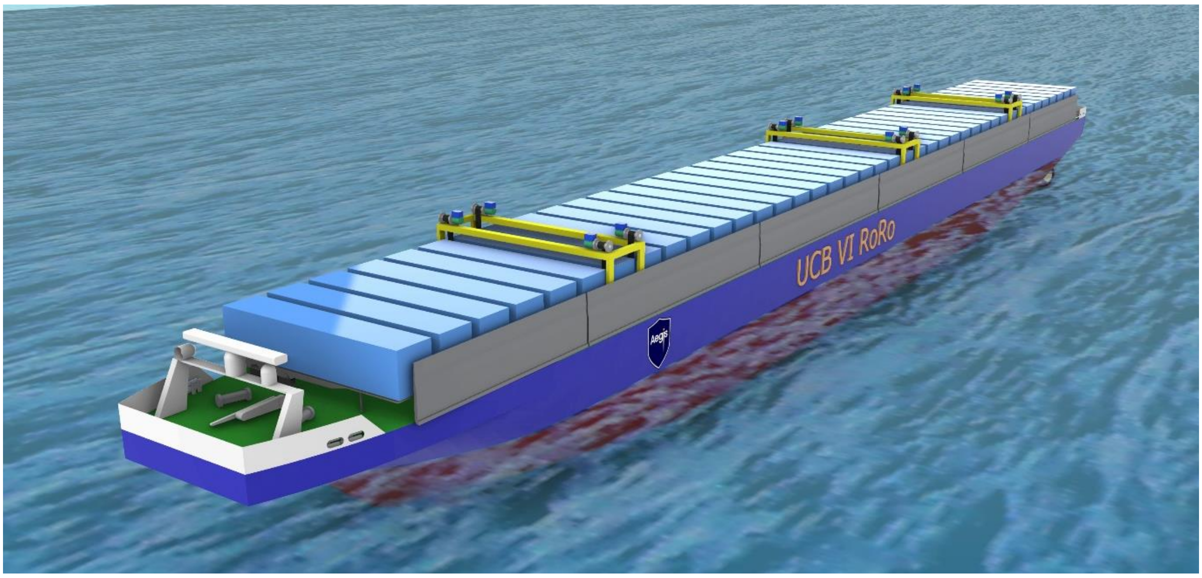


Figure 26: Design of IWW RoRo vessels, CEMT II (upper left), CEMT IV (upper right), CEMT VI (bottom), courtesy ISE

Figure 26 shows the final version of the three different barge designs developed in AEGIS. The midship section is maximised to allow for best possible transport capacity. Furthermore, the omittance of superstructure is also used to maximise the transport capacity. Still, one of the most important features of the developed vessel designs is the different sizes, as smaller vessels can travel deeper into the hinterland and thereby increase the resilience of the supply chain. In addition, the CEMT class IV+ vessel design also caters for transversal loading operations.

Table 1: Main characteristics of developed draft vessel concepts in WP4 (Source: ISE)

	IWW CEMT class II	IWW CEMT class IV	IWW CEMT class VI (transversal loading)
L_{OA}, [m]	55.00	85,00	135.60
B, [m]	6.60	9.50	15.00
T_{Design}, [m]	2.50	2.50	4.50
D, [m]	6.50	8.35	9.35
Capacity	10 (upper deck: 6/tank top: 4)	21 (upper deck: 12/tank top: 9)	69 (upper deck:40/tank top: 29)
Propulsion	Fully electric, 2 azimuth thrusters a 175 kW, bow thruster	Fully electric, 2 azimuth thrusters a 175 kW, bow thruster	Fully electric, 2 azimuth thrusters a 360 kW, channel bow thruster

Moreover, transporting only trailers makes a better utilisation of the vessel's cargo carrying capacity (as opposed to carrying both trailer and truck), and since RoRo enables faster (un)loading operations in comparison to LoLo, the turn-around time in port is also affected. Enabled by battery trailers and battery containers allows for fast turnaround at ports.

IWW GAP 6: Battery trailer charging infrastructure
This is the same gap as SSS Gap 3.

With regards to promising cargo flows, the link between Rotterdam and Ghent/Antwerp is one example that seems highly relevant for such a use-case, however, deploying any degree of autonomy on the ships in these waterways would give rise to the necessity of passing locks and bridges autonomously.

IWW GAP 7: Locks
Locks are required for allowing the IWW vessels to gain access far into the hinterland. Today, the opening of gates and management of water level are supervised by personnel, and a tug may also be required for manoeuvring in and out of the locks. This may imply unnecessary waiting times for vessels, hampering the overall transport efficiency. Some of the big challenges that must be solved for unmanned barges travelling in locks is manoeuvrability of the barge within the lock and keeping its position in the lock. The feasibility of keeping the position within the lock by the vessel manoeuvring system is being investigated in the SEAMLESS project. Other solutions could be vessel- or land-side mooring systems.

Another example is increased utilisation of the Albert Canal, as this improves access to smaller quays located further into the hinterland. Such quays would have little to no intermediate storage so it would need something similar to the VCOP described in chapter 2 to handle the loading and unloading sequence planning, barge stowage planning, and coordination of transfer to trucks.

IWW GAP 8: Digital trailer logistics platform
This is the same gap as SSS Gap 1. However, the VCOP system needs to be tailored for trailers and its logistics.

With respect to the different CEMT classes of the AEGIS designs, the largest is mainly targeted for typical direct runs between ports (i.e. "A-B"), with complete loading and unloading of cargo at each end point. Hence, the loading process is free from any particular commercial stowage sequence. The smaller vessels are more suited for routes often referred to as "milk runs", characterized by having two end points and one to several stops along the route. In this operational context, complete (un)loading at every port along the route is not necessarily required, meaning that a stowage plan for each trip must be created – accounting for commercial priorities and optimal port calls, i.e., efficient cargo handling and fast turn-around time.

One of several perceived big advantages of these two aspects is to pick up and drop of cargo as close as realistically possible to its origin and destination. This includes the possibility to bypass some of the most congested areas of Europe.

3.2 Roadmap

This section presents the roadmap towards the realization of the transport system proposed through use case B in AEGIS.

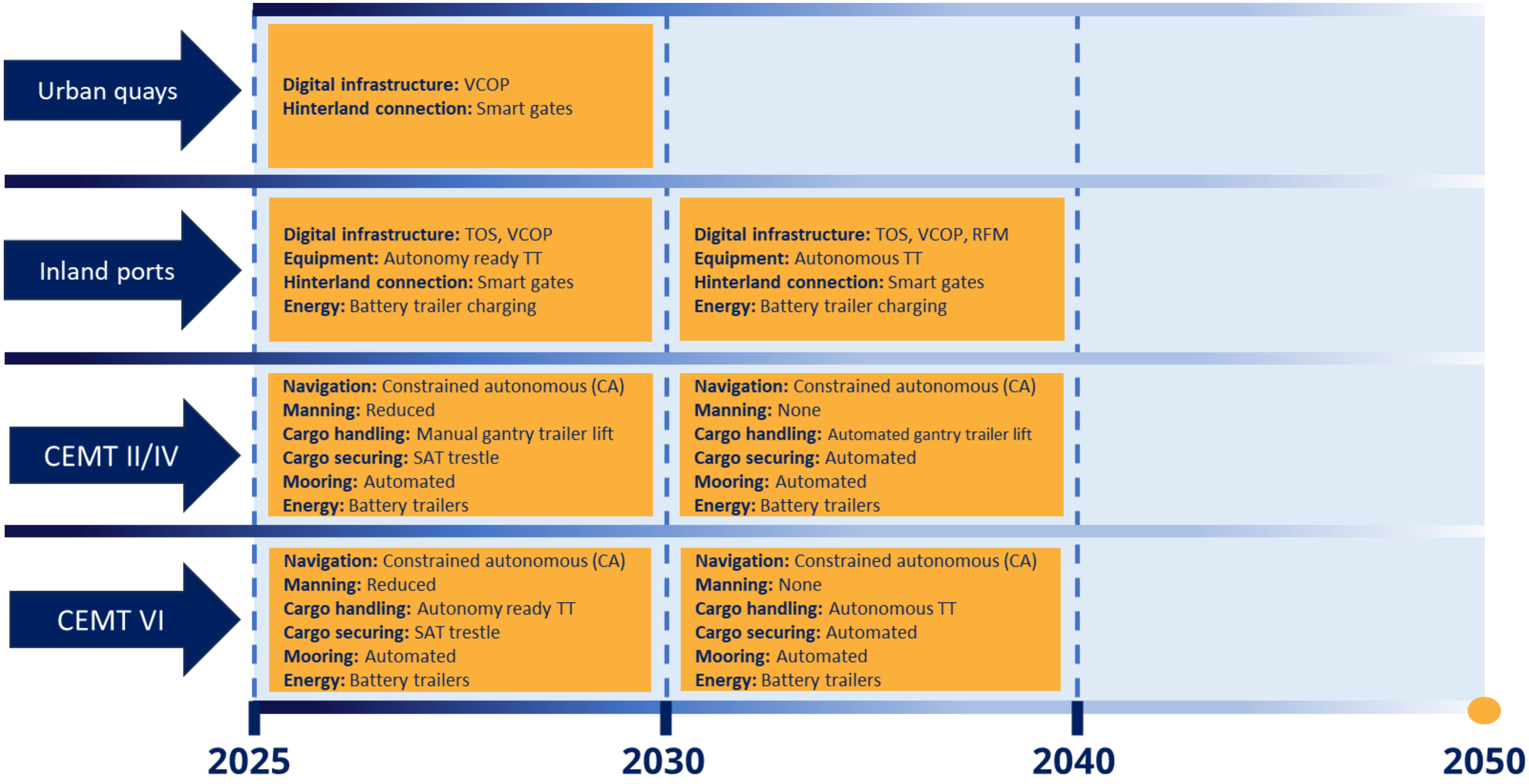


Figure 27: Roadmap towards autonomous inland shipping

3.2.1 Short term

The short term roadmap describes an inland waterways shipping transport system that could be implemented within 2030. *Urban quays* enable transhipment between smaller trucks for urban distribution and reduced crew small inland vessels, with Constrained Autonomy (CA) technology [1]. The connection to last mile transport at *urban quays* will be facilitated by smart gates, separating autonomous and manned operations. Cargo stowage and (un)loading sequence planning is handled by smart systems such as the VCOP. Such systems will also handle booking of last mile transport and scheduling of pick-up and delivery at the smart gate, making *urban quays* ready to be called upon by unmanned vessels.

The *CEMT II/IV* vessels will carry their own electric autonomous ready terminal tractor for loading and offloading. While the terminal tractor needs to be upgraded to be autonomous or at least remotely controlled to realise the full benefits, this is not necessary to make the AEGIS redesign possible to deploy. This, and the fact that cargo securing will require some manual work, even though it is based on semi-automatic twistlocks and trestles, means that the CEMT II/IV vessels will need to have a crew. However, as the vessels can be outfitted with technology for constrained autonomy and automated mooring in this period, they can be operated by a reduced crew.

Larger, *CEMT VI* vessels, will move cargo between large seaports and *inland ports*. As opposed to the smaller *CEMT II* and *IV* vessels, they will not depend on bringing their own terminal tractor. Instead, they are designed for transversal loading and with a gantry crane lifting system enabling a double decked solution. In the short term, the lift will be manual, and they will face the same issues related to securing cargo, meaning that they will need crew onboard. Technology for navigation will be at the constrained autonomy level, and mooring will be automatic, which enables some reduction in the crew.

Passing locks with unmanned vessels is also an unresolved challenge. It is not expected that this will be solved in the short term, further signifying that some crew will be needed onboard all the inland vessel designs in this period.

The *inland ports* facilitate transhipment between the larger *CEMT VI* vessels and the smaller *CEMT II* and IV vessels. They rely on the VCOP system to get cargo information from the different vessels in the transport system and for planning stowage and cargo handling sequences, as well as the TOS for arranging the terminal storage and household moves. Electric autonomy ready terminal tractors transport the cargo between ships and temporary storage at the terminal. Sensor systems allow for recording the terminal tractor movements and can be used for algorithm learning purposes in this phase. Terminal efficiency and safety is improved by smart gates providing an interface between automated and manual operations.

Battery container charging is already reaching market. Within the short term, the *inland ports* will be able to facilitate this, which also enables the fast turnaround expected to be needed for inland vessels to be cost-competitive with trucks.

3.2.2 Medium term

In the medium term, it should be possible to realise the full AEGIS redesign. This will require that *inland ports* become more automated and that inland vessels become unmanned.

Inland ports can become more automated by utilising autonomous terminal tractors which are coordinated by a Robot Fleet Management (RFM) system. This will increase terminal efficiency and increase worker safety as humans will be removed from cargo operations, which historically is a source for accidents and injuries.

Inland vessels can become unmanned if the key enablers cargo securing and cargo handling are automated. The *CEMT II/IV* vessels will upgrade their terminal tractors to become autonomous, while the *CEMT VI* vessels will upgrade their gantry crane lifting system to become automatic. Automating securing of cargo can be done in the same way for all the AEGIS inland vessel concepts, however, this could prove to be the most ambitious target for the medium term.

Passing locks with unmanned vessels is also expected to be solved within the medium term. Weather this will be made possible by onboard technology alone, or if some upgrades of the locks are needed as well, is an open question.

3.2.3 Long term

In the long term we expect inland transport to have a large market share due to transport systems such as the one proposed in the AEGIS project being a cost competitive, green alternative to truck transport. This does, however, depend on extensive and focused efforts on closing important gaps. Which requires policy support.

3.3 Policy support

Many of the items listed for short-sea-shipping in Section 2.4 relate to inland waterway transport as well, however for development of the IWT sector it is in particular the NAIADES III action plan which is the driving force.

Note that policy actions specifically related to autonomous navigation is not discussed herein, as it is addressed in [1].

3.3.1 EC Policies for stimulating activities to close the major gaps

As discussed in section 3.2, the AEGIS redesign can be realisable within the period up to 2040. However, this requires that several gaps are closed. Some of these do imply policy support.

In general, there is still a need to launch research and development projects for automated and autonomous technologies for vessels, vehicles, and cargo handling equipment. Such efforts are ongoing, but at varying maturity level, and it is important to continue the funding of research and development until a sufficient maturity level is reached within each area.

In addition, there are two major challenges that need dedicated attention as it is still uncertain what technological solutions are viable. Namely, passing locks with unmanned vessels and securing cargo without any manual intervention.

Passing locks is a major challenge for realising large scale unmanned inland waterways shipping. While some actors believe that this can be solved by advanced ship systems, it is possible that locks will need to be upgraded, e.g., with auto-mooring. As the best solution is uncertain, it is important to stimulate research on technical, logistical, and business case aspects such that the industry can focus on a common pathway. E.g., if it is found that the realisation of large scale autonomous inland shipping depends on new infrastructure or upgrades at locks, the “chicken-and-egg” problem observed for the widespread uptake of battery containers, will apply. This means that it is highly likely that a similar realisation strategy will be needed.

Nevertheless, the recommendation is that the initial actions are to fund research projects, and then innovation actions for full scale demonstrations, of automated lock passing. Requirements for projects should be that no onsite personnel are needed, and that conventional traffic is not impacted.

As for short sea, securing cargo is another major challenge preventing unmanned ships from being realised. This challenge will probably require a solution that is both technical and logistical, and which might imply changes to existing business models. On the technical side, a solution for securing cargo without manual intervention is needed, on the logistical side it is possible that the technical solutions imply a flow of equipment within the supply chain that would need to be solved, e.g., in the case that automatic twistlocks is a part of the solution. For business models there could be a problem related to who makes the investment compared to who receives the benefit. This might require new, or updated business models.

The recommendation is thus to build a strategy that starts with funding of research on technical solutions, equipment logistics, and business model impacts. The next step would be innovation actions for full scale demonstrations. Finally, once a viable market solution appears, a strategy for market uptake needs to be developed, which might require similar actions as needed for uptake of battery or energy containers, see section 2.4.

As for short sea shipping, establishment of charging infrastructure will be a challenge. For details on policy recommendations on this, see 2.4.3.

3.3.2 NAIADES III

To address the objectives of the European Green Deal and the Sustainable and Smart Mobility Strategy, The European Commission introduced a 35-point action plan for the period 2021-2027, called NAIADES III[18], in June 2021, to boost the role of inland waterway transport in mobility and logistics systems. These action points are spread across four areas proposed by The Commission:

9. Shifting more freight to inland waterways

Flagship 1: Helping waterway managers to ensure a high level of service (by 31 December 2030)

- The Commission will give more support for projects (CEF2 and Horizon Europe) aimed at completing and upgrading the TEN-T network and address bottlenecks.

Flagship 2: Updating the EU's legal framework for intermodal transport

- The Combined Transport Directive[19] is currently the only EU legal instrument that directly supports intermodal transport. This will be revised to fully integrate IWT as essential in intermodal transport.

10. Transition to zero-emission inland waterway transport

Flagship 3: Speeding up certification procedures for innovative and low-emission vessels

- The Commission will assess how to best facilitate and speed up safe testing and certification of innovative and low-emission vessels as part of review of EU Directive 2016/1629.

Flagship 4: Guaranteeing IWT investments take into account climate and environmental objectives

[18] https://transport.ec.europa.eu/transport-modes/inland-waterways/promotion-inland-waterway-transport/naiades-iii-action-plan_en
[19] https://ec.europa.eu/commission/presscorner/detail/en/qanda_23_5588

- The Adaption Support Tool[20] may support the development of climate change adaption strategies and plans for inland waterways.

Flagship 5: Developing *inland ports* as multimodal alternative fuels infrastructure hubs

- A revision of the AFID[21] with the aim of ensuring that necessary recharging and refuelling infrastructure for zero-emission vessels is deployed in *inland ports* by 2030.
- The Commission will also request the European Standardisation Organisation[22] to work on harmonization of standards for alternative fuels infrastructure for *inland ports*.
- Specific actions through CEF and Horizon Europe will support innovative approaches for greening of *inland ports*. This will also be reflected in the revision of the TEN-T Regulation.

11.Smart inland waterway transport

Flagship 6: A roadmap for digitalization and automation of IWT

- Facilitation of the elaboration of a holistic vision for the sector's digitalization and automation, with contribution to adjustments of the Digital Inland Navigation Area (DINA), NAIADES and Digital Transport and Logistics Forum (DTLF).
- Launching a CEF technical assistance project to develop closer public-private cooperation in ITW.
- Demonstration and deployment of holistic, smart and automated shipping concepts through Horizon Europe and CEF.

12.More attractive and sustainable jobs in inland waterway transport

Flagship 7: Smart and flexible EU crewing rules

- Assess the need for legislative initiatives for on-board digital tools for recording and exchange of information on crews and vessels, and crewing requirements for better harmonization at EU level.

There is also a final Flagship 8 related to financing: Supporting the sector and Member States in the transition to zero-emission vessels, with the following financial instruments:

- Recovery and Resilience Facility: EUR 672.5 billion
- CEF/TEN-T: EUR 21.8 billion in the period 2021-2027
- Invest EU, especially "Sustainable Infrastructure Window": EUR 26.2 billion guarantee

The NAIDES III action plan have Flagship areas that have objectives matching the required policies identified in section 3.3.1. In the following it is discussed which could be the best fit for launching concrete calls targeting the gaps discussed in section 3.3.1.

Flagship 5 and **Flagship 8** could be the sources for funding the necessary establishment of infrastructure for battery container charging. In the early phase, it might also be necessary to fund first movers for their investments in the battery containers themselves, considering that rental of battery containers based on energy-as-a-service business models is perceived to be a realistic future scenario.

[20] https://climate-adapt.eea.europa.eu/

[21] Directive 2014/94/EU of the European Parliament and of the Council of 22 October 2014 on the deployment of alternative fuels infrastructure, OJ L 307, 28.10.2014, p. 1.

[22] CEN/CENELEC & ETSI.

Flagship 6 could be the source for funding the necessary innovation projects for development and demonstration of unmanned lock passage. It could also be where the necessary automated cargo securing projects could find their source of funding.

3.3.3 European Committee for drawing up Standards in the field of Inland Navigation (CESNI)

The CESNI was established in 2015 to draw up standards in various fields, in particular as regards vessels, crew and information technology. The purpose of this committee *is to bring together experts from the Member States of the European Union and the CCNR (Central Commission for the Navigation of the Rhine) and representatives of international organisations with interest in inland navigation*[23]. There are three main standards:

European Standard laying down Technical Requirements for Inland Navigation vessels (ES-TRIN)

- The areas where amendments or new developments are required and/or other relevant findings related to autonomy, for ES-TRIN are given in Table 2 in Regulatory framework analysis for the unmanned inland waterway vessel [21]

European Standard for Qualifications in Inland Navigation (ES-QIN)

- This standard harmonises competences at European level, which has gone from an experience-based approach to a competence-based system.

European Standard for River Information Services (ES-RIS)

- To ensure interoperability, the technical specifications for RIS (River Information Services) will have to constantly evolve. Streamlined revision cycles for ES-RIS could make it easier for RIS to evolve towards smart shipping and interoperability with the mobility data space and help with the sector’s digital transformation. To complete RIS deployment by 2030, the Commission is also calling on Member States to further implement smart traffic and transport management solutions in inland waterway transport, with a specific focus on harmonised corridor management based on RIS. This can be supported via continued funding through CEF financial support for a permanent operational structure set up to provide a single point of access for RIS-based corridor information services.

[23] https://www.cesni.eu/en/about-cesni/

4 Intercontinental shipping

The AEGIS project has addressed shipping feeder-loops for SSS and IWW transport, while intercontinental shipping has not been a topic. This section briefly discusses some potential opportunities in relation to intercontinental shipping.

The perhaps most obvious opportunity related to inter-continental shipping lies within moving hinterland transport to and from, and between, intercontinental ports from road to sea. Hence, vessel and terminal concepts from AEGIS could be important enablers for realising such a shift, as the waterborne shuttle service would be a more economically viable and environmentally friendly alternative to road-only transport. Some similar initiatives are already observed, with actors such as Seafar remotely operating ships between the ports of Zeebrügge and Antwerp[24].

Other challenges related to current intercontinental shipping relates to the size of the ships. Low water levels in important canals such as the Panama Canal, restricts international trade. Incidents such as the blockage of the Suez Canal also proved the vulnerability of world trade to incidents with single massive ships. Whether the AEGIS logistics redesign and ship concepts could play a role here is more uncertain as the main driver for these huge ships is the economy of scale. Though several researchers have discussed the prospect of defeating economy of scale [22], this has not been investigated as part of the AEGIS project and as such remains a theory that should be studied in more detail.

[24] Remote controlled barge takes boxes from Zeebrugge to Antwerp - Splash247

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