SUMMARY OF D.1.1

SYNERGETICS: RELEVANT IDENTIFIED TECHNICAL SOLUTIONS

Derived from SYNERGETICS “Synergies for Green Transformation of Inland and Costal Shipping“

Resource: SYNERGETICS Project EU | Synergies Green Transformation

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1. INTRODUCTION AND STRATEGIC CONTEXT

The SYNERGETICS Innovation Action represents a pivotal initiative within the European Union's broader "Fit for 55" package and the Green Deal objectives. As the shipping sector contributes significantly to global greenhouse gas (GHG) emissions, particularly in inland waterway transport (IWT) and coastal corridors, the need for a rapid transition is paramount. However, unlike the automotive sector, the shipping industry faces unique constraints such as vessel longevity, high energy demands for long-range transport, and the extreme heterogeneity of the fleet.

This document provides a summary of Deliverable 1.1, identifying technical solutions that are not just theoretical but ready for deployment. The focus is on retrofitting—the modification of existing vessels to incorporate green technologies. This strategy acknowledges that the current fleet will remain operational for decades, making newbuild-only strategies insufficient to meet 2030 and 2050 targets.

"Synergy" is the core philosophy: adapting mature technologies from heavy-duty road transport and rail (marinisation) to reduce R&D costs and accelerate time-to-market.

2. THE CHALLENGE OF DECARBONIZATION IN SHIPPING

Shipping is categorized as a "hard-to-abate" sector. This difficulty stems from several factors. Firstly, the power requirements of a large cargo vessel or a pusher boat on the Rhine are immense compared to a heavy truck. While a truck might operate with a 400kW engine, a large inland vessel often requires multiple megawatts for propulsion and auxiliary power.
Secondly, the energy storage density of alternative fuels is generally lower than that of conventional Marine Gas Oil (MGO). This creates a trade-off between "greenness" and cargo capacity. If a ship must dedicate 20% of its volume to hydrogen tanks, the economic viability of the voyage decreases.

Furthermore, the regulatory landscape is fragmented. Safety standards for methanol, hydrogen, and large-scale lithium-ion batteries are still evolving, leading to high "first-of-a-kind" costs and insurance premiums.

Finally, the economic structure of the IWT sector consists largely of small family businesses (owner-operators). These stakeholders lack the capital reserves for massive high-risk investments, necessitating clear technical roadmaps and proven retrofit solutions.

3. INVENTORY OF COASTAL AND IWT FLEETS

To implement effective solutions, one must understand the target groups. The report identifies two primary segments:

3.1 Coastal Shipping

Coastal vessels (Short Sea Shipping) are vessels that operate primarily in territorial waters and marginal seas. They are generally smaller than deep-sea vessels (often under 5,000 dwt) but operate in sensitive environmental zones. Key clusters identified include the North Sea, the Baltic Sea, and the Mediterranean. The diversity of tasks—from container feeder ships to offshore supply vessels—means that the power profile varies wildly.

3.2 Inland Waterway Transport (IWT)

The European IWT fleet is characterized by its age. A significant portion of the Rhine fleet was built in the 1960s and 70s. These hulls are often in excellent condition, but the machinery is obsolete. This creates a massive opportunity for engine replacement and hydrodynamic upgrades (e.g., aft-ship modification). Inland vessels operate under strict constraints related to waterway classifications, vessel dimensions, and operational profiles. These include variations in speed, load, and duty cycles. The report catalogs vessels by type: self-propelled dry cargo, tankers, pushers, and tugs, noting that pushers have the highest fuel consumption and thus the highest potential for GHG savings per retrofit unit.

4. CLASSIFICATION OF TECHNICAL RETROFIT MEASURES

SYNERGETICS classifies technical solutions into three main technological pillars. Effective decarbonization usually involves a combination of at least two of these pillars.

- Alternative Energy Carriers: Shifting from fossil-based Marine Gas Oil (MGO) to fuels with lower carbon intensity. This includes drop-in fuels (HVO), gaseous fuels (LNG, Hydrogen), and liquid carriers (Methanol).
- Alternative Energy Converters: Moving from traditional diesel internal combustion engines to more efficient or zero-emission converters, such as modern dual-fuel engines, fuel cells, or electric motors.
- Energy Saving Measures: Reducing the total energy demand of the vessel. This is achieved through hydrodynamic hull optimization, energy-saving devices like propeller ducts, and digital voyage optimization.

The report emphasizes that reducing the energy demand through hydrodynamic measures is a prerequisite for making alternative fuels viable, as it minimizes the volume of green fuels required.

5. ALTERNATIVE ENERGY CARRIERS

A comprehensive analysis of energy carriers requires a "Well-to-Wake" (WtW) perspective, accounting for the emissions during fuel production, transport, and combustion.

- Fossil fuels as MGO and LNG serve as baseline : are associated with high emissions
- HVO Liquid: pp to 90% reduction
- Methanol: near-zero emission (if Green)
- LNG Cryo-Gas: 20% reduction (slip issues)
- Hydrogen Compressed (at 350 bar): Zero (at tailpipe)

Hydrotreated Vegetable Oil (HVO): This is the most immediate "drop-in" solution. It requires virtually no modifications to existing diesel engines. Its primary drawback is the limited availability of sustainable feedstocks and its high price compared to Marine Gas Oil.

Methanol (CH3OH): Methanol is gaining significant traction as a maritime fuel. Being liquid at ambient temperature and pressure, it simplifies storage compared to hydrogen or LNG. However, it is toxic and has a low flash point, requiring specific bunkering procedures and gas-tight engine rooms. When produced from renewable hydrogen and captured CO2 (e-Methanol), it is considered carbon neutral.

LNG and Methane: While LNG was once seen as the primary bridge fuel, its long-term viability is questioned due to methane slip—the release of unburnt methane, which is a potent GHG. The report suggests that LNG is only a viable greening measure if combined with bio-LNG or e-methane.

Hydrogen (H2): Hydrogen is the ultimate clean fuel for fuel cell applications. However, its low volumetric energy density makes it difficult for long-haul IWT. Current solutions focus on compressed hydrogen (350 or 500 bar) or liquid hydrogen (LH2) for ships with larger space availability. The report identifies hydrogen as highly suitable for short-distance ferries and port-based tugs where frequent refueling is possible.

6. MARINISATION: SYNERGIES WITH ROAD AND RAIL

Developing bespoke engines and fuel cells for the relatively small maritime market is prohibitively expensive. SYNERGETICS leverages "marinisation"—the process of taking mass-produced components from the heavy-duty vehicle (HDV) or locomotive sectors and adapting them for the marine environment. Key adaptation requirements for marinisation include:

- Cooling Systems: Replacing air-cooled systems with raw-water or keel-cooling heat exchangers.
- Safety Systems: Adding double-walled piping for fuels, flame arrestors, and gas sensors to meet IMO or ES-TRIN requirements.
- Durability: Marine engines often run at high loads for much longer periods than truck engines, requiring upgraded bearings and thermal management.

By using HDV components, shipowners benefit from lower initial purchase prices and a global network of spare parts and technicians familiar with the base technology.

7. INTERNAL COMBUSTION ENGINE (ICE) TECHNOLOGIES

The modern ICE is far from obsolete. High-efficiency internal combustion remains the most cost-effective way to utilize alternative fuels in retrofits.

7.1 Dual-Fuel (DF) Concepts

Dual-fuel engines utilize a small amount of diesel (pilot fuel) to ignite a mixture of air and a gaseous or low-reactivity fuel (like Methanol). This allows for high compression ratios and high efficiency while maintaining the ability to switch back to 100% diesel if green fuel is unavailable.

7.2 Spark-Ignition (SI) Concepts

Pure gas or methanol engines often use spark plugs. While this eliminates the need for diesel pilot fuel, SI engines generally have lower efficiency and are more prone to "knocking" under high loads. The report suggests SI engines are best suited for auxiliary power units (APUs) or smaller coastal vessels.
The report also highlights Hydrogen Combustion Engines (H2-ICE), which are a lower-cost alternative to fuel cells, providing zero carbon emissions while utilizing existing mechanical drivetrains.

8. ELECTRIC PROPULSION SYSTEMS

Electric propulsion is the foundational technology for a zero-emission future. It separates the energy source from the propulsive force. A ship with an electric motor can be powered by batteries today, and retrofitted with a hydrogen fuel cell tomorrow without changing the main drivetrain.

Key components include:

- Variable Frequency Drives (VFDs): These control the speed and torque of the electric motor with extreme precision, leading to energy savings during maneuvering.

- DC Grids: Modern green ships often use DC distribution systems. DC grids are more efficient for integrating batteries, solar panels, and fuel cells, reducing conversion losses compared to traditional AC systems.

- Electric Motors: Permanent Magnet Synchronous Motors (PMSM) are favored for their high power density and compact size, crucial for retrofit scenarios where space is limited.

9. ADVANCED BATTERY SYSTEMS AND CHEMISTRIES

Batteries are no longer just for small ferries. They are becoming critical for "peak shaving" and zero-emission port arrivals for large cargo vessels.

9.1 Chemistry Comparison

The report evaluates different Lithium-Ion chemistries for marine use:

- NMC (Nickel Manganese Cobalt): Offers the highest energy density but requires sophisticated fire suppression due to thermal runaway risks.
- LFP (Lithium Iron Phosphate): Much safer and offers more charge cycles, though it is heavier. This is the current favorite for inland waterway vessels where weight is less critical than safety.
- LTO (Lithium Titanate): Capable of extremely fast charging (e.g., 10 minutes). Ideal for "hop-on, hop-off" ferry services.

9.2 Battery Management Systems (BMS)

In a maritime context, the battery management system must be integrated into the ship's Alarm, Monitoring, and Control System (AMCS). It must be able to isolate faulty modules instantly to prevent catastrophic fire spread.

10. FUEL CELL APPLICATIONS IN WATERBORNE TRANSPORT

Fuel cells convert chemical energy directly into electricity through an electrochemical reaction, bypassing combustion and achieving efficiencies up to 60%.

10.1 PEM Fuel Cells

Proton Exchange Membrane (PEM) cells are the most mature and have a high power density. They require very pure hydrogen and are sensitive to sulfur or salt in the air, requiring high-grade filtration systems on ships.

10.2 SOFC Fuel Cells

Solid Oxide Fuel Cells (SOFC) operate at high temperatures (600-800°C). Their major advantage is flexibility; they can run on methanol or ammonia directly through internal reforming. However, they have long start-up times and are best suited for constant "baseload" power rather than maneuvering.
The report notes that hybridizing fuel cells with batteries is the optimal configuration, where the fuel cell provides steady power and the battery handles peak loads.

11.HYDROGEN STORAGE AND SAFETY PROTOCOLS

Storing hydrogen on a vessel is one of the greatest engineering challenges in the green transition.

11.1 Compressed Gas Storage (CGH2)

Most IWT demonstrators use 350 bar Type IV tanks (carbon fiber). Safety protocols require these to be stored on deck or in well-ventilated open-air compartments to allow leaked gas—which is lighter than air—to dissipate safely.

11.2 Liquid Hydrogen (LH2)

Storing hydrogen at -253 ° C significantly increases density but requires vacuum-insulated tanks and complex "boil-off" gas management. The report identifies LH2 as the primary solution for larger coastal vessels with high energy demands.
Safety Barriers: Retrofits must include ATEX-rated equipment in gas-hazardous zones, double-wall piping with nitrogen purging, and rapid ESD (Emergency Shutdown) valves.

12.METHANOL AS A TRANSITIONAL FUEL

Methanol is often called the "future fuel available today." Major engine manufacturers (e.g., Wärtsilä, MAN) have already released methanol engines. For retrofits, methanol tanks can often be integrated into existing hull spaces with cofferdams (double walls) and specialized coatings.

Key technical hurdles for methanol retrofits include:

- Low Lubricity: Methanol has no lubricating properties, requiring specialized fuel pumps and injectors.
- Corrosivity: It attacks certain seals and materials like aluminum and zinc, requiring stainless steel or specific polymers in the fuel system.
- Fuel Supply System (LFSS): A methanol ship needs a dedicated supply module that manages pressure and temperature before the fuel reaches the engine.
- The report highlights that methanol's energy density is about half that of diesel, meaning a vessel will need twice the tank volume for the same range.

13.HYDRODYNAMIC OPTIMIZATION STRATEGIES

Efficiency starts with the hull. Many older vessels were designed when fuel was cheap and CFD (Computational Fluid Dynamics) was non-existent. Retrofitting the hull can yield massive savings.

13.1 Retrofit Energy Saving Devices (ESDs)

Propeller Ducts (Nozzles): These surround the propeller, improving thrust at low speeds. They are standard for pusher boats but can be optimized for cargo ships.
Pre-Swirl Stators: Stationary fins placed in front of the propeller that "pre-spin" the water in the opposite direction of the propeller's rotation, recovering energy from the wake.
Rudder Bulbs: Small bulbs attached to the rudder that smooth the water flow behind the propeller hub, reducing drag.

Field tests show that combining these devices can reduce fuel consumption by 5% to 12% with a relatively low investment cost (payback in 2-4 years).

14.AFT-SHIP REPLACEMENT AND HULL MODIFICATION

In some cases, simply adding devices is not enough. The SYNERGETICS project identifies "Aft-Ship Replacement" as a radical but effective retrofit strategy. Older IWT vessels often have very "full" (blocky) sterns that create significant turbulence.

The Process: The entire rear section of the ship is cut off and replaced with a modern, streamlined stern section designed specifically for the vessel's current operational profile. This new section often incorporates integrated electric thrusters and optimized propeller-rudder arrangements.
This approach is particularly viable for tanker vessels where the cargo section (mid-ship) is in good condition, but the machinery and hull shape are obsolete. While the CAPEX is high, the 20-30% reduction in resistance makes alternative fuels economically feasible by downsizing the required energy storage.

15.ECONOMIC IMPACTS AND CAPEX/OPEX BARRIERS

Technical solutions only work if they can be financed. The report provides a preliminary look at the economic hurdles.

16.1 CAPEX (Capital Expenditure)

The cost of a green retrofit can be 50% to 100% of the value of an older vessel. Without subsidies or green loans, most operators cannot afford the transition. The report identifies the need for "Carbon Contracts for Difference" (CCfDs) to bridge the funding gap.

16.2 OPEX (Operational Expenditure)

Currently, green methanol and hydrogen are 2x to 4x more expensive per energy unit than Marine Gas Oil. This
price gap must be narrowed through carbon taxes (like the inclusion of shipping in the EU ETS) and scaling up production of renewable fuels.
The Synergistic Payoff: By using mass-produced "marinised" components, the project aims to reduce the price gap through economies of scale shared with the road transport sector.