synergetics

D2.2 Report on lessons from Past Pilots

Synergetics | Synergies for Green Transformation of Inland and Coastal Shipping

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Executive Summary

Task 2.2, of which the results are presented herein, encompasses an evaluation conducted through desk research, interviews and workshops focusing on pilot projects. The study highlights that there is a very limited set of readily available solutions for greenhouse gas reduction in the operation of coastal and inland vessels and the study identifies several obstacles that hinder innovation and roll-out.

While technological solutions such as usage of hydrogen, methanol and electricity stored in batteries as energy source for vessels, and also energy efficiency solutions have been validated, their roll-out remains a very slow process with lack of progress due to elevated costs. Capital expenditures (CAPEX) are particularly high for retrofitting older vessels, exacerbated by price increases linked to the COVID-19 pandemic and the war in Ukraine as result of the Russian aggression. At the same time, the legalisation is not (yet) in place for inland and coastal vessels to internalise external costs of using fossil solutions and to provide clear operational incentives to green vessels. This financial challenge as well as the current legal framework create an unfavourable environment for both retrofitting and constructing new green vessels.

Operational expenditure (OPEX) can occasionally be minimized, yet the cost of renewable fuels continues to exceed that of fossil diesel. As a result, vessels using renewable fuels encounter clear competitive disadvantages in the open market due to higher break-even prices and lack of willingness by clients to pay a premium for decarbonised transports. Long-term contracts with customers willing to pay a "green premium" are uncommon and operators are waiting for governmental incentives and legal requirements to close the price gap between solutions using renewable energy and continued usage of fossil fuels.

Moreover, also the development of alternative energy infrastructure along waterways and in ports is critical for the uptake of alternative energy sources. However, existing networks are not easily adaptable, and establishing new bunker points or electric power supply is costly and complex. While truck-to-ship bunkering services offer some flexibility, fixed bunker points supplemented by additional services would be ideal to bring down costs. However, these need an economy of scale. The typical ‘chicken-egg’ dilemma prevails in many cases to set up such structural infrastructure facilities.

Technical regulations for vessels (CESNI/ES-TRIN and IMO) are evolving and adaptable. The publishers of the regulations are currently working on incorporating new technologies in order to shorten the processes. However, the drafting and harmonisation of regulations is also a very time-consuming process. Currently, issuing derogations remains necessary for most solutions, which is time-consuming and expensive for vessel owners. Enhancing communication with authorities can contribute to regulatory improvements. The inland navigation sector however faces a specific legal barrier in the Non-Road Mobile Machinery (NRMM) Regulation (2016/1628) for Stage V combustion engines, regarding new engines using hydrogen and methanol. Currently engines suitable for these fuels cannot be placed on the market as both fuels are not recognised as reference fuel for the certification of engines.

The aim of this report was to identify readily implementable solutions for greening efforts, but not many were found. There are viable cases identified for application of energy efficiency solutions. However, the applicability depends on specific conditions and will not be economically feasible for all vessels and operational profiles. Methanol shows potential on the medium term, but is subject to several constraints which block demonstrations on short term, especially because of the non-availability of Stage V engines. The usage of renewable Hydrotreated Vegetable Oil (HVO) as drop-in fuel for existing engines has been demonstrated to be successful and widely applicable, although administrational barriers for HVO do exist. However, because of the high TRL, application of HVO was beyond the scope of this study.

It must finally be noted that during the research remarkably few pilot operators were willing and able to share data about key performance indicators (KPIs). Factors like operational and capital costs, efficiency differences et cetera were barely disclosed because of their confidential and business sensitive nature. This has made the report of a more general nature than might have otherwise been the case.

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1. | Introduction

One of the Work Package 2 key missions is to gather knowledge generated in pilots executed outside of SYNERGETICS. In Task 2.1, potentially interesting pilots to learn from have been identified and assessed. Over 185 pilots could be identified, and a group of over 70 was assessed as potentially interesting to learn from. The other pilots were grouped as probably less interesting and only suitable for evaluation if time permitted. At the time of writing this deliverable, SYNERGETICS partners are nearing the end of the first group of 70 pilots to evaluate: 50 could be evaluated. Others were found impossible to evaluate due to lacking information and/or contact points available.

Task 2.2, of which this deliverable D2.2 is the report, focussed on evaluation through desk research, interviews, workshops (or a combination) of pilots that were finished and had reported some results. Within SYNERGETICS these are called Past Pilots. Ongoing and future pilots are the target of research and synchronization (in other words: networking) efforts in Task 2.3, which is ongoing and will report results in D2.3, to be delivered six months after D2.2 in June 2025. Of the 50 evaluated pilots at the time of writing, 29 were clearly finished and thus in the focus for this deliverable. However, the knowledge gained from evaluating the other 21 pilots is not withheld from this report in its entirety. The general issues and lessons learned flowing from the two sets of pilots significantly overlapped. Nevertheless, D2.3 will contain more information on currently evaluated ongoing and future pilots, pilots that still are to be evaluated and the Synchronization efforts of the work package team.

Central to the SYNERGETICS overall mission is the identification and study of low-hanging fruits: options to reduce the carbon footprint of an IWT or Coastal vessel through retrofit that can be relatively easily obtained. Conversely, the identification and evaluation process in WP 2 tried to identify these low-hanging fruits and find lessons learned gathered during their implementation.

It is important to note that what is part of the research has been depending entirely on the pilots identified in Task 2.1. Since many pilots focussing on electrification, hydrogen and methanol were found, this is the core area of this report. Far less pilots were found targeting energy efficiency measures, so it is possible that they are underrepresented here. The same can be said for drop-in biofuels such as FAME and HVO, the identification part of the work package excluded these from the main targets since they have been proven already (i.e. they are already state of the art and past the pilot phase). This report thus omits them almost entirely.

The nature of the research, which is essentially the aggregation of a broad series of case studies (in SYNERGETICS called Pilot Evaluations) dictates a broadly scattered array of results. Nevertheless, a clear red line is observable: the research has so far not been able to identify new true low-hanging fruits. A wide field of hindrances, which will be sketched throughout this deliverable and touched upon in the conclusion, makes innovation to decarbonize a vessel an uphill battle.

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Directly below can be found a cut-out of the SYNERGETICS Grant Agreement, which details the 2.2 task description. The second chapter details the methodology and explains how the results have been obtained. These results are stated in chapter three, and discussed in chapter four. Chapter five concludes this deliverable and gives a few recommendations to key stakeholders.

Cut-out of the SYNERGETICS Grant-Agreement:

Task 2.2: Lessons from past pilots [M12-M24]

Using the database constructed under T2.1, lessons learned from interesting pilots held in the past will be aggregated and integrated in the SYNERGETICS project.

• Through a desk-study combined with interviews and/or a workshop, find lessons learned from interesting past pilots identified under T2.1. In particular the different impacts and pre-conditions are important: for which vessel types does the pilots work, what are emission reduction impacts and what are the costs, what is the market potential? (SPB leads, other partners to contribute);

• Ensure the take-up of these lessons in SYNERGETICS trough a workshop with SYNERGETICS partners and key players in past pilots. (SPB leads, other partners to contribute).

Involved Partners: SPB (lead), DST, MARIN, ANLEG, ZES, FPS, CMB.TECH, SNAOS, KOE

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2. | Methodology

2.1 Scope

In Task 2.1 a scope for the identification of potentially interesting pilots was set. It is included in chapter 2.1 “setting the scope” of Deliverable 2.1. The scope was loosely set, but did define a clear focus area for the search work: “alternative propulsion or energy saving pilots on life-size vessels in real operation, world-wide, but not oceangoing, with a first focus on recent pilots”. The meaning of the word *pilot* in SYNERGETICS is also defined in this focus area statement: (testing of) alternative propulsion or energy saving on life-size vessels in real operation.

The result of the Task 2.1 work is the T2.1 Pilot Database, containing over 185 identified potentially interesting pilots. Task 2.2 had the mission to evaluate the most interesting past pilots within the database. Therefore, Task 2.2 research and results are heavily shaped by the contains of the database.

In general, this is deemed to be acceptable as it matches the description of the second work package and its tasks inside the grant agreement. It is, however, vital to understand that the executed research was done on pilots and not on alternative solutions. The pilots were used to draw lessons learned and conclusions (if at all possible) about the alternative solutions that were demonstrated by identified pilots- instead of using pilots as supporting evidence in a more theoretical study on a set of techniques. This distinction is critical, since it explains the absence of certain techniques or alternative solutions from this research. It also explains the relatively small attention for technology readiness levels or TRL: after all, the focus on pilots means that all discussed solutions have been demonstrated and are thus on similar TRL levels.

As can be seen in D2.1, energy efficiency pilots have barely been identified. Therefore, these technologies are not wholly and fully represented in the research. Only a focus could be laid on the types of solutions that happened to be identified as tested in a pilot. A reason for this might be these solutions are less heavily promoted and subsidized if they are implemented, thus by owners and operators more likely to be seen as standard optimizations and not as pilots or demonstrations. More extremely, techniques that have reached market readiness, such as many aftertreatment solutions and certain biofuels such as HVO, are fully excluded, and the exact same is true for all drop-in solutions already available on the market. After all, these solutions have already been researched to a large extent and scarce time and resources are better used elsewhere. An exemption to this rule is LNG: LNG pilots are included in the research to learn from the rising and decreasing of the LNG trend- which has valuable lessons in store for other solutions. However, no conclusions about the potential of LNG have been drawn: it’s use case for greening the fleet has already been discussed in many earlier reports.

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2.2 Pilot Evaluation Forms

The evaluation of Pilots identified and assessed under Task 2.1 has been structured by way of the Pilot Evaluation Form (PEF). The PEF acts as a way to store the obtained information and guides the researcher through different questions that might give valuable and insightful answers regarding the pilot. The PEF has been made during multiple iterative sessions where Work Package partners decided together on the possible fields of interest and specific questions to include. Partners of WP 2 were able to use their experience in obtaining information for research purposes from actors through interviews, workshops and desk research.

Fields of interest included in the final version are:

- General Information (name, timeframe, location etc.),
- Vessel Type (dimensions, type, load capacity etc.),
- Journey Characteristics during Pilot (# journeys, description of journeys),
- Pilot Information (about the tested innovation),
- Implementation Issues (about technical implementation),
- Regulatory Pathway (about the regulatory framework and permissions needed for the pilot),
- Business Case (costs, benefits, etc.),
- Replication Potential and Other (to catch any lessons learned outside the above categories).

Guiding the research in this way, the PEF can act as a guide for interviews, desk research and workshops, and in general to store the obtained information per pilot. Although the PEF is relatively extensive in its fields of interest and questions, it was not the expectation to fill every box it contains. Many pilots lack desirable information for multiple of the fields of interest, or specific questions cannot be filled due to sensitivity of the information. The general lessons learned of the pilot are the key target of the work in Task 2.2 and these can mostly be obtained and filled in the relative box in the PEF.

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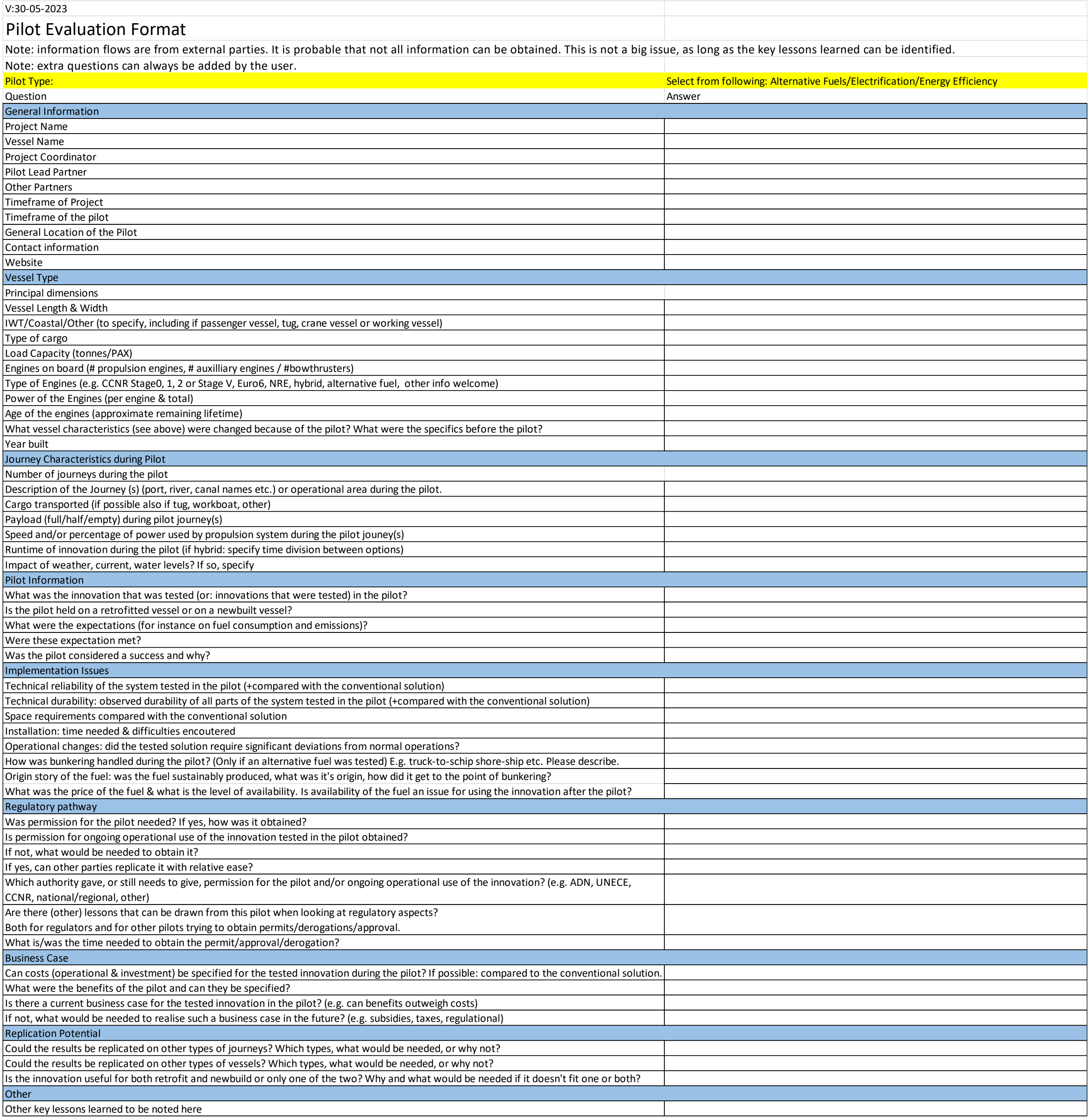

V:30-05-2023	
Pilot Evaluation Format	
Note: information flows are from external parties. It is probable that not all information can be obtained. This is not a big issue, as long as the key lessons learned can be identified.	
Note: extra questions can always be added by the user.	
Pilot Type:	Select from following: Alternative Fuels/Electrification/Energy Efficiency
Question	Answer
General Information	
Project Name	
Vessel Name	
Project Coordinator	
Pilot Lead Partner	
Other Partners	
Timeframe of Project	
Timeframe of the pilot	
General Location of the Pilot	
Contact information	
Website	
Vessel Type	
Principal dimensions	
Vessel Length & Width	
IWT/Coastal/Other (to specify, including if passenger vessel, tug, crane vessel or working vessel)	
Type of cargo	
Load Capacity (tonnes/PAX)	
Engines on board (# propulsion engines, # auxilliary engines / #bowthrusters)	
Type of Engines (e.g. CCNR Stage0, 1, 2 or Stage V, Euro6, NRE, hybrid, alternative fuel, other info welcome)	
Power of the Engines (per engine & total)	
Age of the engines (approximate remaining lifetime)	
What vessel characteristics (see above) were changed because of the pilot? What were the specifics before the pilot?	
Year built	
Journey Characteristics during Pilot	
Number of journeys during the pilot	
Description of the Journey (s) (port, river, canal names etc.) or operational area during the pilot.	
Cargo transported (if possible also if tug, workboat, other)	
Payload (full/half/empty) during pilot journey(s)	
Speed and/or percentage of power used by propulsion system during the pilot jouney(s)	
Runtime of innovation during the pilot (if hybrid: specify time division between options)	
Impact of weather, current, water levels? If so, specify	
Pilot Information	
What was the innovation that was tested (or: innovations that were tested) in the pilot?	
Is the pilot held on a retrofitted vessel or on a newbuilt vessel?	
What were the expectations (for instance on fuel consumption and emissions)?	
Were these expectation met?	
Was the pilot considered a success and why?	
Implementation Issues	
Technical reliability of the system tested in the pilot (+compared with the conventional solution)	
Technical durability: observed durability of all parts of the system tested in the pilot (+compared with the conventional solution)	
Space requirements compared with the conventional solution	
Installation: time needed & difficulties encoutered	
Operational changes: did the tested solution require significant deviations from normal operations?	
How was bunkering handled during the pilot? (Only if an alternative fuel was tested) E.g. truck-to-schip shore-ship etc. Please describe.	
Origin story of the fuel: was the fuel sustainably produced, what was it's origin, how did it get to the point of bunkering?	
What was the price of the fuel & what is the level of availability. Is availability of the fuel an issue for using the innovation after the pilot?	
Regulatory pathway	
Was permission for the pilot needed? If yes, how was it obtained?	
Is permission for ongoing operational use of the innovation tested in the pilot obtained?	
If not, what would be needed to obtain it?	
If yes, can other parties replicate it with relative ease?	
Which authority gave, or still needs to give, permission for the pilot and/or ongoing operational use of the innovation? (e.g. ADN, UNECE, CCNR, national/regional, other)	
Are there (other) lessons that can be drawn from this pilot when looking at regulatory aspects? Both for regulators and for other pilots trying to obtain permits/derogations/approval.	
What is/was the time needed to obtain the permit/approval/derogation?	
Business Case	
Can costs (operational & investment) be specified for the tested innovation during the pilot? If possible: compared to the conventional solution.	
What were the benefits of the pilot and can they be specified?	
Is there a current business case for the tested innovation in the pilot? (e.g. can benefits outweigh costs)	
If not, what would be needed to realise such a business case in the future? (e.g. subsidies, taxes, regulational)	
Replication Potential	
Could the results be replicated on other types of journeys? Which types, what would be needed, or why not?	
Could the results be replicated on other types of vessels? Which types, what would be needed, or why not?	
Is the innovation useful for both retrofit and newbuild or only one of the two? Why and what would be needed if it doesn't fit one or both?	
Other	
Other key lessons learned to be noted here	

Figure 1: a snapshot of the Pilot Evaluation Form

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2.3 Desk Research

The primary way of evaluation for pilots was desk research building upon publicly available knowledge for the case. Often, this led to suitable evaluation results. Many pilots being part of either EU-funded projects (Horizon2020, Horizon Europe, CEF, Interreg or others), or being nationally funded, have significant libraries. In these cases, deliverables evaluating the pilot were often available. It stands to reason that publication of pilot results under (EU-)funded projects was an enabler of the work in this work package. However, even if funded by subsidy programmes as mentioned above, often data on key KPIs could not be obtained. Projects without these requirements often displayed an even sparser stream of information.

It is also interesting to note that negative results (failures) often are not adequately communicated let alone explained in detail. It is observed that innovation projects funded by governments are mostly bound to reach certain objectives. They are therefore not free to explore failed experiments/demonstrations, but have to switch time and effort away to other ways of completing their objectives if a part of the project fails. This is concerning since other projects stand to learn a lot from failures in their predecessors (as was found in the rest of this research).

2.4 Interviews

If not enough information could be collected from the desk study, or if it was judged that direct contact would gather more or better information, an interview was sought. In total, over a dozen interviews were held that were able to significantly enlarge the pool of information flowing from the desk research. In one case, the interview overturned information that had been wrongly displayed online (this concerned a nationally funded project from before 2010, where no central repository of data was active anymore). In this and similar cases, interviews proved interesting sources for information, recommendations and lessons learned. The PEF was used during interviews as both guide and storage point of responses.

2.5 Workshops

Workshops were used to lay contacts to pilots which were later interviewed, to retrieve information from pilots and to exchange information between the project, pilots and between pilots (this last part is a key aspect of Task 2.3). Although it was planned at the very beginning of the Work Package to use workshops for extraction of information, similar attempts in other projects and the first workshops confirmed that this idea was lacking. In workshops, even smaller ones, parties are not always willing to go in sufficient depth for the needs of this task, because of the confidential nature and business sensitive information. Therefore, the focus was changed to getting into contact and obtaining surface-level information to later set steps to gather more information by a combination of interviews with individual parties and a desk study. This approach has worked well, as persons addressed during the workshops were subsequently more willing and open to participate to interviews and providing information for desk study purposes.

During the SYNERGETICS mid-term conference in November 2024 in Brussels, Task 2.2 was able to have a workshop reflecting on lessons learned with pilot operators both in the audience and on stage. The results also contributed to this deliverable. Furthermore, the results of research from Task 2.2 were validated in another workshop with stakeholders including Advisory Board members online in October 2024. In both workshops, researchers were able to show research outcomes and to get feedback on this. This both led to valuable input and general validation of the results.

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2.6 Data handling, ethics requirements and obtaining sufficient results

The Pilot Evaluation Forms have been filled with information that was either available publicly online or that was obtained during an interview. The interviewees were aware of their rights regarding ethics requirements. Their names and contact details have not been stored as the information is only relatable to a certain pilot on the Pilot Evaluation Form. It was also clear to the interviewees what would happen to the information they provided. Furthermore, communication about obtained information will only be done in an anonymised and aggregated matter. Like this, no sensitive information needs to be handled and all ethics requirements are obtained. Therefore, the copies of all Pilot Evaluation Forms are stored safely on the SYNERGETICS data handling platform- but will not be made publicly available. This means they are also omitted from this deliverable.

As explained above, obtaining sufficient results required some shift in approach early on in the work package. At the end of Task 2.2 however, roughly 50 Pilot Evaluation Formats have been filled, leading to a rich source of information to discuss in this deliverable.

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3. | Pilot Evaluation & Lessons learned

3.1 Overview of evaluated pilots

During the identification phase in Task 2.1, 185 pilots had been identified, with roughly 70 of them being assessed as potentially relevant for SYNERGETICS regarding type of innovation. Of these, at the moment of writing, 50 pilots have been evaluated by way of the Pilot Evaluation Format as described above. Of these 50, 29 are closed pilots clearly finished and therefore held in the past – even if the vessel is still sailing with the innovation.

The other 21 are ongoing, or have not yet started. It stands to reason that not every desired pilot could successfully be evaluated. In general, most pilots funded through an EU funding programme had some kind of paper trail and contacts for possible interviews available to be found online. A lot of pilots that were locally funded, or where the funding source was unclear or private, did not offer these resources. This made the evaluation of these pilots more challenging and correspondingly, pilots that have information and contact points available online were evaluated more extensively and (especially) with more satisfying results.

The 21 ongoing or future pilots (and ongoing and future pilots that have not been reviewed yet) are the direct subject of study in Task 2.3, and will be discussed in the upcoming deliverable D2.3. However, since their evaluation is already completed it must be clear that the relevant results also have been used underlying in this deliverable. After all, even though this deliverable focusses on learning from past pilots, it is not the goal to focus too much on lessons learned that will be overturned by ongoing pilots in D2.3.

In this set of 29 past pilots, IWT vessels form a slight majority (15) over coastal vessels (14), with the majority of pilots being held on relatively small vessels both in coastal shipping and IWT. Regarding innovation type, most pilots evaluated (16) target alternative fuels (Methanol ICE, Hydrogen ICE and Hydrogen Fuel Cell applications), 11 focus on electrification of the propulsion and only 2 target energy efficiency. These results are globally in line with the results presented in the 2024 SYNERGETICS TRA paper, and discussed in Deliverable D2.1. A broader discussion of the reasons for these statistics has been included in D2.1 and will not be repeated here.

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3.2 Lessons learned from Past Pilots

Lessons learned have been structured along the types of innovations: electrification-, alternative fuels- and energy efficiency pilots, to get a clear understanding of the situation per type.

3.2.1 Electrification Pilots

Electrification Pilots cover all activities where power is delivered by electricity, either in fixed- or swappable battery packs on board. In general electrification is mostly seen for small craft covering smaller distances, while in more recent years also larger craft (mostly IWT) are using electricity for their propulsion in very small numbers. Especially concepts using swappable batteries in containers are popular for larger IWT vessels – albeit still in the early stages of uptake. It is of importance to note that electric sailing is technically possible for almost every vessel class. However, constraints in the operational profile (e.g. the relatively low range of autonomy), vessel dimensions and most prominently the business case led to significant problems in the roll-out of this technique.

A trend, that is important to note, is the usage of batteries in vessels that (are planning to) use alternative fuels to deliver the power for their electric drivetrain. Pilots found that were (planning to) operate on fuel cells, usually with hydrogen, often use fixed battery packs for reasons of peak shaving, redundancy and hotel-load. Some pilot vessels found are not in the phase of fuel cell usage yet and currently use the battery pack in combination with diesel generators. In this set-up there are a small number of vessels (both in IWT and Coastal Shipping) that can sail up to four hours without direct tailpipe emissions due to the usage of the battery pack on board. Similar systems can be used to cut emissions when the vessel is moored on a location without onshore power supply. The key lesson here is that there is not always a clear boundary between electrification and alternative fuel pilots. If the vessel uses an electric drivetrain, some kind of battery solution is often used.

The use case for electricity in both coastal shipping and IWT is tough, although certain types of vessel owners might find it more suitable than the majority. The main issue here are the investment (CAPEX) costs. To sail on electricity a vessel needs an electric drivetrain, a battery (storage) on board and a way to get electricity on board. The first two have a high impact on the CAPEX: battery costs are still reported as very high, and in practice very difficult to finance for vessel owners (barring small craft such as daytrip vessels and ferries), retrofitting a standard mechanical drivetrain to an electric drivetrain is also expensive. Furthermore, there is no plug-and-play electrical drivetrain available, both for retrofit and for newbuild, so during the installation phase a lot of testing of interactions between subsystems is needed. This process is by pilot operators seen as complicated, time consuming and very costly. Discussions with pilots and installing parties gave a clear image: often, retrofitting a mechanical drivetrain to an electric drivetrain is so expensive that costs rise above the current value of the vessel. In principle, this makes it impossible to finance a retrofit at most banks – unless other stakeholders like shippers or governments take steps to support the project (e.g. subsidies, contract types). Storage room for electricity (batteries) on board is also an issue. Electricity offers less autonomy for the same storage volumes compared to the commonly used fossil fuels. This means that either more storage space is required to travel the same distance or more frequent refuelling (recharging) is needed Since space is constricted on many vessels, the capacity for energy storage on board will be decreased and many more bunkering (charging) stops will have to be developed. Charging electricity will also be more time consuming than the current bunkering process[1].

Operational costs (OPEX) are more bearable, it is even possible that electricity will become cheaper per generated kWh than fossil diesel in the near future. Especially maintenance costs are reported as lower than regular fossil maintenance costs in several pilots. However, the large CAPEX costs will still hamper the uptake a lot since the difference will most probably not be stable (fossil fuel prices depend on the

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[1] Three to four hours are reported for one specific pilot: https://www.portofrotterdam.com/en/news-and-press-releases/first-fully-electric-inland-vessel-to-sail-with-zespacks-in-april-2024

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volatile oil market). Furthermore, fossil diesel for IWT vessels is in most countries exempt from taxes that are implemented for electricity. Although the tax on electricity is not that high, this does create an uneven playing field.

An interesting business model is the *Energy As A Service* (EAAS) concept that is currently used by one company[2] and has been the focus of study in EU Funded projects. The model entails that instead of buying the costly batteries needed for electrical operation, vessel owners rent these from a central company that handles the procurement, maintenance, repairs, insurance, and logistics that appear once batteries need to be delivered on board. The common scenario is to use twenty-foot containers ("battery containers") so handling can be done by standard container equipment. The company Zero Emission Services is operating such a business model and is rolling it out with support from the Dutch Government. Key points of attention are the need for a network of points where empty containers can be swapped with full ones and where empty containers can be charged from the grid. The congestion on the Dutch electricity grid is making it hard to open these points as fast as wanted. The model with containerised batteries in combination with energy as a service seems suitable for uptake in vessel segments that sail fixed trips between two or more container terminals. Vessels that have large periods of downtime (idling) can make use of charging from shore, which takes a long time, but only if the location of their idling is equipped with suitable charging infrastructure.

Ferries transversing small distances (like in IWT, but sometimes also relevant for coastal ferries) can make use of solutions that charge batteries during on- and offloading of passengers. This solution is in use in the Netherlands where a couple of ferries are equipped with batteries. They start the day fully charged, then get charged a little each time they are on- and offloading and at the end of the day they have just enough electricity left to reach their overnight quay where they are charged fully again for the next morning. Diesel generators are installed, but only in use for situation with strong winds, so usually the ferries are 100% electric in operation.

Similar solutions are in use in coastal shipping, for instance to transverse the 4 km Kattegat, where the world's largest battery ferry is operating. Although technically impressive, this way of operating needs a lot of investments in batteries and charging infrastructure and is not economically feasible for every ferry route. In the Kiel fjord and several other locations, pilots have been found on ferries that only recharge at night which leaves room for one central charging location. Ferry pilot operators also specifically point out the noise reduction benefits offered by electrification.

Generally, of smaller size, daytrip vessels, often offering small cruises across lakes or through cities have been the pioneers of electrification efforts in coastal and IWT shipping. A large number of pilots has been conducted using these types of vessels. The main takeaway here is the technical feasibility, especially when vessels are small and make relatively small roundtrips around the same stop- and starting point due to which the central point can be used as the charging location. Yet, funding for both the vessel and the charging infrastructure is still often necessary to start a pilot. The pioneering in this subsector has also underlined the importance of the timing in uptake of vessel and charging infrastructure. There are some instances of vessels that had to stop operating because there was no more funding (or no business case) for the charging infrastructure. This is especially relevant since in cases of early uptake, charging infrastructure usually has a very limited customer base. As with ferries, pilot operators in this segment underline the added benefit of noise reduction due to electrification. Sometimes, this is the reason for incentives to electrify by local governments.

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[2] Zero Emission Services, based in the Netherlands: https://zeroemissionservices.nl/

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3.2.2 Alternative Fuel Pilots

3.2.2.1 LNG

SYNERGETICS partners have been involved in the LNG uptake phase in the last decade, which has led to valuable lessons learned. Specifically, task leader SPB has been the coordinator of the CEF-funded LNG Breakthrough project[3]. Here, partners worked together to equip three vessels with LNG powertrains and to realise a bunkering station for LNG. The project ended in 2020, but SPB has kept contact with the partners, including vessel operators using LNG. This has led to valuable knowledge that is interesting to include in this deliverable. Even if LNG has not become established for large shares of the fleet and it is still a fossil fuel, the process concerned the introduction of an alternative fuel requiring a different energy storage on board of vessels, new technical regulations, different energy convertors and also providing new bunkering facilities and infrastructure. These types of changes and the processes are also applicable for the introduction of renewable fuels such as hydrogen, methanol and swappable battery containers. Therefore, there will be a lot of learning potential.

The reason LNG is not used as much as foreseen currently is a mix of reasons: first of all, the operational cost benefits (OPEX) of LNG dematerialised in the startup phase due to falling oil prices. This led to waning interest as there was no return on investment anymore to offset the investment costs (CAPEX). Second, investment costs are significant and, third, emission reduction was negatively impacted by methane slip. Currently, only a couple vessels are known as sailing on LNG, with some vessel owners even converting the vessel back to a standard diesel drivetrain. Regarding the energy transition, it is however foreseen that fossil LNG can be replaced or blended with renewable methane, such as Bio-LNG on the short/medium term and e-LNG on the medium/long term. Therefore, the investments and efforts made to introduce LNG in inland navigation and coastal shipping shall not be seen as stranded assets or wasted time and money as they can apply drop-in renewable Bio- or e-LNG to decarbonise the operations using methane as fuel.

The main lesson to be learned are the infrastructure-, or bunkering-, issues that operators of LNG vessels are facing currently. From the start of LNG uptake in Inland Waterway Transport, LNG has been delivered to vessels by truck. Truck-to-ship bunkering required little investment from the fuel supplier (no fixed bunker equipment) but available quays, local permits for LNG bunkering on said quays and a flexible schedule of the truck are significant operational and legal requirements. In the startup phase of LNG uptake, both fuel providers and local regulators were enthusiastic about LNG and wanted to offer these necessities to barge operators.

Currently, enthusiasm for LNG in IWT as a fuel to reduce emissions has fallen and oceangoing vessels still using LNG are serviced by ship-to-ship bunkering and/or fixed bunkering points; this led to less attention for the (renewal of) local permits for LNG handling on quays. Ergo, less locations are now available to bunker LNG from a truck. Fuel suppliers however are past the start-up phase for LNG supply, even though LNG never really "took off' for IWT, the suppliers of LNG have achieved a relative match between supply and demand. In practice that means that they have just enough means of transport available to satisfy the demand, so the trucks servicing customers have schedules that are much tighter when compared to a few years ago. This means that to get LNG delivered on board, a vessel operator has to allow for much more lead time than before. In practice, suitable quays for truck-to-ship bunkering have decreased and the bunker appointment has to be made weeks in advance now. Since a lot of vessel operators do not know exactly where the vessel will be in even a couple of days, this way of bunkering has become operationally challenging.

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[3] https://lngbinnenvaart.eu/

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The above teaches us that the step to fixed infrastructure for alternative fuels shouldn't come too late, since there are multiple factors that could decrease the usability of start-up bunkering solutions such as truck-to-ship bunkering relatively fast. Also, the uptake of the alternative fuel in question itself can lead to a bottleneck since the schedules of truck-to-ship bunkering solutions can fill up fast when multiple vessels adopt it – or when an alternative fuel gets adopted by another market entirely. This underlines the necessity for joint uptake of vessels and bunkering infrastructure.

3.2.2.2 Hydrogen

As early as 2008/2009 initiatives were found where relatively small passenger vessels such as round-trip vessels were converted to Hydrogen Fuel Cell applications in the Netherlands and Germany. Technically, these pilots faced little to no serious issues and successfully implemented the technology (even if it was complicated and took time to correctly implement) – the crew usually needed a minimal amount of getting used to the electrical drivetrain and the solution took up a lot more space than conventional diesel applications but no further issues were reported. Apart from their size and operational profile these pilots had another thing in common: the reason for eventual failure.

Although operational for many trips, in the end these pilots failed because the bunkering solution halted operations. In Germany, a bunkering solution for a pilot vessel called FCS Alsterwasser was realised with public funding, but after the funding period ended, no business case could be made to keep the bunker point up and running for just one customer. In the Netherlands, hydrogen bunkering for a pilot was realised in conjunction with the refuelling of hydrogen powered city buses. However, these buses stopped operating, which led to ceased bunker point operations as well. Both examples never found a replacement to deliver hydrogen on board of the vessels. These examples underline the importance of the robustness of the bunkering solution, preferably including fallback options. For the evaluation of current business cases these older examples are less relevant due to price fluctuations and inflation since the time period. However, it can be noted that these pilots were heavily funded by governments and one vessel most probably got the hydrogen delivered at a loss by the supplier to showcase possible market uptake.

More recently hydrogen was proven as technically viable once more by several pilots. The very recent developments of hydrogen in common-sized IWT cargo vessels will be covered by D2.3, which focusses on current and future pilots. The pilots in the timeframe of this report happened in the coastal sector, where dual fuel solutions of hydrogen in combination with common diesel in dual fuel internal combustion engines was demonstrated. In these cases, the percentage of hydrogen used can be relatively high but will not reach 100% due to the need of diesel as a pilot fuel. These dual fuel solutions excellently fit the SYNERGETICS scope, however. As with the earlier hydrogen applications discussed above, technical implementation was not seen as a large hurdle. The technique of dual fuel engines and all necessary changes on board such as hydrogen fuel tanks, piping, etc proved to be reliable. However, some issues were found, for instance the lifetime (number of filling cycles) of hydrogen cylinders which negatively adds to the business case. The energy density at 350 bar was seen as troublesome to operations: higher pressure storage was noted as a possible positive impact on operational implementation. Touching upon this subject, specialised companies to install and service hydrogen applications were not always easily found. The bunkering solution often depended on one or a few options, but apart from the costs of getting hydrogen delivered, it was not reported as a hindrance for uptake at the moment.

The largest hindrance for uptake found was the business case. This goes both for the pilots described directly above as for a couple of pilots that failed to materialize because of a failing business case, the latter are mostly observed in IWT. All hydrogen-related pilots report high costs. CAPEX costs are high because investments needed to install on board are very expensive, combined with the fact of rising costs for any technical services on vessels, this makes the business case very hard.

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One pilot operator outlined an example of why this is so expensive for fuel cell applications, even when the vessel that was retrofitted already had diesel electric propulsion: Since power delivered by the Fuel Cell is DC and power needed by the engines is AC, a DC-AC converter had to be installed. Since the solution worked only when power from the Fuel Cell was stored in a battery pack before being distributed to the electrical engine, a battery pack and a cooling installation for it had to be installed. Also, the main switchboard had to be remodelled and many safety measures (fire extinguishers, fire pump) had to be installed. Sensors for safety parameters were also needed. In general, these systems are relatively complex and thus expensive. To these already costly investments, the costs of the fuel cell itself and hydrogen storage solutions should still be added. CAPEX for hydrogen ICE installations is reported as a little less high, but still hurting the business case a lot.

OPEX is for hydrogen pilots usually also still a very negative element in the business case compared to fossil operations. Hydrogen costs were reported as between €8 and €20 per kilogramme of compressed H_2, and in the eyes of many pilot operators need to fall significantly still if a business case is to materialise. In terms of the caloric value, this equals a price of 6.6 – 16.6 eurocents per MJ while the price for diesel (EN590) for inland or coastal vessels is currently around 1.6 eurocents per MJ. Powertrains using fuel cells may be a bit more energy efficient (e.g. 55% efficiency for fuel cells vs 40% efficiency for diesel engines); this slight advantage obviously does not close the gap of 400% - 1000% higher energy prices compared to diesel fuel per MJ.

For this, pilot operators point to the possibilities of accelerating the supply chain of hydrogen and to governmental policies closing the price gap with fossil diesel.

One operator reports that for both OPEX and CAPEX hydrogen operations (fuel cell) were estimated to be twice as high as fossil diesel operations. Although another reported far smaller differences for OPEX: 26%. It could not be made clear however, how these comparisons were made and if they are correct and valid. Moreover, possibly, further energy savings could be achieved in the operations of hydrogen fuel cell drive vessels, for example by means of reducing sailing speeds which can have a dramatic impact on the required power and energy. In any case, the conclusion is that sailing with hydrogen is much more expensive. Getting commercial clients to pay for the price difference is a recurring issue and has led to failure (sometimes before even starting) of many pilot projects.

More modern hydrogen solutions in IWT as discussed directly above sometimes (plan to) make use of swappable containers that can be easily handled by a container terminal. This solution is reported as very suitable for the initial phases of uptake and later operational phases. However, complicating factors exist. First it was reported that containers being moved by both truck and vessel would be held liable for dangerous goods standards for both road (ADR) and maritime transport (ADN) – this was reported as a hindrance that can be worked with, but still something to take due note of. Another issue is the availability of locations to swap this container, it is already reported that users of these containers actively avoid busy terminals since there they will not find available handling spots for the swap. Preferably, less busy terminals are used where a truck can easily be arranged to get alongside the vessel and be handled by the terminal cranes for the swap. Currently and for the near future this seems a good solution. However, the fact that users already avoid certain terminals raises questions of the durability of this approach in case of larger uptake.

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Regarding regulation and safety, it needs to be noted that in IWT a derogation is needed for hydrogen applications. This is a significant process and operators report that it is of key importance to move to clarity regarding needs and requests (processes, technical constraints, safety measures) from all involved authorities (National, CCNR, EU and Class Societies) as soon as possible. It should also be noted however that guidelines for hydrogen implementation on IWT vessels are available[4] and regulation upcoming in the coming years (ES-TRIN 2025). One pilot operator further reported that they could find no training available for crew for hydrogen operation on board, it is reported by inland regulatory bodies that working groups (CESNI/QP) are working on this.

3.2.2.3 Methanol

During the last decade, methanol used in dual fuel internal combustion engines has seen a significant uptake mainly in deep-sea-shipping (which is outside SYNERGETICS' scope). Also, in coastal shipping (under IMO regulations) similar innovations have been piloted and are currently in operation – some of them reported running hours already far over 10,000. In IWT, rules and regulations for methanol usage are partly available (e.g. ES-TRIN methanol requirements are published and will enter into force on 1.1.2026). However, the regulatory barriers from the side of the NRMM regulation were reported to induce hurdles for bringing a methanol engine of any kind on the market for IWT vessels. The NRMM regulation[5] excludes Methanol as a reference fuel for engines brought on the market. Therefore, the only suitable option[6] would be, to use the route of a provisional certificate through the member state. However, it seems the European Commission is currently recognising unregulated pollutions from methanol. This considers formaldehyde emissions. The lack of emission limits for formaldehyde makes it difficult to ensure appropriate environmental protection in accordance with the regulation. Currently there seems thus little reason to expect that methanol engines will be available for IWT in the short term. Related to the above, only few pilots demonstrating methanol in IWT were found.

One of them was successful after converting an existing CCNR-2 certified engine to operate on Methanol with fossil diesel as pilot fuel. The results were similar to the observed pilots in coastal and deep-sea shipping. It was also noted that the engine was quite easily converted. However, large issues are found with the regulatory framework: In principle, converting an existing engine to methanol would make it lose its current engine certificate. Then, new certification would be mandatory under current regulation (NRMM Stage V). This process is, as described above, currently practically impossible. The evaluated pilot however was able to obtain permission to convert the engine under the existing CCNR-2 certificate. It is highly unlikely that this "route" of bringing methanol to the IWT fleet is suitable for uptake outside of a minimal number of research demonstrations. More information on methanol engines suitable for IWT can be found in SYNERGETICS deliverables D1.1, D3.16 and D3.17.

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[4] CESNI approved guidelines in October 2024: https://www.cesni.eu/en/actualites/cesni-meeting-on-17-october-2024/

[5] https://eur-lex.europa.eu/eli/reg/2016/1628/oj

[6] There exists another option through Article 34 of the regulation where the engine placed on board remains the property of the engine manufacturer. This is deemed not suitable by most stakeholders for large scale roll-out, but only in case of a demonstration. One key issue here is that the manufacturer must remain the owner, but most vessel-mortgages will require that engines and similar installations that are "fixed" on board are part of the collateral of the mortgage. Therefore, the manufacturer runs a lot of risk in case the vessel owner would default on the mortgage: the bank could lay claim on the vessel, including the engine.

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As stated above, the dual fuel internal combustion engine is the general application of methanol encountered in deep-sea and coastal shipping. Only a minimal number of pilots of methanol fuel cells were found[7]. Dual fuel engines encountered needed at least a few percent of common fossil fuel (MGO) as pilot fuel (or ignition improver). Commonly 5% was seen as the minimum, but one operator reported being able to use 3% MGO as pilot fuel and operating smoothly. Higher diesel percentages are observed over the entire operational range, but we can conclude high percentages of methanol (up to a maximum of 95-97%) are possible. Methanol dual fuel engines are usually based on marine engines that are already widely used, which is beneficial both in costs, time to market and crew training for the engine. Some operators even reported that the used dual fuel engines could run on other combinations than a Methanol-MGO split, for instance LPG and LNG were mentioned. This would allow the operator a relatively easy switch to a different set of fuels if circumstances would demand it. Similarly, operators report seamless switching between common fossil fuel and methanol.

When green- or bio-methanol is used, this will largely reduce the carbon footprint of the vessel operation. However, it was reported by operators that bio-methanol is still not widely available and therefore many times regular (fossil) methanol was used. It stands to note that in this case, carbon is still emitted at a significant level. Another issue found for some engines was the dependence on methanol with a very high level of purity, something that is also not always widely available. Bunker opportunities for fossil methanol, however, is perceived as readily available and not significantly more complicated than diesel bunkering when crew is acquainted with the safety precautions.

The business case of dual fuel methanol engines seems relatively positive, especially when compared to some other options to decrease carbon. CAPEX-wise, large investments are needed. First, the engine is costly, not many data was disclosed about costs. One operator estimated engine conversion costs around €350,000-€450,000 per MW. Further investments would be needed regarding installation. For instance, in addition to acquiring a fuel tank, the piping on board usually needs to be replaced with heavier and double walled pipes and the valves need to be refined to be suitable for methanol’s higher pressure. These tanks and pipes need to be made from stainless steel and tanks will generally need to be bigger since twice the volume of methanol compared to fossil diesel will be needed for the same operational autonomy. Again, not many clear numbers for total CAPEX costs were found, but there are indicators that the CAPEX here is more bearable than other greening solutions.

OPEX costs rely on fuel costs and maintenance. It was reported that fuel costs for bio methanol are still more expensive than fossil diesel. Maintenance regimes were reported to change, which could lead to extra costs. However, sometimes better efficiency (or at least equal efficiency) compared to diesel engines was reported. It seems that even though the costs look relatively bearable there is currently still no business case. However, the flexibility of dual fuel engines, combined with the apprehension regarding upcoming regulations increasing the costs of emitting carbon, make that some vessel owners already choose this option. If costs for emitting carbon rise, they can easily make the switch to (bio) methanol in the near future.

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[7] Factually, the only such pilot found concerned a system that reformed methanol on board into hydrogen and used that as input for a hydrogen fuel cell. The test found a too high failure rate of the installation and no further pilots or uptake could be observed. This does at the moment not appear as a suitable option for true widespread uptake.

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3.2.3 Energy Efficiency Pilots

Energy efficiency has had the attention of vessel owners and operators for a long time. However, it seems that innovations are not often demonstrated with much publicity. At least, during the identification of pilots performed under task 2.1, only a very small number of energy efficiency pilots were found. Therefore, not many pilot evaluations could be completed. As discussed in D2.1 as well, the question remains if the lack of pilots identified also means a lack of implementation: perhaps vessel owners integrate energy efficiency measures in the design process and forgo the seeking of attention and raising of awareness that usually comes with greening pilots.

Nevertheless, some areas of energy efficiency did draw attention – i.e., could be evaluated and are assessed as interesting in T2.1. First, the area of wind assisted ship propulsion is interesting to note. This technique which entails making use of (favourable) wind conditions when sailing has been widely tested in oceangoing maritime transport. In one instance it was tested on a coastal vessel. Here retractable foils (so-called suction wings) were installed on board and could be used when wind conditions allowed. Cost data could not be obtained, but it was made public that in favourable conditions up to 20% of fuel consumption could be reduced. On an annual basis this averaged out to 6-8% in fuel savings. The crew, however, needs to be made aware when the system can be used and when not. A sensory system is available to automate the evaluation process and alert the crew when the foils can be set up or should be retracted. During the pilot, the vessel sailed on coastal routes in Europe. No pilots of this wind assistance technique for Inland Vessels were found.

Second, the optimisation of the hull design and especially the aft ship can increase the efficiency of the ship. In the last decade pilots were found that were able to design the aft ship and/or the total hull of newbuild vessels in such a way that large percentages of fuel savings could be obtained without reducing payload. Amongst other innovations, experiments with retractable tunnels were held (a tunnel is installed to avoid ventilation of the propeller at low draughts, but the tunnel does not positively influence water inflow during normal river depths).

Furthermore, father-son engine concepts were found beneficial when power demand is spread across two areas of requirement during a journey (e.g. river vs. canal in one journey). It has been reported that a 20% to 32% decrease in fuel consumption has been measured, while one design then also allowed for 8% more cargo to be carried. These innovations were thus able to demonstrate usability and large reductions of OPEX. Initial costs are not always clear, but it stands to reason that there is some kind of business case, especially for design changes at the time of building that reduce OPEX during the entire lifetime of the hull.

Solar panel installation also deserves a mention in this paragraph. Similar to panel installation on houses, many instances have been observed of vessel owners installing solar panels on board. Usually this is done on the roof of the wheelhouse in IWT. The few panels there installed are usually meant to fulfil energy requirements from the living spaces of the vessel and other hotelling needs. Currently there is one dry bulk IWT vessel sailing which has its entire area (including the moveable cargo hatches) covered with solar panels. This allows solar energy to supply the entire hotel load energy requirements (for freight carriers only, passenger vessels' hotel load requirements are still too high), and thus saves fuel, but also brings comfort in terms of noise reduction as often the generator can be shut down.

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More vessels are planned to undergo similar installations, and even coastal vessels are showing interest. If a suitable battery and converter are used, the generated electricity can also be used for vessel propulsion with an electric drivetrain. The business case for this innovation is suitable, but installers report most vessel owners make the investment with the comfort of reduced generator running hours in mind. One installer also provided a very interesting outlook on why the sector often appears hesitant to adopt innovations: after the solar system is installed and tested it can take multiple years for hardware failure to appear. For the installer that means that knowledge on what parts to swap is gathered relatively slowly- and once it is known, the actions should be implemented on all vessels where the system is installed. For the vessel owner this means that the first years of a new-on-the-market system are perceived as risky. After all, if it takes a certain amount of time to earn the initial investment back, but no system has been operating for that amount of time yet, the vessel owner cannot be sure it is a good investment. Therefore, piloting these systems is hard because many vessel owners are positive about the idea, but would like to see it tested for the needed duration before they invest their money in it. This hindrance was first encountered in solar panel pilots, but turned out to be relevant for all innovations in the coastal and IWT sectors.

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4. | Discussion

4.1 Areas of interest

The lessons learned while evaluating interesting past pilots have now been described per innovation type (as observed in T2.1 and as reported in the T2.1 Pilot Database). During the research however it became clear that there are multiple categories that are impacting innovations to green the fleet of each innovation type. In this task they are called areas of interest, and four of them have been identified: *Technical Implementation, Infrastructure, Regulatory Framework and Business Case*. It stands to reason that any pilot that strives to reduce the emissions of a vessel will be impacted by these areas of interest and therefore they deserve specific separate attention. Below can be found a description of each area of interest that strives to give a broad summary of what pilot operators have learned about the area in the past.

4.1.1 Technical Implementation

The area of interest called Technical Implementation is mainly characterized by the denominator of specific limitations per innovation type. As could be read in chapter three, different types of innovations face different types of technical limitations. Below the most critical limitations found by pilot operators are listed.

- **Energy density**: an issue with most alternative fuels (and when using electricity to propel a vessel) is that these fuels carry less energy per measure of volume and weight compared to fossil diesel. This has several implications (more space needed for storage on board and/or bunkering needed more often, more time needed for the bunkering process) that hinder the uptake of these alternative sources of power.
- **Safety limitations**: alternative sources of power such as hydrogen, methanol and battery electricity must be stored under different conditions compared to fossil diesel. In general, the safety considerations can be seen as reachable but, in many cases, they have been known to increase the need for extra systems and procedures- thus having a negative impact on CAPEX costs and on the general operations of the vessel.
- **Retrofitting disadvantage**: existing vessels have not been designed with alternative propulsion solutions in mind. Therefore, to install such innovative systems, often much work is needed to remove old systems and subsystems, to re-lay pipes & valves and remodel the steelwork of the vessel. These works add heavily to the costs of installing innovative solutions and thus contribute negatively to the business case.

These limitations have a negative impact on the business case and infrastructural requirements related to bunkering of alternative fuels. In general, pilot operators see a steady moving pace of the technology on the market improving (getting more energy dense ways of storage, safer and easier to use). However, the pace is not described as particularly fast and not many[8] expectations of positive developmental breakthroughs in the near future were reported. However, it must be noted that the demonstration of many decarbonisation systems in the latter years is a positive development.

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[8] Overall not many, yet batteries might be an exemption.

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Some more interesting lessons learned related to the development of innovative solutions were reported by pilot operators. First, the pace of innovation (for instance regarding the development of fuel cells) could also be delaying interested vessel owners to take the step and start investing in and operating on such systems. The main reported problem was the fact that, if technology developments are fast moving, it is almost guaranteed that a system bought now will be out-dated in a relatively short time span. For vessel owners, this makes the investment decision harder because in principle, this situation makes the system depreciate harder as an asset, thus losing value fast. To this can be added the fact that later movers will have the advantage of a better system and thus immediately have competitive advantages over the early mover. Second, vessel owners have a tendency to be rather reserved in sharing lessons learned from innovations with other vessel owners. This can lead to the situation where each of them has to reinvent the wheel again, which is costly regarding time and efforts (although it must be noted that equipment providers do aggregate knowledge between similar projects and play a supporting role here). Third, hardware failure impacting all systems of a set production date might take years to appear. This means that in the very beginning of the roll-out phase of a system both its lifespan and the maintenance and repairs needed during that lifespan are essentially uncertain. That makes it difficult for vessel owners to make a sound investment evaluation and thus many are hesitant to make the investment. Since later movers would have the advantage of a system that has been tested (by, and at the costs of, early movers) this is again an example of an *early mover disadvantage.*

4.1.2 Infrastructure

Infrastructure appeared as an area of interest during the pilot evaluations because of the changes needed to bunker alternative fuels or recharge electricity. It was often reported that fossil diesel is easy to handle, store and transport and that there is a sufficient network of bunkering points to take it on board. Some operators reported that bunkering is done without stopping as the fuel provider would send out a bunker vessel carrying fuel that performed ship-to-ship bunkering while on the move. Also reported was, that vessels currently bunker relatively infrequently. Apparently, the energy density of fossil diesel provides vessels with such a wide range of operation that bunkering often is an afterthought.

Earlier research[9] and discussion with operators showed that the current bunkering points for fossil diesel are not suitable to offer a full range of alternative energy sources. Drop-in biofuels like FAME and HVO can be delivered by many regular diesel bunker points in the Netherlands and Belgium, but it is not realistic to expect these parties to offer hydrogen, methanol or electricity for instance. The ways of handling, storage and safety precautions are very different compared to fossil diesel, and might not always be suitable for combination on one bunker point.

As explained in the paragraph about technical implementation, energy density and ease of handling of sustainable alternative solutions is often very different. While a vessel sailing on fossil diesel probably bunkers less than weekly, the same vessel sailing on batteries would need to charge (or swap) daily. For hydrogen and methanol, the same issues were found, but in smaller magnitudes.

Generally, the solution used in the evaluated pilots is truck-to-ship bunkering or the swapping of containerised units, sometimes combined. Truck-to-ship bunkering is a suitable solution overcoming the issue that alternative fuels are not yet widely available on fixed bunkering locations. Such fixed locations do exist, but are still often out of reach for vessels when considering their area of operations. Truck-to-ship bunkering is thus suitable, but makes the vessel owner dependant on available quay-space to perform the bunkering, local environmental regulations concerning the movement of fuels and the availability and time schedule of the fuel supplier. A good solution (often the only one) for early uptake of a fuel type, but questions can be raised to its ongoing suitability when the fuel type gets more popular both in and/or outside of the IWT and coastal fleets. A spike in demand can easily disrupt schedules

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[9] See deliverable D4.2 of the PLATINA 3 project. Link for download: https://platina3.eu/download/clean-energy-infrastructure/

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and availability of bunkering trucks. Swapping a containerised solution (battery pack or 'tanktainer') is a relatively new way of operations that attempts to overcome the classical chicken-and-egg problem by making use of existing container terminals to perform the swap. It can in principle be done at all locations able to handle containers and thus opens the wide range of container terminals as possible swapping locations. It can be combined with truck-to-ship bunkering when the fuel supplier brings the containerised unit to the terminal for the swap and directly takes away the empty container coming from the vessel. It stands to reason that this has many of the same issues that were reported for general truck-to-ship bunkering.

A desired state for further uptake, as flowing from the evaluations, would certainly be a growing network of fixed bunkering or swapping points. These locations (for swapping containerised units container terminals might be an option) must however fit certain criteria: the fuel type desired must be brought to the location and stored there. This can be complicated. For instance, for swapping points of batteries, batteries should ideally be charged at the swapping point. However, congestion on the energy grid (observed in the Netherlands) might greatly delay the necessary connections and types of electricity to become available at the chosen location. Storage of large amounts of alternative energy sources (for instance hydrogen) might mean that large safety precautions are necessary.

This leads to the current situation where in general, realising fixed bunkering (or swapping) points takes time, expertise and is seen as expensive – pilots have indeed fallen through when considering these costs. Several pilots, going back to the early 2000s showcase how vital the bunkering solution is to a successful roll-out, with pilots dropping out of successful operations when the bunkering point went out of business.

The above relates to the often-reported chicken-and-egg problem regarding bunkering infrastructure: there is no bunkering solution, so no vessel is going to use the alternative fuel. But if no vessel is using it, no fuel supplier is going to invest to offer a bunkering solution. During pilot evaluation it could clearly be seen that fuel suppliers try to work around this issue by servicing early mover with truck-to-ship services. Steps towards fixed points for bunkering or swapping encountered were usually backed either by governments or by larger undertakings, able to roll out bunkering networks timed to (and necessarily geographically matched with) the uptake of the alternative fuel in the fleet.

4.1.3 Regulatory Framework

The regulatory frameworks of coastal shipping and IWT operations differ significantly. Most coastal ships fall under IMO, with some coastal subsectors falling directly under national regulations. IWT transport falls under EU rules and regulations such as ES-TRIN for vessel safety and the NRMM Regulation for the engines of inland vessels. These environments do have in common the challenge to update the regulatory framework to the needs and wants of vessel owners and -operators facing the challenges of greening the fleets. The regulatory framework is set for the state of the art, and not yet suitable for all innovations – since these and their impacts and requirements are largely unknown yet. A clear example here is the certification of Stage V methanol combustion engines which is not yet possible because methanol is not a recognised reference fuel in the regulations. Also because of the risk of formaldehyde emissions, an impact assessment seems to be required before the European legislation can be updated to enable methanol as fuel for new engines to be supplied to inland vessels. It is expected that this process will take several years. Other examples are in the adjustment of the technical regulations for vessels. Here we see step-by-step updates of ES-TRIN to provide the requirements to make vessels itself ready to use hydrogen and methanol as fuel.

Updating the regulatory framework is in progress for both coastal and IWT, but here regulators are also dependent on pilot projects sharing information. It must be noted that this is not always going as smoothly as hoped for, which leads to slower regulatory implementation than otherwise possible. If the regulatory framework for a specific innovation is not yet set, some kind of derogatory process can be started to obtain (temporary) permission to demonstrate and use the innovation on board of a vessel. These derogations often have a set timeframe, although they might be renewed. If regulations that

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match the innovation are set in place, the derogation holder must be brought under these regulations- but it must be noted that the experiences with LNG showed no major issues here for IWT.

Pilot operators in the further past have often reported the derogation process as time-consuming and complicated. And it is indeed the case that this can take long and that multiple bodies evaluate the proposed design and comment on it. However, multiple pilots reported that with thorough preparation and design, usually involving classification societies at the earliest stages, the process is navigable. As an example for how long this can take, please see the figure below where the Horizon Europe project RH2IWER showcases the time needed to obtain a derogation for hydrogen implementation in combination with a fuel cell in Inland Waterway Transport. Depending on which type of certificate is needed, the process can range from 25 to 72 months.

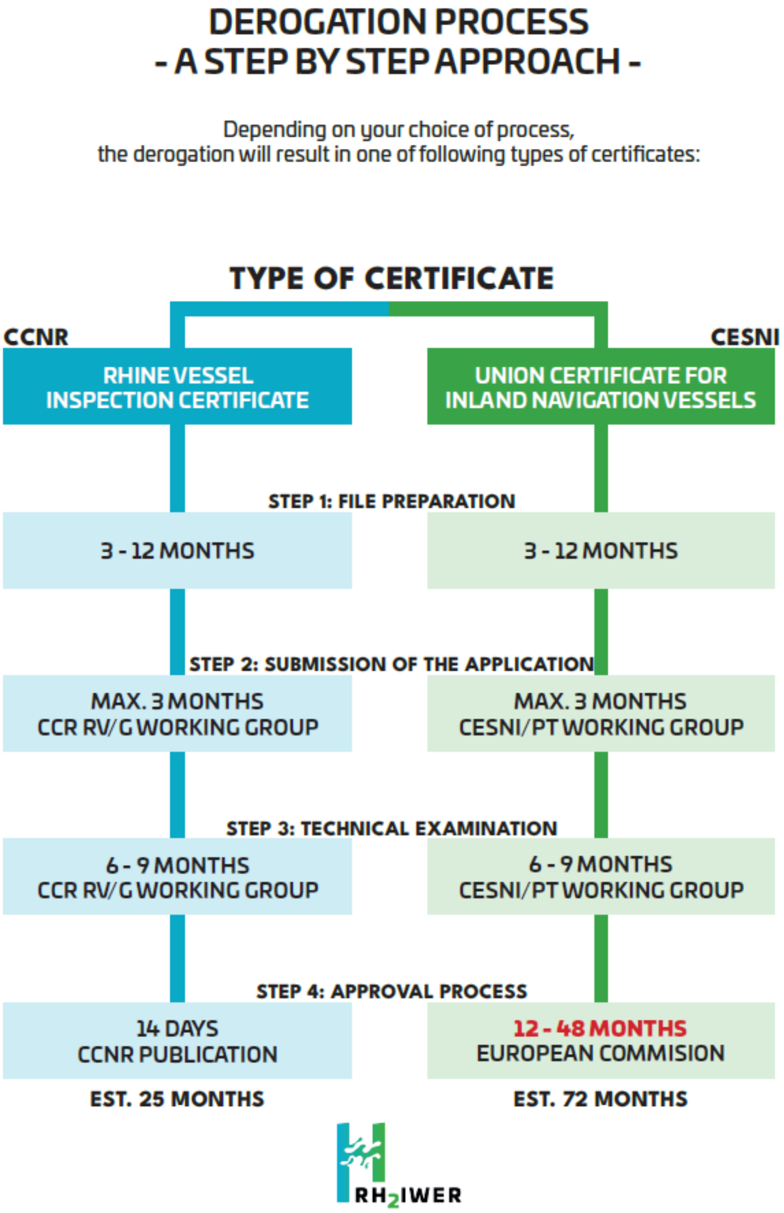

Figure 2 Derogation process for hydrogen implementation. Source: RH2IWER project (rh2iwer.eu).

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In the past, pilot operators reported that the set-up of the regulatory framework took longer than hoped for. Currently, it seems these processes have been sped up and regulations on innovative solutions can be expected in the coming years. In the meantime, the draft requirements are often published by CESNI as interim guidelines, which can be used to assess the safety of pilot vessels more quickly.

Apart from the regulatory framework for the shipping sectors, the NRMM Stage V regulation[10] impacts the availability of engines for the IWT sector. As mentioned, in the current version of the NRMM regulation, the innovative fuel options hydrogen and methanol are not included in the list of reference fuels. Therefore, the only suitable[11] option would be to use the route of a provisional certificate through the member state. However, the European Commission is currently facing difficulties regarding the formaldehyde emissions related to methanol usage and has stated the need for an impact assessment of these emissions to be able to ensure environmental protection when evaluating requests for provisional certificates. Therefore, currently there is no expectation that new methanol engines will be available for IWT in the short term. It might only be possible to modify existing older engines (pre Stage V) which are already certified, such as the Methatug in Antwerp, demonstrated in the FASTWATER project, although this route seems only useful for specific research purposes, so large commercial uptake seems unlikely. However, there is now more awareness on the risk of formaldehyde emissions which further slows down such applications. This hinders the uptake of the application of these fuels in internal combustion engines and explains why methanol pilots are lacking in IWT. This is especially a showstopper for newbuild vessels which are legally obliged to install new (Stage V) certified engines but it also blocks replacing or adapting already installed Stage V engines on board of vessels to have these Stage V engines commercially certified to run on methanol. A quick start of an impact assessment for formaldehyde emissions flowing from methanol to lift uncertainties seems would be a good step in the right direction.

4.1.4 Business case

The final area of interest that arose during the pilot evaluation process is the business case. Evaluating the identified pilots, it first of all has become very clear that the greening decision is an investment decision. For vessel owners that decision is in a vast majority of cases driven by the possibility of earning back the initial investment. Most evaluated pilots could find no suitable business case without government intervention like subsidies or specific demands or regulations. The business case is reported as the major obstacle for greening in any way, shape, or form.

The key aspect reported here is that as long as large parts of the inland and coastal fleets are able to keep operating on fossil diesel without measures to close the price gap with sustainable alternatives, the vessel operators using fossil fuels are much cheaper and thus have a competitive advantage compared to the few vessel operators which are using renewable fuels. Many operators of vessels involved in greening pilot projects noted that this was a significant early mover disadvantage and are heavily in support of imposing governmental measures to close the gap in the business case between fossil fuel operation and operation with renewable fuels.

There are different reasons why costs for greening a vessel are high. The issue can be split along investment costs (CAPEX) and operational costs (OPEX). Investment costs include the purchase of systems and technologies, as well as the work required to install them on board and meet safety requirements. These costs are incurred before the vessel starts sailing (in case of retrofit: starts sailing again). Mostly the work associated with CAPEX costs is carried out on shipyards that facilitate and execute the work and bill the customer for the end product, multiple subcontractors are usually involved. A large part of the issue is the rising costs for any technical services on shipyards (interviewees also reported rising costs for work not related to greening), often described as inflation, and linked to the Covid-19

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[10] https://eur-lex.europa.eu/eli/reg/2016/1628/oj

[11] For the other, less suitable option, see Paragraph 3.2.2.3, specifically footnote 6.

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pandemic and the Russian aggression in Ukraine. It can also be observed that the current capacity of shipyards is overbooked. Whatever the reason, having technical services on a vessel has become far more expensive than just a few years ago, with some pilot operators reporting a doubling in prices over the last decade. When this key issue is combined with the fact that innovatory systems are usually not yet installed in a standardised manner and mostly lack benefits of scale, it can become clear that CAPEX for retrofitting or building a vessel with a decreased carbon footprint is a very expensive business. Good examples are costs incurred to retrofit vessels from diesel electric to fully electric. Without battery costs included a lot of work needs to be done still, cooling and converting systems often need to be installed for instance, with costs often rising over a million euros. Other operators report that in their view, the step from fully-mechanical to diesel-electric would often in costs exceed the value of the vessel – without any truly innovative alternative solutions taken into consideration yet.

Operational costs (OPEX) are incurred during the operation and relate to actions, maintenance and technical services to keep the vessel in operation. While electrical operations – important for battery electric and fuel cell propulsion systems – are said to reduce operational costs due to lower maintenance needs and higher efficiency, many alternative fuels still have significantly higher operating expenses (OPEX) compared to fossil diesel. These prices may fall in the future, but that is outside of the influence of vessel owners and not always easy to include in the investment decision. Pilot operators did report, as stated above, overall support for measures such as the Emission Trading Scheme (ETS) from the EU, and similarly REDIII, FuelEU Maritime and the CSRD regulations were pointed out as positives. These regulations might partially decrease the price gap between fossil diesel and renewable energy solutions. Especially the possibility for Member States to bring IWT under ETS2 could be groundbreaking in bridging the price gap between fossil fuel operations and operations on sustainable alternatives.

Apart from OPEX and CAPEX, vessel owners need long term contracts with customers to finance new vessels. However, the number of potential clients willing to do so, let alone combined with higher costs for greening is perceived as so small that it is barely significant. Clients (shippers of goods) are perceived as operating in a framework designed to decrease costs to obtain the cheapest transportation solutions possible. The ideal customer (a shipper offering a long-term contract and at least partly paying for the extra costs of greening) does barely exist out of a handful of cases.

To overcome this gap, some frontrunners in the sector are starting to experiment with ‘carbon insetting’. Having similarities with carbon offsetting, the idea was first reported to this work package by a pilot operator that had already brought on the market a green vessel, but that could not find clients both willing to pay the “green premium” and able to use the vessel. Clients could be found that wanted to pay extra for the service of zero-emission transport, but these clients had diverse cargo streams that couldn’t be bundled into the same vessel – and each of them on their own had too small cargo streams to fully charter it. This led to the idea of decoupling the physical usage of the vessel to transport cargo and the benefit of zero-emission transport. Selling cargo transportation services of the vessel at regular price levels, physical customers whose cargo was carried by the vessel could no longer automatically claim the benefit of zero-emission transport since they did not pay the price for it. This benefit is to be offered for sale at a digital marketplace where transporters of goods over similar geographical distances can buy these proves-of-carbon-reduction and use them for their own internal carbon reporting, thus reducing their carbon footprint. To credibly do so, accreditation agencies are involved and are monitoring the process. Carbon insetting remains for the moment the most innovative way to tackle on short term the challenging business case for greening the fleet that was identified in this research. The trust in this system must be maintained by independent monitoring. It must however be noted that if an area covered by carbon insetting is brought under regular emission trading schemes, it is unclear whether carbon insetting can be continued on medium term. It might be most suitable to temporarily bridge the price gap until the regulatory framework that does so is in place (such as introduction of REDIII and ETS in inland navigation and coastal transport by vessels below 5000GT).

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4.2 Summary of lessons learned

For an overview and the readers' convenience, a list of the lessons learned including a description, and indications of relevance per innovation type and area of interest is presented below.

1. High CAPEX costs for retrofit & newbuild
    a. Area of interest: business case
    b. Type of innovation: all
    c. Impact on greening potential: negative
    d. Description: Over all innovation types, a trend of rising prices to get work done on vessels is observed. This includes greening practices and normal maintenance or building exercises. Interviewees have reported steep price increases especially since the Covid-19 crisis. A doubling of costs for the same action at a wharf is even reported compared to the last decade. Retrofitting procedures are reported as quickly rising above the value of the vessel in costs in the case of large retrofits.

2. High OPEX costs for alternative fuels
    a. Area of interest: business case
    b. Type of innovation: Renewable Fuels, partially Electrification
    c. Impact on greening potential: negative
    d. Description: Most pilots working on alternative fuels reported higher operational costs compared to fossil diesel operations. Renewable Fuel prices are still significantly higher compared to fossil diesel. The lowest reported price difference was 26%, with multitudes of this being also mentioned – although not many pilots were willing to share these price details.

3. Lower maintenance costs for electrical drivetrains
    a. Area of interest: business case
    b. Type of innovation: Electrification, partially Renewable Fuels if combined
    c. Impact on greening potential: positive
    d. Description: A few electrification pilots reported cost benefits deriving from the electrical propulsion line. This includes specifically lower maintenance costs and (less often reported) higher levels of efficiency of the system.

4. Additional benefits of electric propulsion
    a. Area of interest: technical implementation & business case
    b. Type of innovation: Electrification
    c. Impact on greening potential: positive
    d. Description: Electrification pilots often report high levels of noise reduction when going fully or partially electric. Especially for passenger vessels in the tourist sector, this is a driver of adaptation. In freight transport, it is a driver for innovations that can reduce the generator usage while the vessel is moored such as smaller battery packs and/or solar panels.

5. No plug-and-play electrical drivetrain
    a. Area of interest: technical implementation & business case
    b. Type of innovation: Electrification, Renewable Fuels if combined
    c. Impact on greening potential: negative
    d. Description: Both for newbuild and for retrofit, no standard electrical drivetrain is available. This means that in both cases for all vessels, a lot of details need to be worked out separately and a lot of subsystems have to be matched together through thorough testing and programming. This is time consuming and drives up costs. Although similarities can be seen in ICE drivetrains, electrical drivetrains are seen as more complicated and hence more costly.

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6. Ferries and small craft are suitable for electrification
    a. Area of interest: technical implementation
    b. Type of innovation: Electrification
    c. Impact on greening potential: positive
    d. Description: pilots have showcased widely that relatively small passenger vessels/ferries that execute short roundtrips can be electrified. The solution is either charging during on-and offloading combined with charging after operational hours, or only the latter. This is however expensive and the business case heavily depends on local incentives.

7. Fossil diesel tariff exemption
    a. Area of interest: business case
    b. Type of innovation: all
    c. Impact on greening potential: negative
    d. Description: fossil diesel for IWT is exempted from taxes and tariffs, while electricity delivered to the same sector does not benefit from the same exemption. Even though the taxes may be relatively small, it is significant and is seen by pilot operators as a hindrance for further uptake.

8. Long-term contracts needed to finance innovation investments
    a. Area of interest: business case
    b. Type of innovation: all
    c. Impact on greening potential: negative
    d. Description: Large investments needed to decarbonize a vessel require long periods of stable income for a vessel owner to be able to finance the costs. Especially in inland shipping, many vessels are active on the open (or spot) market and do not have these long-term contracts with their customers. Most shippers are unable to offer these contracts.

9. Shippers largely unwilling or unable to pay for greening
    a. Area of interest: business case
    b. Type of innovation: all
    c. Impact on greening potential: negative
    d. Description: it is observed by pilot operators that the largest part of the customer group is at the moment still unwilling or unable to pay a premium for decarbonized transport. These groups are currently not incentivized enough to do so, but regulations such as ETS, ETS2 and CSRD might change that in the future. When customers do value green transport, they are usually drivers of greening activities. Currently however, many pilots fail to materialize because the customer is unwilling or unable to pay the price in combination with the long-term contract needed.

10. Early mover disadvantage when competing with non-movers
    a. Area of interest: business case
    b. Type of innovation: all
    c. Impact on greening potential: negative
    d. Description: the existing negative cost difference with fossil diesel operations means all vessel owners opting to invest to reduce the carbon footprint of their vessel operate at a competitive disadvantage compared to the majority of the fleet that does not take steps to green their vessel. There currently is nothing in place that counteracts this, but regulations such as those mentioned directly above and RED III might act as counterbalances. The proposed Energy Taxation Directive (ETD) in the Fit-for-55 package will also have a positive impact, but it remains to be seen if it will be accepted by European Parliament and Member States which have a veto right.

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Furthermore, it must be noted that pilot operators are doubting if impacts from these regulations are strong enough to close the entire gap.

11. Carbon Insetting as temporary solution
    a. Area of interest: business case
    b. Type of innovation: all
    c. Impact on greening potential: positive
    d. Description: it is hard to find customers willing to pay a premium for green transport. However, even if they are found, it is hard to bundle their cargo in one vessel. To overcome this issue, carbon insetting is currently tested by some operators. Here, the extra price for green transport is sold separately on a platform where shippers can buy the reduction rights or carbon credits and set them into their own supply chain. Physical users of the vessel pay a price similar to what they pay for a non-green vessel, but cannot claim the reduction of the carbon footprint. Although still in the testing phase, this seems a relevant solution for the period where the coastal and inland fleets are not yet covered by any form of emissions trading.

12. Timeframe of the regulatory framework (CCNR, CESNI, IMO)
    a. Area of interest: regulatory framework
    b. Type of innovation: all
    c. Impact on greening potential: -
    d. Description: setting up new rules and regulation for alternative solutions takes time. However, pilot operators can positively impact this process by sharing information with authorities. Sharing information with the regulatory bodies will increase the probability that future statutory requirements are largely in line with successful pilot projects with the additional benefit that the need for adaptation and/or refit after expiration of derogations can be limited.

13. Until regulations are finalised, derogations can be used
    a. Area of interest: regulatory framework
    b. Type of innovation: all
    c. Impact on greening potential: -
    d. Description: pilots that are going to operate before the legal framework exists can obtain derogations. This process is costly and it is also quite time consuming since all design aspects need to be thoroughly assessed to ensure the safety of pilot vessels. This cannot be done without classification societies or technical services and involvement of authorities at the earliest instance. It is however navigable, although the need for externally hired consultants may arise and costs can be significant.

14. Engine Regulations Impact Engine Uptake using renewable fuels
    a. Area of interest: regulatory framework
    b. Type of innovation: Renewable Fuels
    c. Impact on greening potential: negative
    d. Description: apart from regulations from IMO, CESNI and CCNR covering the vessel operations, IWT engines are covered by separate EU regulation (NRMM Stage V[12]). NRMM Regulation currently does not include hydrogen or methanol as a reference fuel for certification to bring engines commercially to the market. Therefore, no internal combustion engines using these fuels can be brought on the market for IWT usage. A solution is not expected before 2027. Provisional access may be granted, but

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[12] https://eur-lex.europa.eu/eli/reg/2016/1628/oj

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due to growing awareness and concerns for formaldehyde emissions, that route seems currently not suitable for methanol engines.

15. Current bunkering network is not suitable to obtain alternative energy sources
    a. Area of interest: infrastructure
    b. Type of innovation: Electrification & Renewable Fuels
    c. Impact on greening potential: negative
    d. Description: although a large network for bunkering of fossil diesel exists, these bunker points are mostly not suitable to offer (a range of) alternative fuels due to the specifics of the alternatives. Drop-in biofuels like FAME and HVO are of course the exemptions.

16. Need for denser network of bunker points
    a. Area of interest: infrastructure
    b. Type of innovation: Electrification & Renewable Fuels
    c. Impact on greening potential: negative
    d. Description: since many alternative power solutions have a lower energy density than fossil diesel, bunkering will need to be done more often. In case of swapping, charging or classic bunkering, these points require time and significant investments to set up. Furthermore, there is a chicken-and-egg problem that dictates that vessels cannot widely operate on a fuel without a network of bunker points, but that a bunker point has no closing business case if only a few vessels make use of the fuel type.

17. Truck-to-ship bunkering is the go-to solution for early uptake phases
    a. Area of interest: infrastructure
    b. Type of innovation: Electrification & Alternative Fuels
    c. Impact on greening potential: positive
    d. Description: many pilot projects covering significant distances and thus having to bunker at multiple points currently make use of truck-to-ship bunkering. This form of bunkering requires only available quay space and sometimes permission from local authorities. If a containerised solution is swapped, truck-to-ship services are sometimes used to bring the energy container to the vessel at a terminal. This way of bunkering allows for the build-up of a userbase of alternative fuels without the expensive investments needed for multiple fixed bunkering locations. This way of bunkering is vulnerable to changes in fuel demand (for instance from other sectors): if demand rises, fuel providers might see themselves challenged to fulfil the need of their customers. In such circumstances, fixed bunker points offer more certainty of service.

18. Infrastructure is the enabler of renewable fuel roll-out
    a. Area of interest: infrastructure
    b. Type of innovation: Electrification & Renewable Fuels
    c. Impact on greening potential: -
    d. Description: many pilots failed because their bunker solution fell through. This calls for a joint approach were vessel operator and fuel provider investigate in common how the fuel will be brought on board during the operational phase. The fuel provider will need a business case for the bunker solution that might not be filled by one pilot vessel only. Combined setups might offer solutions.

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19. Congestion on the electricity grid & cost issues for infrastructure
    a. Area of interest: infrastructure
    b. Type of innovation: Electrification & Renewable Fuels
    c. Impact on greening potential: negative
    d. Description: realising fixed bunkering points is expensive and can rely on local permits. However, when realising charging and swapping points for electricity, some member states like the Netherlands are faced with congestion on the electricity grid which might significantly delay the laying of necessary cabling and most critically their connection to the grid so charging can be done with the right power.

20. Materialisation time of hardware failure: the technical early mover disadvantage
    a. Area of interest: technical implementation
    b. Type of innovation: all
    c. Impact on greening potential: negative
    d. Description: any innovative system will not have had long operational runtime yet. Therefore, typical issues (hardware failure and/or children's diseases) have not yet been identified, the lifetime of the system is not certain yet and the costs of repairs and maintenance during the lifetime are unknown. One can also wonder how long the service provider will be around, especially start-ups can be seen as prone to failure. These are risks when evaluating an investment decision. Early movers will have to take on these unknowns and their costs and impracticalities, while later movers can inform themselves by waiting and finding out. This has made a large part of the IWT and Coastal vessel owners hesitant regarding investing in innovative systems.

21. Lower energy density of alternative solutions denominates the use case
    a. Area of interest: technical implementation
    b. Type of innovation: Electrification & Renewable Fuels
    c. Impact on greening potential: mostly negative
    d. Description: most alternative solutions have a lower energy density than fossil diesel. Thus, to operate similarly, either a larger amount of space on board needs to be used to store the energy carrier, or bunkering is needed more often. Both options change the way of operation of the vessel and have impacts on the business case that are mostly negative.

22. Safety limitation of alternative solutions effect operational use
    a. Area of interest: technical implementation
    b. Type of innovation: Electrification & Renewable Fuels
    c. Impact on greening potential: negative
    d. Description: many alternative fuels have different characteristics than fossil diesel. Hydrogen, methanol and electricity for instance can be dangerous for humans in different ways than fossil diesel. This has effects on the way these alternatives are stored and handled and which safety precautions shall be taken. In general, the necessary safety measures can be time consuming, costing in space and require both CAPEX and OPEX costs. Crew training facilities for safely handling alternative fuels are also time consuming and costly, but more importantly, they are not always widely available.

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23. Fast depreciation of assets in innovative environments
    a. Area of interest: technical implementation & business case
    b. Type of innovation: all
    c. Impact on greening potential: negative
    d. Description: assets lose value over time and when they are outdated. Some pilot operators reported that the fast-moving pace of innovations might mean a system to green a vessel that is acquired today might be outdated in a couple of years already. That raises questions on the depreciation speed, and usually comes with certain advantages for the newest system compared to the last generation. The advantages would translate to competitive advantages for the later mover. Therefore, this is an argument in the investment decision to wait as long as possible to invest in an innovative system. This can be seen as an early mover disadvantage.

24. Reinventing the wheel
    a. Area of interest: technical implementation
    b. Type of innovation: all
    c. Impact on greening potential: negative
    d. Description: it is reported that vessel owners have the tendency to under-share gained knowledge and that each new innovator is thus reinventing the wheel again-at least partially. More openness could help reduce the time, effort and costs needed to do so.

25. Retrofitting disadvantage
    a. Area of interest: technical implementation
    b. Type of innovation: all
    c. Impact on greening potential: negative
    d. Description: retrofitting is almost always more complicated and relatively more expensive than installing the same innovation on a newbuild vessel since the latter can be designed while taking the innovation into account. Retrofits often need a lot of steelwork, updating of pipes, valves and subsystems that are reported as being very expensive.

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4.3 Interpretation of the results

Now that the research results have been summarized above, it's important to interpret the findings for each type of innovation. It is worth noting that very few pilot operators were willing or able to share data on key performance indicators (KPIs). Information on factors such as operating expenses (OPEX), capital expenditures (CAPEX), and efficiency differences was scarce. As a result, this report is more general than it might have otherwise been.

It is also important here to remember the low-hanging fruits as described in the introduction. Per innovation type a note is added to explain if this can be considered a low-hanging-fruit or not. Here, low-hanging is set to mean a solution that is relatively easy to obtain for existing vessels.

4.3.1 Results interpretation for Electrification

Successful electrification of small and medium sized passenger vessels and of medium sized cargo vessels has been demonstrated as technically possible. The regulatory framework for electric vessels is observed by operators as relatively set and straightforward.

The business case is however very challenging since the necessary systems and certainly the batteries needed are very expensive. The costs of the batteries can be avoided by using *Energy As A Service* concepts where the battery can be leased; usually in containerised form as demonstrated for inland container transport. If swapping is not suitable, recharging of batteries on board is needed relatively often when compared to fossil diesel operations. The latter is only suitable for a subset of the fleet that executes small roundtrips such as ferries, some other passenger vessels, and very minor part of cargo vessels since these categories have significant downtimes. There have been observations of vessels installing smaller fixed battery packs to obtain a limited range of battery powered operations, but this range is small and the installation is not simple or cheap. On a positive note, it is worth to observe that electrical systems often require far less maintenance than related diesel systems. However, this does decrease operational costs. On the other hand though, electricity as on-board power supply (e.g. battery systems) is currently still reported as significantly more expensive than fossil diesel.

Retrofitting vessels to be electrically driven is technically possible, but difficult since the existing drivetrain needs to be removed for a large part and the new electrical installation needs to be installed in a vessel that was not designed for electrical propulsion. Since there is also no pre-assembled or plug-and-play electrical system to order, much time and expertise is needed to combine the different subsystems with each other. This makes retrofitting an extremely costly operation, and reports have been that to retrofit a mechanical vessel to electric is often rising above the worth of the vessel – thus rendering the operation financially practically impossible. Even diesel-electric vessels are not easily retrofitted to make use of a battery for propulsion. Newbuild vessels that can be specially designed for electric propulsion face less of these challenges, yet costs there are still reported as much higher than for fossil diesel newbuilds.

Charging high-capacity batteries is a specific challenge. Charging may take a long time, and not all local energy grids are suitable to charge a vessel. Swapping a battery in a container is faster and could theoretically be done at any container terminal. However, significant investments are still needed to roll out a suitable network.

Even though technically possible, the high costs of the systems and the extensive installation works for retrofit rule electrification out as a low-hanging fruit, even though it is technically doable.

4.3.2 Results interpretation of Renewable Fuels

Below is an overview of the main renewable fuels encountered during the research. It needs to be noted that HVO was excluded from the scope of research because this is already a mature solution and available for wide application, which also does not need specific technical research and development efforts to adapt engines. For hydrogen and methanol there are options to use them in internal combustion engines with mechanical drivetrains or to use them with fuel cells. The latter produce electricity from fuels and thus need an electrical drivetrain. If fuel cell applications are discussed, many of the same issues that are related to electrification are thus logically applicable. Fuels such as hydrogen and methanol are only fitting for decarbonization when renewable versions are used. Thus, apart from the challenges described below, the production of these fuels requires attention.

4.3.2.1 Hydrogen

Hydrogen applications have been proven technically viable over the last decades, both in fuel cells and in internal combustion engines. Hydrogen on board can be stored in many ways but most often pressurised storage has been observed. The regulatory framework for hydrogen application on board and bunkering is not finished, but will be in the coming years. Derogations have been reported as obtainable, although it does take time, effort and money to do so.

The business case for hydrogen applications is still a very though one. Hydrogen is still reported as far more expensive directly compared to fossil diesel; a factor 4 to 10 in terms of the costs per MJ of caloric energy. From a CAPEX point of view, systems needed for hydrogen propulsion have also been reported as very expensive. Especially in the case of fuel cell applications, which need an electrified drivetrain, a buffer battery to cover load changes, and face many of the same difficulties as noted under electrification. Furthermore, the lifetime of fuel cells is quite limited compared to the lifetime of combustion engines. Bunkering hydrogen is also a large challenge, although the first bunker points are available and fuel providers offer truck-to-ship services.

Hydrogen applications in internal combustion engines are possible and might have a more obtainable business case than fuel cell applications. However, after treatment for NOx emissions might still be needed and currently the regulatory framework on the side of IWT engines is still a hindrance to bringing these engines on the market for IWT. Currently, engine providers would only be able to obtain temporary and local permissions. In coastal shipping, since the engines are under IMO regulations, this is not the case and engines can be brought on the market. However, still relatively small interest is observed.

Retrofitting vessels to hydrogen application would face many of the same issues that are described under electrification. Especially the storage of hydrogen on board would be a challenge since far more space will probably be required to accommodate the fuel tank. In case of swapping a containerised unit (MEGC, successfully demonstrated), a part of the cargo hold may need to be specifically transformed for this.

Even though technically possible, high costs of systems, installation and the fuel costs of hydrogen rule it out as a low-hanging fruit.

4.3.2.2 Methanol

Methanol has mostly been demonstrated in deep sea shipping, and sometimes in coastal shipping, with dual fuel engines. The nature of a dual fuel engine allows the vessel operator flexibility regarding bunkering and fuel usage, which has been reported as a great benefit- although the need for diesel as a pilot fuel rules out 100% zero emissions with these engines. Methanol has been reported as being easier to handle and store than for instance hydrogen, but still needs adaptations compared to fossil diesel operations. The regulatory framework for seagoing vessels (including coastal) seems to be in place and is reported as navigable. For inland vessels, technical regulations (within ES-TRIN) are adopted and will enter into force in January 2025.

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The business case for bio-methanol seems to be a little more obtainable than for other options described. However, for e-methanol, expected on medium/long term, the price of the fuel is expected to be higher than the price of green hydrogen which will change the business case. There is a need for large investments, but they are reported as more reasonable than for electrification and hydrogen. OPEX-wise, bio-methanol is still much more expensive than diesel. In short, there is no closing business case now, but the gap is reported as less wide than for other options. Although, it must be underlined again that almost no hard data on cost KPIs were obtained so the solidity of this statement is not the highest.

One major hurdle for methanol in IWT vessels is worse to the situation for hydrogen because of the concerns about formaldehyde emissions. Current engine regulations for IWT rule out methanol as an option, this will not be changed on short notice. As with hydrogen combustion engines, a temporary approval could be sought after. However, current worries regarding formaldehyde emissions from methanol combustion make authorities less likely to prolong temporary approvals. This option seems not suitable until the formaldehyde issue has been addressed.

Retrofitting vessels to a methanol dual fuel engine in coastal and deep sea shipping has been successfully performed. Some diesel engines themselves can even be retrofitted to run on methanol. It seems this solution would be suitable for more coastal vessels, and if regulatory hurdles are overcome also for IWT vessels. However, the systems and the technical services are still reported as costly.

For coastal shipping, bio-methanol application in a dual fuel engine can certainly be classified as a lower hanging fruit than other potential solutions discussed. However, the costs of the installation and methanol as a fuel are still too high to truly classify methanol as a low-hanging fruit. For inland vessels, the same can be said, but they face additional regulatory barriers.

4.3.2.3 LNG

Although LNG is a fossil fuel, it has been included in the evaluation part of the research to be able to learn from the relatively large number of LNG pilots. These pilots were successful in showing the technical viability of LNG-powered vessels. However, the environmental benefits of LNG in terms of decarbonisation are too low to reach the ambitions of the maritime sector as a whole and specifically the IWT and coastal sectors.

LNG applications are already market ready and the pilots held are far in the past. LNG has not really taken off in inland and coastal shipping due to reasons described above but also due to high costs of the installations and relatively high fuel costs. Similarly, the usage of Bio-LNG has not been observed in the identification phase of Task 2.1, although Bio-LNG is already used in road transport. Most likely the willingness to pay for Bio-LNG in road haulage operations is higher than in the waterborne sector.

LNG therefore cannot be classified as a low-hanging fruit.

4.3.2.4 Not covered: drop in biodiesels (FAME, HVO)

Not covered in this research, since it is already widely tested and market ready (and therefore not part of the T2.1 scope), is HVO (Hydrotreated Vegetable Oil). A high-quality renewable diesel that can act as a drop-in solution in many diesel engines. The HVO sold today on the market is usually made from Used Cooking Oil (UCO). In case HVO is applied in pure form, called HVO100, it can reach 87.4% GHG reduction WTW based on UCO as feedstock. HVO30 (a blend of 70% fossil diesel and 30% HVO) can be applied to comply with the EU Taxonomy threshold and still is within the EN590 specification for which all engines are certified and allowed to operate. HVO100 has been approved by many major engine manufacturers as well for use in their engines[13]. HVO is more expensive than fossil diesel, but the price difference is not very significant, compared to other alternative fuels. Increasingly, customers

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[13] https://www.neste.be/en/renewable-diesel-hvo/product-information/product-information/oem-approvals

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are paying inland vessel owners to use HVO for transportation services in order to reduce the carbon footprint of their transport.

Non-hydrotreated biodiesels such as FAME are also market ready, but only suitable for a very specific subset of the fleet or at a low blend rate (typically 7%, known in the market as “B7”). Vessels that use large amounts of fuel and operate near-continuous are the best target group since FAME will segment over time. Still, significant changes to fuel handling operations and installations (fuel tank, pipes) will have to be made, but large companies may have the capacity to make such investments and to earn it back through the lower fuel price of FAME compared to other renewable fuels (like HVO, bio-methanol).

One issue concerning HVO blending is from an administrative point of view: from a taxation perspective there might be significant obstacles for using HVO as the alternating bunkering of fossil diesel and HVO would create a random blend in the tanks of a vessel which would constitute a tax and/or customs infringement.

Drop in biodiesels, and especially HVO, are one of the few true low-hanging fruits available. Although it is uncertain if enough HVO will be available to decarbonise the Inland and Coastal fleets.

4.3.3 Energy Efficiency pilots

As already stated in the introduction, only a relatively small amount of identified and evaluated pilots were related to energy efficiency. The two evaluated measures were large-scale solar panel installations on board and the use of wind assisted ship propulsion (retractable sails or foils).

Given the small number of pilots identified and thus evaluated, strong conclusions cannot be drawn. These installations are costly, often require operational changes and are suitable for certain sailing profiles only. Foils or sails are most useable on open seas, probably not for inland vessels and for many coastal vessels – even though some coastal vessels might benefit. Solar panels are useful, but only have a significant effect when they cover large parts of the vessel, which will not be suitable for all vessel types.

When installed on the best fitting vessel type with the most suitable type of operational profile, these systems earn themselves back, so there is a business case in principle; even if it might be uncertain because not many operating hours have been demonstrated yet.

While a thorough investigation is necessary beforehand, these energy efficiency measures can be low-hanging-fruits. However, their effectiveness depends entirely on the specific characteristics of the vessel and its operational profile.

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5. | Conclusions and recommendations

5.1 Conclusions

As has been outlined in the introduction, the mission of Task 2.2 was to gather lessons learned from past pilots outside of SYNERGETICS. Chapter 3 details these lessons learned and they are discussed in chapter 4. In general, it can be stated that greening the Inland Waterway and Coastal fleets must be considered as an uphill battle.

Technically, many innovative solutions to green the fleet have been proven in operation: hydrogen, methanol, electrification, and several energy efficiency solutions have been piloted in a wide extent of operational applications. However, the practical rate of uptake in the sectors is still relatively small due to a wide palette of issues.

Overall, capital expenditure (CAPEX) costs are very high, and for some innovations, they can exceed the value of the vessel. This makes it challenging to secure financing for innovative investments. Retrofitting, i.e. converting an existing vessel to incorporate green technologies, is particularly costly. This is because old systems must be removed, and significant steelwork is required to install new systems in vessels that were not originally designed for them.

In addition to the high costs associated with systems like fuel cells and batteries, this research highlights another important issue: the cost of all types of work on vessels has risen sharply since the COVID-19 crisis and has continued to increase due to the ongoing war of Russian aggression in Ukraine. These rising costs are especially notable when compared to prices at the beginning of the last decade. Together, these factors create an unfavourable environment for both retrofitting existing vessels and building new ones with innovative green solutions.

In operational expenditures (OPEX) certain cost items can sometimes see reductions, for instance in the case of electrification where electrical systems are reported as needing less maintenance. In general, however, energy costs compared to fossil diesel are still much more expensive for renewable solutions.

The combination of CAPEX and OPEX costs leads to a very challenging business case. On the open market, where many vessels operate, green vessels will face a competitive disadvantage compared to similar vessels still operating on fossil diesel. Generally, the latter will both be cheaper regarding OPEX, and have not invested large amounts of CAPEX that will need to be earned back. Therefore, the costs of their services will be significantly lower – effectively pricing the greener vessels out of the market. The best solution available to operators of greener vessel is a long-term contract with a customer willing to pay the extra price for greening (sometimes called "the green premium").

Unfortunately, the number of shippers willing to enter such contracts is quite minimal. Related to this, many operators of innovative pilots are eagerly awaiting governmental incentives that close the price gap. Proposed measures by the European Commission from the Fit-for 55 package like ETD, ETS, ETS 2, CSRD and REDIII are seen in a positive light, but it remains the question if their impact will be high enough to drastically alter the situation.

Infrastructure plays a key role as enabler of the uptake of a renewable source of energy. However, the current network for fossil diesel bunkering cannot easily be used for renewables and setting up new bunker points is complicated and expensive. Points that need to charge batteries, either on board or in battery containers, are often faced by congestion on the energy grid, meaning waiting times for connections might be long. Truck-to-ship bunkering services are very suitable to overcome this problem. However, in periods of rising demand for the renewable form of energy, this service offers less certainty for vessel owners. In the end, a network of fixed bunker points supplemented by other services would be ideal.

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The regulatory framework is moving forward and showing itself as adaptable to the necessary changes in the coastal and inland sectors. Regulation is either in place, or can be expected to be in place in the coming years. Meanwhile, derogations are a temporary (albeit time-consuming and costly) solution that has demonstrated its usefulness. The framework set by IMO (coastal) and CESNI & CCNR (inland) is generally reported as sufficient, even though some operators think derogation processes could be handled faster. Pilot operators can also play a vital role in helping drafting and improving regulations by sharing information with authorities, which is sometimes lacking. The inland waterway sector however is severely impacted by the NRMM Stage V regulation[14] regarding engines to be brought on the market. For hydrogen and especially methanol this is a hurdle that cannot be overcome until a major revision of these EU rules. This blocks demonstrations and further development & roll-out of hydrogen, and in particular methanol, as fuel for inland vessels.

Having sketched the general situation around greening efforts in inland and coastal shipping, it is also of importance to circle back to one of the core SYNERGETICS-missions: identify and analyse low-hanging fruits. This report focussed on pilot operations, and not on greening techniques that were already market-ready. It still must be noted that only few potential low-hanging fruits were identified: energy efficiency solutions (under use case specific conditions) and, to a much lesser extent, methanol. Bio-methanol cannot be classified as truly low hanging due to several constraints and issues, but seems potentially lower hanging compared to other options. Possibly the only true low-hanging fruits have been exempted from the scope of this research because they are currently market ready: high quality biodiesels like HVO have largely proven themselves to work and can lead to low carbon operations. Although it is uncertain if enough HVO will be available to green the Inland and Coastal fleets.

A final overall remark must be the fact that during the research remarkably few pilot operators were willing and able to share data about KPIs. Factors like OPEX and CAPEX costs, efficiency differences et cetera were barely discovered. This has made the report of a more general nature than might have otherwise been the case.

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[14] Regulation (EU) 2016/1628: https://eur-lex.europa.eu/eli/reg/2016/1628/oj

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5.2 Recommendations for vessel owners and policy makers

Recommending actions to stakeholders is not the main goal of Task 2.2, so the recommendations presented below should not be seen as all encompassing. However, some lessons learned clearly could be impacted by stakeholders. Therefore, it was deemed suitable to include a small recommendations section as presented below.

5.2.1 Recommendations to policymakers

- *Reduce the price gap.* As has been shown in the lessons learned, early movers are faced with significant competitive disadvantages when competing with non-movers that are still operating on generally cheaper fossil diesel and do not have to earn back large greening investments. Incentives are coming to the market through REDIII and ETS 2 opt-in possibilities, which will practically increase the price of fossil diesel. Member States choosing to use the ETS 2 opt-in for IWT contribute directly to reducing the price gap – benefits would further increase if a level playing field between member states is sought (i.e. join opt-in). However, the impacts of these regulations are not yet clear and may not be enough to remove the early mover disadvantage. Clear monitoring is needed and the inclusion of coastal and inland sectors under ETS 2 opt-ins should be prioritised. Also, ETD (still under negotiation between EC, EP and member states) may have a positive impact to reduce the price gap.
- *Incentivise shippers.* The sectors need their customers to pay extra for greening initiatives, but shippers are probably faced with the same early mover disadvantages where competitors that do not pay extra for green transport can deliver a cheaper service or end product. Although CSRD is a clear step in the right direction, it is not a monetary incentive in itself. Efforts to push shippers to pay for greener transport should be stimulated.
- *Support development of infrastructure for bunkering and/or charging.* Lessons learned show the critical importance of bunker/charging infrastructure. Although mainly the area of fuel providers, governments could support their efforts by being responsive and adaptive regarding local permits. Special attention should be given to the congestion situation on the national energy grids in the member states. Energy grid congestion is harming the roll out of a charging/swapping network for electrification solutions. AFIR[15] requirements, currently in place for providing onshore power supply in inland waterway and maritime ports, might be enhanced to steer ports towards more availability of alternative fuels and electricity for vessel propulsion.
- *Remove barriers deriving from the NRMM Regulation.* Fuels that are not on the list of reference fuels cannot be used to certify an engine under the current NRMM regulation. Updating this list with new reference fuels such as hydrogen and possibly methanol (including dual-fuel applications) will clear a regulatory barrier for decarbonising the IWT fleet. For methanol, an impact assessment regarding formaldehyde emissions is needed in short order to see if the fuel can fit under the NRMM Regulation (either provisionally or on the list of reference fuels). Synergies can be sought with German regulations for stationary combustion plants. Though directive (EU) 2015/2193 does not mention formaldehyde, its German implementation "44. BImSchV" regulates formaldehyde forming.
- *Lift administration barriers for HVO: The core research did not focus on drop-in biodiesels. However, HVO and FAME were encountered several times. One interesting issue arose. Recently it was discovered that from a taxation perspective there might be significant obstacles for using HVO as alternating bunkering of fossil diesel and HVO (e.g. in case HVO should not be available everywhere along the route) would create a random blend in the tanks of a vessel which would constitute a tax and/or customs infringement. This could become a significant barrier for HVO uptake and seems to deserve attention.*

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[15] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32023R1804

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5.2.2 Recommendations to vessel owners

- *Find the right customer*. The few cases of successful green vessels with a closing business case are supported by shippers willing to enter long-term contracts and pay extra for green transport. Currently, only a small minority of shippers is willing to do so. Nevertheless, many shippers could be impacted by current or future regulations incentivising them to decrease carbon along their operations and supply chain. To be able to find the right customers, knowledge is needed on the impacts that regulations such as CSRD, ETS and others will have on specific target groups. For example, in coastal shipping, certain windfarm operators are already looking for green transport solutions because of similar regulations. In inland shipping, shippers working for governmentally tendered projects have long been keen on contracting vessels with NOx-emission reduction technologies installed. Customers may need to be actively informed about the impact of relevant regulations and the potential solutions that transport providers in inland and coastal shipping can offer.
    - It might be a suitable first step for any vessel owner to start this process with biofuels like HVO if other options are out of reach. A trend has been observed where more shippers are willing to (partially) pay the price for HVO, and this could be a first step in developing relationships to build upon for further decarbonisation steps when the time is right.
- *Cooperate to gain and share knowledge and realise economies of scale.* Vessel owners are generally well-positioned to implement measures aimed at greening their vessel. However, it is indicated that many owners are essentially reinventing the wheel in this process. This redundancy can lead to unnecessary expenditures of time and resources, which could be mitigated through the open sharing of knowledge acquired during innovation efforts. Additionally, there are potential opportunities for joint procurement of equipment needed for retrofitting vessels. By collaborating in this manner, vessel owners can leverage economies of scale to achieve lower prices. It can be recommended to explore options for pooling vessels to facilitate joint procurement of retrofitting equipment and services. When pursuing regional collaborations for specific technological solutions- such as swappable battery systems. This approach may also help to address the "chicken-and-egg" dilemma related to energy infrastructure along waterways and in ports.
- *Prepare for the regulatory pathway.* When starting an innovative process, check all regulatory steps necessary to come to operation, initiate first contacts as soon as possible and include, if relevant, classification societies as early in the design process as possible.
- *Consider the total circle.* When starting an innovative process, consider all relevant practicalities. Not only on board of the vessel, but also regarding the bunkering or charging solution. Failure to timely do so, can lead to failure of innovative efforts after significant amounts of time and money have already been spent.
- *Monitor business case pilots.* Carbon insetting might be a temporary solution to gain extra income related to greening of a vessel until regulations like ETS (2) become relevant. Pilots are ongoing. Similarly, pilot operators are working with swappable containerised energy solutions (battery containers, MEGCs) that might be an option to make the business case and/or operational use case more attractive.